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Complexity of Engineering Disciplines as an Engineering Gate Keeper? Exploring Literature Related to Students' Selection of and Admittance into Engineering Majors

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Abstract

Engineering disciplines have evolved over the last two centuries as technology has advanced, creating additional opportunities for engineers to solve new problems. These disciplines attract different numbers of students, adapting to solve new problems with new technology. While the definition of an engineering discipline is not explicit, engineering programs must decide what majors to offer their students to prepare them for modern and future engineering problems. Additionally, students must navigate the different disciplines as they use their knowledge and perceptions of disciplines to select their major of choice. The purpose of this literature review is to gain a more complete understanding of how students explore different engineering disciplines, what factors affect their choice of major, and how students apply to their selected major. Students have different knowledge of engineering disciplines before starting college, so engineering programs have introduced courses and communities aimed at helping expose students to each major offered at that university. Students also have different perceptions of engineering disciplines that affect their views on a major and if they consider studying it or not. A student's knowledge and perception of engineering disciplines, as well as their values and goals, are used to inform their selection of a major. Students must also navigate different matriculation paths and major application processes used by universities. After being accepted into a major, students may still doubt if they want to study engineering or if their major aligns with their interests and future career plans. While research has been conducted on this process students face and what factors can affect the decision of their major, research is lacking on students who are not accepted into their major, disrupting students' planned paths into engineering and jeopardizing their future as an engineer. Future research should address how universities can best support these students to continue increasing the number of engineers.

Introduction

The history of engineering is extensive and can be traced back as far as people have been using mathematics, science, and creativity to invent products, processes, and systems that improve human life and address the needs of society. Due to varying needs and degrees of expertise needed, specializations and disciplines within the field began to emerge. The formation of civil engineering, often considered the first engineering discipline, occurred during the perfect storm of rapid growth in the electrical, steel, and chemical industries and the increasing number of institutions specializing in industrial arts [1]. Following shortly behind civil engineering were additional engineering disciplines that aligned with the 'second' industrial revolution, including electrical engineering [2], mechanical engineering [3], and chemical engineering [4]. In the United States, civil engineering's professional society was formed in 1852, followed by mining and metallurgical engineering in 1871, mechanical engineering in 1880, electrical engineering in 1884, and chemical engineering in 1908. Although professional societies can also be used to date the official establishment of a discipline, they do not completely reflect the status of that discipline's educational standards and curricula. As the education of engineers began to shift

towards science-based education and away from vocationally-based education as a result of World War II, a more diverse set of engineering disciplines emerged [1].

As technology advanced and grew, society's problems and needs became more complex and specialization areas became more specific, allowing more engineering disciplines to take shape. Examples of engineering disciplines taking shape more recently in the past few decades include usability engineering [5], web engineering [6], and mechatronics [7]. In some cases, additional and more specific disciplines are considered 'branches' or 'sub-disciplines' of the 'original' disciplines that many consider to be the primary engineering disciplines: civil, mechanical, electrical, and chemical [8]. For example, in Dixit et al.'s [3] book describing the history of mechanical engineering, he also explains production engineering, industrial engineering, manufacturing engineering, automobile engineering, aerospace engineering, and mechatronics. He classifies these six engineering disciplines as "offshoots" of mechanical engineering due to the fact that "students of these disciplines study several subjects of mechanical engineering" [3, p. 8].

The reality of engineering and its associated disciplines and specialization areas is that it is murky. There is no clear definition of what does and does not constitute an official discipline of engineering. There is not an official ruling on what the primary disciplines are, secondary disciplines are, and how disciplines are derived from or related to one another. Steinmann et al. [9] explored the complexities of what does and does not constitute an engineering discipline, how many disciplines exists, and how diverse the disciplines are. Findings from this article noted that not only was it unclear how many disciplines there are in engineering, but the hierarchy of these disciplines is unclear, and the language used to describe or classify engineering disciplines is not consistent across sources. Steinmann et al. [9] also note that the evolving field of engineering disciplines is changing and adjusting to serve the world's problems, technological advances, and society's needs, even into non-technical areas. Aiming at a target that is continuously moving and morphing based on a fast-paced society is a difficult task, so how are incoming engineers expected to identify their discipline of choice to guide their engineering education?

Problem Statement

As Steinmann et al. [9] found, defining the engineering disciplines is a difficult task. The newer and more specialized engineering disciplines do not have the popularity and awareness as the older established disciplines, and significantly less people are able to explain them in detail. Alternatively, the traditional engineering disciplines have had to change and adapt as society has evolved and advanced technologically, leaving the traditional societal perceptions of those engineering disciplines outdated. Along with having unclear definitions of engineering disciplines, distinctions between different disciplines are hard to make. Many disciplines share similarities in knowledge, skills, and abilities that are developed throughout engineering curricula, further blurring the lines that separate the different disciplines. What information related to engineering disciplines provides perspective engineering students with enough clarity to make an informed decision and choose an engineering discipline? Where is this information coming from?

On the Accreditation Board for Engineering and Technology's (ABET) website, over 50 'discipline' options are available to filter the accredited engineering programs [10]. No one university or engineering program could offer all possible engineering disciplines. Universities across the United States offer various combinations of engineering disciplines based on resources available. Additionally, limitations may apply as to what level of degree is offered for each discipline at different universities. What also varies between universities is how students apply to and are accepted into discipline specific engineering programs [11]. What role might institution and the availability of discipline-specific programs and admittance to those programs play in how students choose disciplines and matriculate through engineering?

The purpose of this literature review is to gain a more complete understanding of undergraduate engineering students' experiences in learning about, selecting, and applying for an engineering discipline of their choice after entering college. This paper will summarize the results of a review of literature concerning engineering disciplines. First, current trends in engineering disciplines will be reported, and then literature associated with engineering students' knowledge, perceptions, and decisions related to engineering disciplines will be reviewed. Finally, a discussion of future directions for research related to the selection of engineering disciplines will be presented.

Review of Literature

Learning about Engineering Majors

Students considering majoring in an engineering discipline may have different information on what each major entails. For example, Singer et al. [12] discuss their on-going study of how first year students define different engineering disciplines. In their Work-In-Progress paper, Singer et al. [12] discuss how students captured some core components of systems engineering, such as the design and management of systems, but students also discussed other components that are contained in the discipline or missed other core components completely. The differences between disciplines, the vast number of disciplines, and varying student interest has shown a need for engineering programs to help students navigate these considerations.

To help introduce students to topics related to specific disciplines, some universities discuss different majors in their first-year coursework. With a goal of introducing students to each major fairly, Hein et al. [13] incorporated questions into their courses that relate to different majors, however noted that some majors, such as mechanical and civil engineering, were easier to incorporate while others were more difficult. While these courses aim to fairly and accurately introduce students to disciplines, Reid and Reeping [14] state that first-year engineering programs tend to be 'personal,' designed to meet the objectives of the instructors without integrating into the curriculum of different majors. To assist colleges in classifying the different content in introductory courses, Reid and Reeping [14] proposed a classification scheme to be used in first year courses, resulting in a tool used to better communicate the focus of first-year courses and identify gaps between skills developed in these courses and skills required of future courses. Olds and Miller [15] implemented a program allowing students to explore different disciplines and connections between them, resulting in significantly higher graduation rates among the group in the program, although these rates could also be impacted by the community built in the program. Brozina and Meyers [16] also implemented a program focused on

informing their students on the different majors available to them, finding this program to be effective in helping their students select a major.

These studies suggest that students define and learn about engineering majors differently than students in other programs or institutions. Not all students begin an engineering program with the same background information of each major, so some students may have more ground to make up in learning about each major. Additionally, first-year instructors play a role in affecting how their students learn about each major and what topics are focused on in their coursework. Because each student is affected by their previous knowledge on engineering majors and how they approach learning about them, ensuring that all students have equal ability and access to information on majors presents a challenge of preparing students to select an engineering major.

Perceptions of Majors

While it is important to consider and critically look at the educational programs that have been put into place to formally educate engineering students on the differences and similarities between engineering disciplines, it is not realistic to conclude these programs are the only way students receive information regarding various engineering disciplines. The field of psychology tells us that knowledge is also socially constructed [17] and in some cases social perception can heavily influence the social reality [18]. These results suggest that engineering students will learn about the engineering disciplines outside of the carefully constructed lessons that come from their instructors based on messaging from society, such as media and personal narratives. When exploring how students gather information about engineering disciplines to make an informed decision, their socially constructed perceptions should also be considered.

Shivey and Sullivan [19] quantitatively explored undergraduate engineering students' perceptions of different engineering disciplines and found that not all engineering disciplines were equivalently describable. Students were more familiar with common and well-known engineering disciplines, such as electrical or mechanical engineering, compared to specialized and not as broadly recognized disciplines, such petroleum engineering. Additionally, a student's familiarity with an engineering discipline was related to how closely that discipline aligned with the students' interests [19]. This research also found that gender played a role in how engineering was perceived, as women rated the field of engineering as more prestigious than men [19]. While Shivy and Sullivan [19] noted the variations in how engineering students perceive different engineering disciplines, other researchers have explored similarities between students' perceptions of various engineering disciplines.

Kajfez et al. [20] qualitatively explored the perceptions that first-year engineering students had regarding various disciplines, noting that common themes across all students were that engineering disciplines involved processes, research and design, and a process of building, maintaining, and improving. While the first-year students in this study seemed to agree on the broad idea of what an engineer does across disciplines, they had different perceptions on how much different disciplines work with other people [20]. An additional finding of this study showed that students specifically identified the mechanical engineering discipline as broader than others and associated it with more 'options' moving forward. Kajfez et al. [20] note that they did identify differences in student perceptions of engineering disciplines, offering the explanation that those perceptions could be related to differences in engineering disciplines

offered as majors, matriculation structures, and diversity of the student body at the universities in their study.

Similar to Kajfez et al. [20], Palazolo, Ivey, and Camp [21] also explored how first-year engineering students perceive the different engineering disciplines but focused on quantitative results from a survey of engineering students at a single institution. Palazolo et al. [21] reports that the results of this survey indicate that generally most first-year students perceive engineering disciplines as having a significant impact on society as well as strong career opportunities, but do not as strongly perceive the need for creativity in all of these fields. Additionally, this article demonstrates the variation in perceptions across disciplines, as the number of participants varied in how they viewed different disciplines impacting society, the importance of using current technology, and the professional responsibility associated with each discipline [21]. Similarly, Canney and Bielefeldt [22] also explored how students view socially responsibility in engineering and how those views are different between engineering disciplines. Their work found that positive social responsibility in students differed across the engineering disciplines with which they associated. Canney and Bielefeldt [22] also noted that the largest differences in social responsibility between majors were reported by first-year engineering students, potentially indicating that this difference may be magnified for this sub-population of students due to their prior perceptions of the discipline instead of elements of the curriculum that they have not yet encountered.

The suggestion that students may form perceptions of engineering disciplines prior to key curricular elements is echoed by Stevens et al. [23], whose research followed two engineering students as they navigated the first year and a half of their undergraduate engineering degree prior to being admitted to a specific discipline's major. Stevens et al. [23] found that the students began to construct an engineering identity based on their prerequisite math and science courses, ultimately rejecting the identity based on their engineering courses as they did not match the perception of engineering from the prerequisites. While these courses were likely not painting a clear picture of engineering, they influenced these students' experiences with regards to continuing in engineering or not. Based on this study, it does not seem unreasonable that these differing perceptions of engineering disciplines identified by the literature reviewed also could have influence over engineering students' decisions when selecting an engineering major.

These studies show that students have different perceptions of engineering majors, such as how each major aligns with their interests and how much each major focuses on social responsibility and its impact on society. Because each student has different desires for a major and their future career, some students may be attracted to a major based on these perceptions while others may be dissuaded from applying to that major. Because these perceptions differ across students, understanding how these perceptions affect their major selection presents another challenge of preparing students to select an engineering major.

Deciding on Majors

In addition to exploring perceptions of the different engineering disciplines, Palazolo et al. [21] also asked first-year engineering students who or what influenced their decisions regarding selecting an engineering major. Students who took this survey reported that they were most influenced by their own interest in the field and the potential for career opportunities and were

least influenced by recommendations of teachers or contact with a professional engineer [21]. But as the research in the previous section indicated, student perceptions of disciplines can be formed prematurely and these perceptions likely influence their interest in the field and career opportunities they see as a result. These findings are similar to those of another study published a few years later by Zahorian et al. [24], who reported that the most influential factors students consider when choosing an engineering major are personal academic interest, job prospects, and the potential to contribute to society. This research also found that perceived academic difficulty and class lectures played the least significant role in engineering major selection [24]. These results seem to indicate that when selecting an engineering major, students employ forward thinking beyond their academic experience. An additional important finding reported by Zahorian et al. [24] is that participants in this research indicate that experiences previous to their first year had a strong influence on their engineering major selection. Although there exist significant amounts of literature on introducing engineering to students in their K-12 experiences through both formal and informal learning environments, that is beyond the scope of this literature review. However, this result does show that engineering students do not start at the same level of exposure to engineering, complicating how programs can inform students on this decision.

Noonan et al. [25] also reports that in their study, about 1/3 of first-year students had decided on their engineering discipline of choice before their first semester. However, this article also notes that by the end of the first semester, still less than half of the students had decided on an engineering discipline to major in, suggesting that few students only used their first semester to inform their decision. The results of their study discuss the importance of programs needing to educate students regarding engineering major choices beyond the first semester, as data showed that the majority of students who remain in engineering decided the summer before matriculation and that the majority of students who left engineering still planned to major in it after their first semester [25]. These results indicate that the second semester of first-year engineering students' education is a critical period for decision making regarding engineering major choices. Lischtenstein et al.'s [26] findings are similar, using both surveys and interviews to gain insights into students' exposure to engineering prior to coming to college and finding that this exposure was limited, resulting in their intention for a particular major to waiver. As students progressed through their early engineering education experience, Lischtenstein et al. [26] identified survey (or introductory) courses that reviewed engineering disciplines as valuable, helping them gain the knowledge and experience needed to make informed decisions.

Some studies have found that the identity of students can affect what disciplines they are interested in majoring in. A study by Tilak [27] explored the factors that influenced Indian engineering students' choice of engineering discipline, finding that social groups, gender, and where students are from all contribute to students' ultimate choice of engineering discipline between traditional engineering disciplines (e.g. mechanical or civil engineering) versus modern engineering disciplines (e.g computer science engineering). Verdín et al. [28] found that representation of women in a particular discipline is associated with increased interest in women selecting that major for women who aligned with agreeableness and interest in helping others. Cardador et al. [29] also found that when women in engineering selected specialties in their major, their decisions were affected by peer feedback and what they felt they were naturally good at.

Recent research has also shed light on the importance of students' confidence in making that decision. Ehlert et al. [30] found that confidence in choice of engineering major was a strong predictor of retention within that major, suggesting that students who are more confident in their decisions are more likely to remain in their major. However, Ehlert et al. [30] also found that confidence in their decision was not strongly tied to persisting in engineering, suggesting that students who are confident in their major are just as likely to leave engineering as those who are not confident.

These studies show the complexity of the process that students use to select a major. Students are affected by their interest in a field, job opportunities, and how majors may contribute to society. Additionally, some students decide on a major before attending college, but the majority of students may need more than one semester to make their decision. Students also use courses designed to review different engineering disciplines to help guide their decision, showing that these first-year courses may play an important role in this decision. Additionally, student demographics have been shown to affect what majors students are more likely to select. Because this decision process is so complex and it may be affected by many different concepts, understanding a model that captures how students make this decision is an important challenge to consider.

Applying to Majors

Orr et al. [11] discuss how universities utilize different processes for students to enter an engineering major, specifically describing the most common processes used. Through a quantitative study on the differences between first-year engineering (FYE) programs, direct matriculation (DM) programs, and post-general education (PGE) programs, Orr et al. [11] found significant differences between them. FYE programs had more students graduate in their first choice of major, fostered persistence overall in engineering, and lead to a faster graduation, but also acted as a barrier for transfer students and students who wanted to switch into the program, requiring them to take specific courses related to the program first [11]. DM programs helped students to identify with a discipline earlier, had high persistence, and fewer barriers for transfer students, but students may have inaccurate information about each major before entering a major and struggle to switch between programs due to their specific requirements [11]. PGE programs make the process easier for both transfer and switching students, however typically result in longer times to graduate [11]. Orr et al. [11] suggest a combination between matriculation paths that allows students to associate with a discipline early while remaining flexible for other paths into engineering. Mohammadi-Aragh et al. [31] discuss a hybrid matriculation model that allows students to continue using the DM model but allows undecided students to enter into a FYE program to provide them additional time to select a major while meeting common requirements to apply. Other than the matriculation paths, engineering programs may differ by how they accept students into majors. For examples, they may automatically accept students into a major once requirements are met (e.g. [32]) or require them to apply to specific majors after meeting the requirements (e.g. [33]). Additionally, engineering programs may set standards that guarantee a student their first choice, (e.g. [34]), or one of their top three choices (e.g. [35]).

These studies show that students in different programs and institutions apply to their major using different processes. While some students may be guaranteed a spot in their major of interest,

others may have to compete with their peers for limited spots in a major. Engineering programs may differ by what requirements they have for students before applying to a major, such as prerequisite coursework. Additionally, institutions may alter their application process each year, complicating any research being performed on any particular application process. The differences used at different institutions and the ever-changing processes used present a challenge in understanding how all students apply to engineering majors.

Statistics on Engineering Majors

The number of engineers varies greatly by discipline. Data from 2019 shows that mechanical engineering has the highest number of new graduates that year at around 35,000, while the number of computer science (20,000), electrical (14,000), civil (14,000), and chemical (11,000) engineering degrees are the next highest [36]. While these disciplines represent the largest number of degrees awarded, over 20 majors are included in the report, with additional majors included in the 'Other' category representing over 9,000 degrees. Between 2009 and 2019, engineering disciplines have seen very different changes to the number of degrees earned annually [37]. For example, while the number of engineering degrees has increased by 83%, computer science in engineering has more than tripled the number of degrees earned, chemical engineering has more than doubled, but civil engineering has only increased by about 16%. When considering underrepresented students in engineering between 2011 and 2016, Hispanic students have seen 95.9% and 148.5% increases in aerospace and bioengineering/biomedical engineering, respectively, while Black students have seen 23.4% and 86.9% increases in the same disciplines [38]. In 2012, Hispanic students earned degrees in industrial, civil, and electrical engineering above average, while Black students earned degrees in industrial, electrical, and chemical engineering above average [39].

These data show that the number of students in engineering disciplines is changing significantly but may be changing differently for different populations of students. While some majors are growing due to student interest, other majors seem to be more stagnant at their current level. Additionally, interest in certain engineering majors different across demographics. These studies suggest that students are entering engineering majors at different rates. Understanding why these differences exist and if they are important may help address potential inequities in students of different demographics and is another important challenge of this process.

After Entering a Major

After students apply to a major, they may still transfer to a different engineering major or outside of engineering, so engineering programs should not assume these students have settled into a major and their path is set. Lichtenstein et al. [40] found that when surveying engineering students after they entered a major, almost half of the juniors still had some doubt about majoring in engineering, pointing to relying on their classroom instruction experiences to affirm staying in engineering. These results suggest that even after students have entered a major, they may still require support to decide to stick with engineering. Theiss et al. [41] studied how engineering students move between majors, finding that approximately a quarter of students in their study switched engineering majors at some point, with some potentially returning to their initial major. These results show that students may not initially select the best major for themselves, potentially moving around between different engineering majors. Paulson et al. [42]

examined differences between engineering majors after students selected them, finding that some majors were more likely to have students transfer into or out of them and that these results differed for underrepresented students and majority students. The results of these studies suggest that many students are not decided on a major when they enter it and that trends of students switching majors may be dependent on their identities. Other research has identified differences between majors that may also affect students switching majors. Lichtenstein et al. [40] studied how undergraduate students make decisions about their careers, finding that a single experience, like an internship or co-op, can alter a student's career choice, while Main et al. [43] found that different disciplines participate in co-ops at different rates.

These results combined suggest that students may encounter career altering experiences in co-ops or internships, but different majors may be more or less likely to encounter these experiences while the students are still able to switch majors. These studies show that despite students having entered a major, this major selection process may not be over as they potentially reevaluate their interest and desire to complete a particular major. This potentially extends the students' process of selecting an engineering major and presents the challenge of determining the ending point of this process for researchers to consider.

Conclusions & Future Work

This literature review focused on understanding engineering disciplines and how students interact with them as they learn about different majors, decide what majors they are interested in, and apply to their major. While some disciplines are well established in engineering, the total number of disciplines makes it impossible for students to learn about each discipline and for universities to offer each as a major. Additionally, there does not exist a formal agreed upon definition that can be used to identify different disciplines and specializations. This ambiguity complicates how students can interact with different disciplines as they select what engineering major to study. By reviewing literature related to how students interact with engineering majors, the paper sought to explore how different students learn about, select, and apply to engineering majors.

Various engineering majors attract different numbers of students, but underrepresented students are not choosing the same majors as majority students. To help students learn about different disciplines, engineering programs have utilized courses and programs specifically designed to allow students to explore their major options, helping students to select a major while also improving retention. However, students may have different perceptions of majors learned outside of classrooms, such as their familiarity with different majors and beliefs on how much each major works with other people, impacts society, and considers social responsibility in its careers. As students decide what major they want to study, they may consider their personal academic interests, potential career opportunities, and the ability to contribute to society. Students also decide on their major of choice at different times, with some students have selected a major before beginning to study engineering and other students waiting until their decision is required before selecting a major. Once decided, students may face different matriculation paths, such as a common FYE program or a direct matriculation, as well as different applications that may or may not allow guaranteed admission. After entering a major, students may continue to face doubt about studying engineering or potentially switch to a different engineering major. Students in

different majors may also face different experiences, such as co-ops or internships, that can affect their decision to continue with their selected major.

This literature review highlights the complexity of the process students navigate when learning about, deciding on, and applying to a major. Throughout this process, students' decisions can be affected by their previous knowledge of engineering, their experiences that form perceptions of engineering disciplines, and their identity, potentially affecting students interested in different engineering majors uniquely. However, the literature reviewed shows that research is lacking on studying students that do not follow these steps. Students may utilize their knowledge and perceptions of engineering majors to decide what major to apply to, but what happens when they are not accepted? While students may consider other engineering majors, they may also consider leaving engineering if their vision for their career path seems impossible after being rejected from their selected major. If we want to retain more engineers, gaining knowledge on what happens when they experience disruption in this process will help us develop support systems that can be put into place to retain engineers beyond the application to major process when they are faced with rejection.

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