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RESEARCH ARTICLE

Determinants of Intra-major Specialization and Career Decisions Among Undergraduate Biomedical Engineering Students

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Abstract
Biomedical engineering is a broad and interdisciplinary field that prepares graduates for a variety of careers across multiple career sectors. Given this breadth, undergraduate degree programs often have formal or informal opportunities for students to further specialize within the biomedical engineering major to develop skills in subdisciplines of biomedical engineering. While previous work has explored factors that influence student decision-making of engineering major choice, including the role of gender, limited work has explored factors that influence intra-major specialization in biomedical engineering. The present study sought to expand on existing research to understand factors that influence biomedical engineering students' choice of intra-major specializations and how, if at all, these factors are related to gender. Grounded in social cognitive career theory, the present study leveraged quantitative surveys from undergraduate biomedical engineering students to understand factors influencing intra-major specialization choice, including the impact that students viewed on their career plans. Participants rated multiple factors as important in their intra-major specialization decisions, with professors/classes rated as the most important influence and alumni as the lowest. Similarly, participants rated multiple outcome expectations of their specialization, although income was rated lower than other factors. Participants most commonly indicated interest in pursuing careers in industry and medicine. We found some differences in intra-major specialization, outcome expectations, and career interests by gender, with women students indicating a higher influence of professors/classes and higher expectations for their track decision to provide a career with a good income. Further understanding of how undergraduate students select specializations in engineering coursework will inform curriculum design and student advising.

Keywords Social cognitive career theory · Undergraduate · Survey · Gender · Intra-major specialization

Introduction

Research on engineering student major selection indicates that students choose bioengineering or biomedical engineering (BME)[1] based on interest in the content, because the broad scope allows for pursuit of various careers upon graduation and because they believe they can help others [1–3] among other reasons. While most engineering majors remain largely dominated by men [4, 5], many undergraduate BME programs have shown equal or higher rates of women students enrolled than men compared to other engineering disciplines [6]. This enrollment breakdown may be due to how BME is viewed as a field. As compared to other engineering majors, BME is viewed as a major with more direct ties to medicine and altruism [7]. Additionally, biology as a field is not viewed to be as masculine as engineering and tends to enroll more women [5]. Thus, the biology aspect of BME curriculum may be more favorable to women interested in STEM who do not identify with masculine stereotypes and values.

Although it is undoubtedly important to understand the influences shaping students' and particularly women's selection of BME as a major, selection of the major is only one choice that students make regarding their engineering

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[1] In this study, we surveyed participants from a bioengineering program which at the institution of study is considered synonymous to what other institutions refer to as biomedical engineering.

specialization. Once in the BME major, students often select a "track" or "specialization" that specifies elective coursework—what has been referred to as "intra-major specialization"[2] [8]. While a sizable body of work has examined factors related to student choice of engineering in general, and BME in particular as a major [9–15], there is considerably less research about how students make decisions about intra-major specialization among engineering majors, and very limited research to our knowledge which focuses on the factors that influence intra-major specialization decisions for BME students (see [8]). Further, while some research has looked at how BME career interests and hurdles related to job and career prospects [1, 16], no research of which we are aware has examined the relationship between BME intra-major specialization and career interests. Finally, while some studies have examined gender differences in career outcomes for BME students [17], to our knowledge, no studies have examined gender differences in BME students' intra-major specialization. This is surprising given that scholars have shown that gender is a highly influential factor in women's choice of, and experiences in, engineering majors [11, 18–20].

These are important gaps in our understanding for several related reasons. First, intra-major specialization within BME is likely to shape the remainder of students' engineering education and preparation. Second, intra-major specialization may impact the work experiences (i.e., internships) that students pursue to gain specific skillsets in a subfield of their engineering discipline. Third, intra-major specialization decisions likely have important implications for BME students' downstream career interests. Thus, understanding the factors that contribute to BME students' intra-major specialization as well as the relationship between specialization and career interests is important areas for exploration. Further, understanding gender differences in track selection and the relationship between track selection and career interests may be particularly important to understand as women continue to be underrepresented in certain engineering subfields, roles, and career paths. For example, there is some evidence that women engineers pursue purely technical roles to a lesser extent than men engineers [21–23]. Moreover, examining gender differences may help shed light on the factors impacting women's career paths and decision-making in engineering and may be particularly important given challenges to representation for women in engineering.

To address these gaps, our research examines the factors that are most influential in BME students' intra-major specialization track decisions, how these choices relate to career interests, and the role gender plays in these relationships. We situate our work in the social cognitive career theory (SCCT) framework [24] to answer the following research questions:

1. What proximal contextual supports (curricular and extra-curricular) are most related to student intra-major specialization track choice in BME? Do the relationships between these factors and track choice vary by gender or track?
2. What are students' career outcome expectations associated with intra-major specialization track selection? Do these outcome expectations vary by gender or track?
3. What career sectors and career paths do BME students report most interest in pursuing? Do these career interests vary by gender or intra-major specialization track?

Background

Intra-major Specialization

Intra-major specialization exists in many engineering majors and can range from informal guidance in selecting elective courses to formalized in-program requirements that become listed on a student's transcript [8]. Tracks and specializations offered are not constant across BME programs, but for BME programs that formalize tracks in program requirements the most common tracks are Imaging, Biomechanics, Computational, and Cell and Tissue Engineering [25]. In programs with formalized track requirements, track selection often determines the coursework required for degree and track completion. For example, students in BME programs who select an Imaging track will likely take more electrical engineering geared courses, while students who select a Cell and Tissue Engineering track will likely take more biology-centered courses.

The limited research on intra-major specialization in engineering reveals several findings. First, students use interest and enjoyment of classes to determine whether they would be a good fit with certain specializations within the major [8, 26]. Second, program structural constraints, such as whether prerequisite courses for all tracks are readily accessible, can cause students to move away from some intra-major specializations even when they have interest [8]. Third, students report certain career values (e.g., having an impact, wanting to lead, desiring the opportunity to do high quality work, and importance of pay and prestige) as important to their choice of intra-major specialization [27]. Fourth, program factors—including classes and faculty teaching quality, work experience gained through internships while in school, and being exposed to guest speakers working in a particular subspecialty area—have been shown to influence intra-major specialization decisions [27]. Fifth, short-term factors, such as courses taken, appear more influential in decision-making

[2] In this study, we use the term intra-major specialization to refer to the track or specialization.

regarding specialization than long-term factors, such as career potential [28]. Finally, students often lack certainty about what they plan to do with their major [26, 29] and are susceptible to peer influence about which specialization they should select [8].

Our research builds on these extant findings to examine the influences on, and career implications of, intra-major specialization decisions particular to BME majors. We draw on SCCT to conceptualize and explore the possibility of factors that may be critical to BME students' decisions to specialize within their major and to consider the relationships between BME students' track selection and their career interests.

Social Cognitive Career Theory

Social cognitive career theory (SCCT) explains the processes through which individuals form interests, make choices, and form expectations about educational and occupational pursuits [24]. Research on SCCT has consistently shown that social identities (e.g., gender, race, and disability status) and cognitive factors (e.g., self-efficacy, interests, and outcome expectations) inform students' academic interests and career choice goals [24, 30–32]. Specifically, students are more likely to pursue career-related goals to the extent that they believe in their own abilities, have interest and enjoyment, and perceive that their pursuit of career goals will elicit desired outcomes (i.e., "outcome expectations"; [31, 33]). These cognitive factors are further informed by both contextual supports (e.g., parental and professor support, access to role models and financial resources) and/or contextual barriers (e.g., financial constraints and instructional barriers) that either encourage or discourage students' particular career-relevant decisions [15, 31, 34, 35]. Social identities, such as gender or race, also influence interests, choices, and outcome expectations [24].

In this study, we sought to identify factors that contribute to BME students' intra-major specialization decisions using SCCT as a supporting framework. Adapting elements of Lent and colleagues' (1994) SCCT model of career choice, we focused our analysis on the role of proximal contextual supports (e.g., advisors, peers, alumni, and classes/professors), outcome expectations (e.g., the ability of a particular specialization track to help students secure a good income) in shaping BME students specialization track interests and decisions and examined the relationship between these decisions and students' post-graduation career plans. Also, given that person inputs are part of the Model of Career Choice and given overwhelming evidence that gender influences choices and experiences in engineering majors [9] and that women appear to be drawn to disciplines that include broad, systems perspectives (e.g., [11, 19, 20, 36]), we also examine the personal input of gender in all relationships examined. Indeed, a recent study, with a nationally representative sample, found that gender was the most important variable in predicting choice of an engineering major [19]. Other influential factors for women appear to be mentors, opportunities to do interdisciplinary work, and considerations for cultural and environmental features of design [9, 36]. Given gender being a predicting variable of major, we suspect gender also plays a role in track specialization and consequently career aspirations. Comparing women and men on these various relationships allows for a determination of potential gender patterns and biases and can thus enhance the accuracy and scope of the findings, thus contributing to a more complete understanding of the relationships examined.

Taken together, our review suggests that while some research has examined factors influencing intra-major specialization among engineers, no research to our knowledge has examined factors particular to BME majors. Further, SCCT provides a useful theoretical lens for furthering an understanding of the factors influencing career-relevant decisions about intra-major specialization because it accounts for various factors that may influence this choice.

Positionality

We recognize that our identities influenced our decisions to ask certain research questions and guided our interpretations of research findings [37]. The research team included undergraduate, graduate student, and faculty members from whose training disciplines included BME, labor and employment, and engineering education research. Two authors completed undergraduate and graduate biomedical engineering programs, with one of these authors having completed both undergraduate and graduate BME degrees at the institution of study. One author is a BME instructor and previously served as an undergraduate advisor for the undergraduate program at the focal institution. All authors identify as women and have research interests in the impact of gender in student career decisions. As a team, we regularly discussed how our experiences impacted our interpretation of the findings as part of a reflexive process while conducting the research [38].

Methods

This study is part of a larger, mixed methods study that seeks to further an understanding of how engineering students choose intra-major specializations and desired career paths. For this analysis, we specifically focused on responses from BME students. The study takes place at a public Midwest R1 institution. We focused on BME students because these students were more likely to indicate interest in non-traditional engineering fields (medicine) and the specializations in BME are connected to other engineering disciplines. Additionally, in our sample, the BME major[1] had a smaller number of tracks that allowed us to complete some analysis at the track level. Due to this focus and the fact that the study took place at a single educational institution with distinct specialization tracks, we purposefully only report participant gender and not additional demographic data to protect participant anonymity. All procedures and measures were approved by the IRB before data collection began.

Program Context

In the program studied, students are counseled by professional advisors for their entire academic journey. At the time of the study, the program was in its nineteenth year. Compared to other engineering majors upward of one thousand students, the BME program is a relatively smaller size, with only three hundred and sixty-one undergraduates in Fall 2021. Students are required to meet with their advisor at least once per year to discuss coursework, careers, and other topics. By the end of their second year, students choose their intra-major specialization track from the following options: Biomechanics, Imaging and Sensing, Therapeutics, Cell and Tissue Engineering, and Computational and Systems Biology. Some tracks require prerequisite courses that students may begin taking in their first or second year before they officially declare a track. Each specialization track requires completion of fifteen hours of coursework within the engineering college. This coursework can be within or outside of BME, but all courses must be approved for the track by the BME department. As of Fall 2021, women accounted for 52% of undergraduate students enrolled in the bioengineering program. This is the most women enrolled in a program within the College of Engineering and is comparable to national data for biomedical engineering programs [6].

Recruitment

In Fall 2021, a survey was distributed on Qualtrics to students enrolled in the BME major in their second year or higher in the program. The survey was advertised through flyers posted in engineering buildings and through direct emails to engineering students by departmental academic advisors. Students were offered a $15 gift card for participation.

Participants

A total of 99 BME students (about 37% of second year students and beyond enrolled) responded to the survey (N = 99); 38 men, 51 women, and 10 respondents who did not specify a gender identity. The number of participants from each education year is shown in Table 1. Most participants were second-year (N = 48) or third-year (N = 39) students in the BME program.

Table 1 Participants by year in program.

Year in program	Number of participants
Second	48
Third	39
Fourth	8
Fifth or above	4

Table 2 Track selection of survey participants.

Track selection	Number of participants
Therapeutics	23
Cell and Tissue Engineering	18
Computational Systems Biology	10
Imaging and Sensing	6
Biomechanics	7
Undecided or not included	35

Measures

Intra-major Specialization Proximal Contextual Supports

Students were asked to rate (on a scale of 1 = not important at all to 5 = very important) a set of potential contextual influences that may be positive or negative, on their intra-major specialization. Potential influences included advisors, peers/friends, alumni, professors/classes, extra-curricular activities, and internships. We selected these influences because they align with possible proximal contextual supports in the SCCT model [39] and have been identified in other studies of intra-major specialization choice [8]. An open-ended "other" item was also provided for students to report other influences not listed. Extracurricular activities are defined here as activities that occur outside of the academic requirements for graduation.

Intra-major Specialization Choice

Students were asked to write in their chosen or planned intra-major specialization (track). Of the 99 participants, we were able to assign tracks to 64 participants (Table 2). Track choices were Biomechanics, Cell and Tissue Engineering, Computational Systems Biology, Imaging and Sensing, and Therapeutics. Participants who listed multiple track possibilities were coded as undecided and grouped with those who did not specify a track. Cell and Tissue Engineering and Therapeutics were the most commonly listed tracks by students who have selected a track. The majority (88.5%) of respondents who did not specify a track or were undecided were enrolled in their second or third year of the program.

Intra-major Specialization Outcome Expectations

Students were asked to rate (on a scale of 1=not at all to 5=to a great extent) the extent to which they believed that their chosen or planned intra-major specialization track would lead to each of six positive outcomes. Outcome expectations were measured with 6 of 8 items from the validated Rogers, Creed and Searle (2009, 2010) professional outcome expectations scale [40, 41] (see also [42]). Reduced items were presented to minimize participant fatigue associated with survey length. Expectation outcomes choices were "Allow you interaction with your colleagues," "Let you practice skills that best suit your perceived abilities," "Provide you with a good income," "Allow you to perform a broad spectrum of work," "Be compatible with your interests," and "Allow you to achieve your desired professional success." The two excluded items–"Be intellectually stimulating" and "Provide you with work satisfaction"–were chosen for exclusion because we expected the least variability in participant responses to these items. We rationalized that students were likely to anticipate that all engineering tracks would be intellectually stimulating and associated with anticipated work satisfaction. The item removal decision was also made within a broader context of wanting to do what was possible to minimize survey length which could be associated with increased incompletion rates due to participant fatigue.

Career Plans. In the career plans, section students were asked to select the career sector that they are most interested in entering after they finish their education. Options were industry, medicine, academia, and government. Students could select as many career sectors as applicable.

Gender. Participant gender was measured with the following options: woman, man, and non-binary. Participants could elect to skip this question.

Open Response. At the conclusion of the survey, students were provided the opportunity to write in additional comments that they wanted to share with the study researchers.

The complete survey is included in the Appendix.

Data Analysis

All analyses were conducted in R with the rcompanion [43], psych [44], dplyr [45], ggplot2 [46], corrplot [47], tibble [48], foreign [49], nnet [50], stargazer [51], Hmisc [52], pls [53], and DescTools [54] packages. Pearson's Chi-square tests were run to identify if there were significant relationships between variables. Effect sizes for Pearson's chi-square were calculated by Cohen's w (ω) [55]. $0.10 < \omega < 0.30$ is considered a small effect size, $0.30 < \omega < 0.50$ is considered a medium effect size, and $\omega > 0.50$ is considered a large effect size [55].

Table 3 Summary statistics for intra-major specialization track decision influences.

Track influences	Average	Min	Max	SD
Advisors	3.20	1	5	1.45
Peers	3.44	1	5	1.22
Alumni	2.51	1	5	1.31
Professors/classes	3.99	1	5	1.01
Extracurriculars	3.18	1	5	1.23
Internships	3.33	1	5	1.40

Results

Curricular and Extra-Curricular Influences on Track Selection (RQ1)

All track influences were measured with values ranging from 1 (not at all) to 5 (to a great extent), but with different standard deviations (Table 3). Alumni, advisors, and extracurriculars were reported as least influential, and professors/classes and peers were reported as most influential.

Figure 1 shows a boxplot of the values for track influences. The range, median, and outliers are shown for each of the six track influences measured. While professors/classes had the highest average score, there were several outlier measures where students ranked this influence lower. Alumni and professors/classes are skewed toward the higher scores, while advisors, peers, extracurriculars, and internships are skewed toward the lower scores.

Of the 99 respondents, 28 wrote about additional influences for track choice (Table 4). The additional influence most stated by respondents was career and personal goals. Other additional influences mentioned more than once included family, future academic goals, such as further education and workshops, research interests, other experiences or resources, and personal interest. Concern about future employment, opportunities available due to the COVID-19 pandemic, and mentors were each mentioned one time.

Track selection influences were also analyzed considering gender differences (Fig. 2). Women were significantly more influenced by professors/classes, while men reported significantly higher scores for internships as influential according to Chi-square tests.

Chi-square test results (Table 5) indicated that there was a moderate ($\omega = 0.428$) significant gender difference in the influence of professors/classes ($\chi2(4, N=51)=16.31$, $p=.003$); however, no significant gender effect for any of

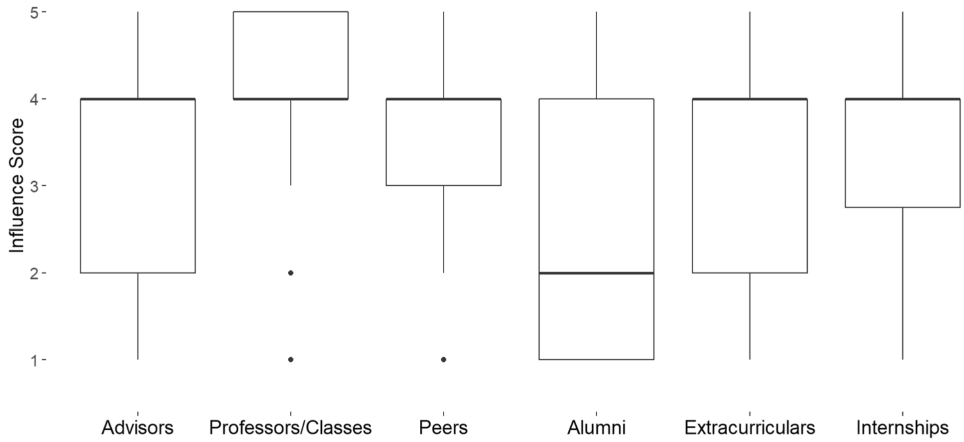

Fig. 1 Boxplot of Intra-Major Specialization Track Decision Influences. Edges of the boxplot mark the upper (75th) percentile and lower (25th) percentile. Whiskers extend to the largest and smallest values within 1.5 times the interquartile range of the corresponding percentile.

Table 4 Additional influences of intra-major specialization track decision.

Other influence	*N*	Percent	Average score
Career and personal goals	6	21.4	5
Future academic goals	5	17.8	5
Family	4	14.3	4.25
Research interests	4	14.3	5
Other experiences or resources	4	14.3	4.5
Personal interest	3	10.7	4.67

the other influences. Further, Chi-square tests showed no relationship between specific track choice and any of the influences. The results are not presented because there was no statistical significance.

Student Outcome Expectations of Intra-Major Specialization Track Selection (RQ2)

Intra-major specialization track outcome expectations were scored on a scale from 1 (not at all) to 5 (to a great extent). Summary statistics showing the average, standard deviation,

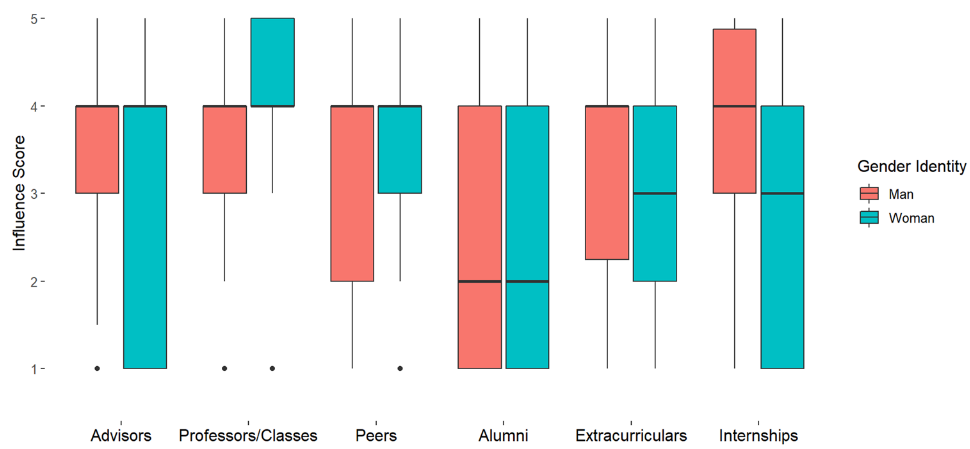

Fig. 2 Boxplot of intra-major specialization track decision influences by gender. Edges of the boxplot mark the upper (75th) percentile and lower (25th) percentile. Whiskers extend to the largest and smallest values within 1.5 times the interquartile range of the corresponding percentile.

Table 5 Pearson's Chi-square test results.

Track influence	Women				Track			
	df	χ^2	*p*	ω	df	χ^2	*p*	ω
Advisors	4	3.74	0.443	0.205	16	11.38	0.785	0.422
Professors/Classes	4	16.31	0.003**	0.428	16	24.99	0.069	0.625
Peers	4	3.03	0.553	0.185	16	21.96	0.145	0.586
Alumni	4	0.570	0.966	0.080	16	15.18	0.511	0.487
Extracurriculars	4	2.40	0.662	0.164	16	9.79	0.877	0.391
Internships	4	5.42	0.247	0.247	16	18.67	0.286	0.540

Significant at $^*p<0.05$, $^{**}p<0.01$, and $^{***}p<0.001$, df: degrees of freedom, χ^2: Chi-square statistic, ω: Cohen's w

Table 6 Summary statistics for track outcome expectations.

Track outcome expectations	Average	Min	Max	SD
Be compatible with your interests	4.33	1	5	0.91
Allow you to achieve your desired professional success	4.21	2	5	0.80
Let you practice skills that best suit your perceived abilities	4.11	1	5	0.96
Allow you to perform a broad spectrum of work	4.02	1	5	0.86
Allow you interaction with your colleagues	3.96	2	5	0.70
Provide you with a good income	3.86	1	5	0.92

Min minimum, *Max* maximum, *SD* standard deviation

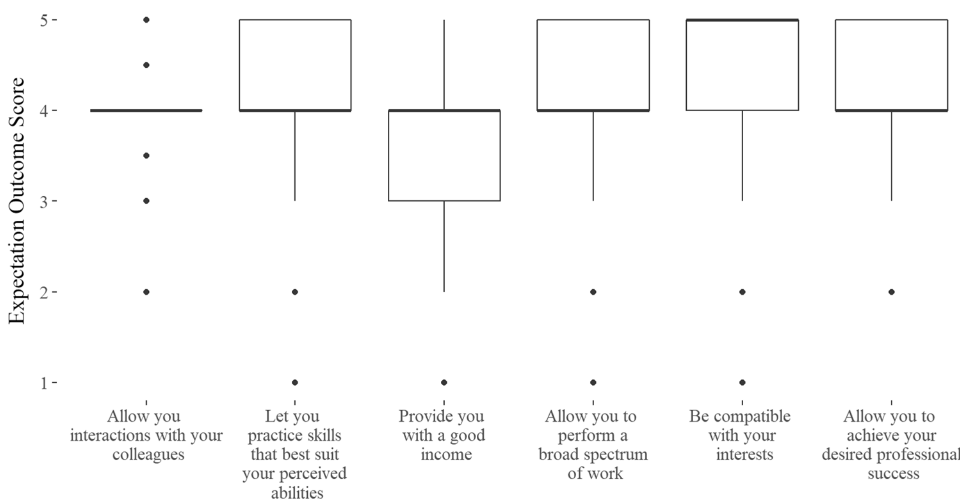

Fig. 3 Intra-major specialization track outcome expectations. Edges of the boxplot mark the upper (75th) percentile and lower (25th) percentile. Whiskers extend to the largest and smallest values within 1.5 times the interquartile range of the corresponding percentile.

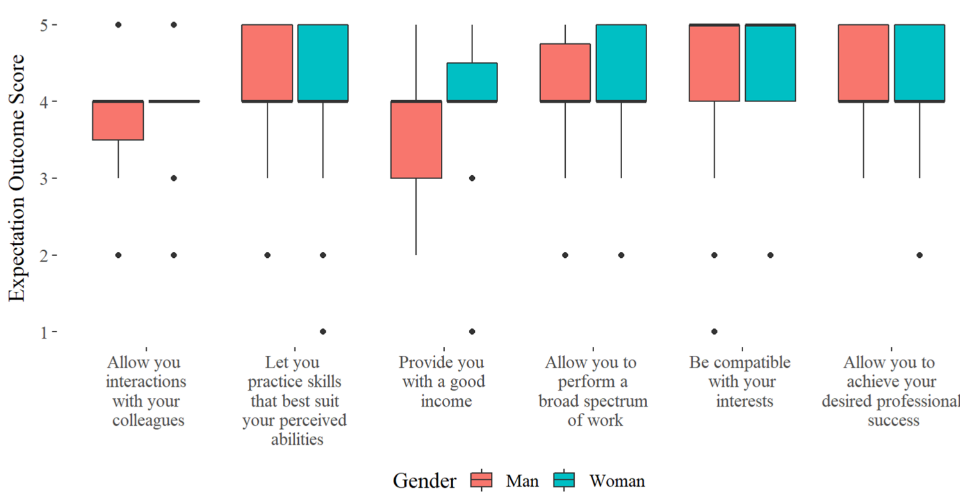

Fig. 4 Intra-major specialization track outcome expectations by gender. Edges of the boxplot mark the upper (75th) percentile and lower (25th) percentile. Whiskers extend to the largest and smallest values within 1.5 times the interquartile range of the corresponding percentile.

and range are summarized in Table 6. The outcome expectations of "Be compatible with your interests" and "Allow you to achieve your desired professional success" were on average rated the highest. "Allow you interaction with your colleagues" and "Provide you with a good income" had the lowest average scores.

Figure 3 depicts a boxplot showing the range, median, and outliers for track outcome expectations. Ability to practice skills, a broad work spectrum, compatibility with interests, and an ability to achieve desired professional success skewed toward higher scores. Provide a good income skewed toward lower scores. All outcome expectations had a median score of 4 or higher. Allow interaction with colleagues contained the most outliers.

Track outcome expectations were then analyzed by gender (Fig. 4). Women tended to rank the outcome expectation of providing a good income higher than men. Both men and women scored the outcome expectations of let

Table 7 Pearson's Chi-square test results.

Track outcome expectation	Women				Track			
	df	χ^2	p	ω	df	χ^2	p	ω
Colleague interaction	3	2.92	0.402	0.182	12	13.38	0.342	0.457
Practice skills	4	1.04	0.903	0.108	16	21.24	0.167	0.576
Good income	4	9.95	0.041*	0.334	16	16.96	0.388	0.515
Broad spectrum of work	4	3.11	0.539	0.187	12	13.1	0.362	0.452
Compatible with interests	4	3.31	0.507	0.193	16	15.5	0.491	0.492
Achieve desired professional success	3	2.51	0.474	0.168	12	7.35	0.834	0.339

Significant at *p<0.05, **p<0.01, and ***p<0.001, df: degrees of freedom, χ^2: Chi-square statistic, ω: Cohen's w

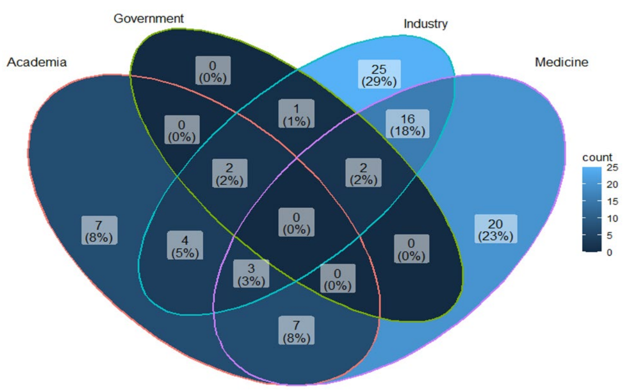

Fig. 5 Student interest in career sectors. Students could select multiple career sectors. N=97.

Intra-major Specialization Track Relationships to Student Interest in Career Sectors and Career Paths (RQ3)

Figure 5 shows a Venn diagram of possible career sectors for which students indicated interest. Students could select more than one career sector. Of the four career sectors provided, the most commonly selected sector was industry (54.6%), followed by medicine (49.5%). Of the students who selected multiple career sectors, the most common dual selections were industry and medicine (18%) and medicine and academia (8%).

We next analyzed students' indicated interest in a career sector by intra-major specialization track and gender (Table 8). While the sample sizes were limited, the data indicated there was a small (ω = 0.214) significant gender difference in interest in industry (χ2(1, N=89)=4.08, p=.043) and a small (ω = 0.251) significant gender difference in interest in medicine (χ2(1, N=89)=5.60, p=.018). Women students indicated more interest in industry (N=53) than in medicine (N=48). Specific track choice had a modest (ω = 0.404) significant effect on industry interest (χ2(4, N=63)=10.01, p=.038). Specifically, there was higher interest in industry for the Biomechanics and Computational and Systems Biology tracks and lower interest in industry for students in the Cell and Tissue track (Table 9). Students in Cell and Tissue Engineering track indicated more interest in medicine than

Table 8 Interest in career sector by gender and intra-major specialization track.

Career Sector	Women	Track						
	df	χ^2	p	ω	df	χ^2	p	ω
Industry	1	4.08	0.043*	0.214	4	10.01	0.038*	0.404
Academia	1	2.42	0.119	0.165	4	7.02	0.135	0.337
Government	1	3.12	0.077	0.187	4	3.76	0.440	0.246
Medicine	1	5.60	0.018*	0.251	4	4.64	0.326	0.274

Significant at *p<0.05, **p<0.01, and ***p<0.001, df: degrees of freedom, χ^2: Chi-square statistic, ω: Cohen's w

you practice skills, allow you to perform a broad work spectrum, compatibility with interests, and achieve desired professional success similarly. Allow interactions with colleagues skewed toward lower scores for men and higher scores for women.

Chi-square test results (Table 7) indicated that there was a moderate (ω =0.334) significant gender effect for the outcome expectation that the track choice would provide a good income (χ2(4, N=51)=9.95, p=.041)); however, no significant relationships were found for the other track outcome expectations with gender. Additionally, Chi-square tests showed no relationship between specific track choice and any of the outcome expectations.

Table 9 Interest in industry career path by intra-major specialization track.

Track	*N*	Medicine	Government	Academia	Industry	% Industry
Biomechanics	7	4	0	0	6	86
Cell and tissue engineering	17	11	0	8	5	29
Computational systems biology	10	3	0	3	8	80
Imaging and sensing	6	4	0	2	4	67
Therapeutics	22	15	2	4	13	59

students in other tracks. Few students indicated interest in a government career path.

Discussion

Although research has explored the factors influencing students' decisions to pursue BME as a major (e.g., [1–3]), limited work has investigated factors related to students' choice of specialization *within* the BME major. Moreover, while studies have examined how BME students describe their career interests and job prospects [1, 16], as well as gender differences in career outcomes [17] to our knowledge, no research has examined how gender influences track choice. This study, informed by prior research on intra-major specialization and SCCT, examined the factors that BME students' report being influential to their intra-major specialization track selection, the outcome expectations that they associate with particular BME specialization tracks, and gender differences in these relationships. Further, the study explored the career sector interests of BME students and again examined gender differences in these interests. In exploring these relationships, we answered three research questions.

RQ1: What curricular and extra-curricular factors are most related to student track choice in BME? Do the relationships between these factors and track choice vary by gender or track?

In our study, undergraduate students on average rated professors/classes as the strongest of the five influences on intra-major specialization. On average, alumni and advisors were rated the lowest of the five influences, and peers, extracurriculars, and internships were all rated, on average, as modestly influential. Importantly, these terms were not defined for survey participants, and these terms may be defined differently for survey participants, for example, in defining the breadth of "extracurriculars." Taken together, these results suggest that individual faculty and courses can have a significant influence on student intra-major specialization decisions. This may be of particular importance for introductory classes or prerequisite classes. While, on average, students rated alumni influence lower than other influences, some students still rated this highly. This may be because only certain students have access to alumni from which to gain perspective. Advisors had an average high rating, but a large skew toward lower rating, especially for women. Students are only required to meet with an advisor once per semester for class registration, but it is possible some students meet with an advisor more often and this may have influenced their rating. Interestingly, women students reported on average a higher rating for influence of professors/classes, suggesting that the women in our study more than men may be swayed toward (or away from) particular intra-major specialization tracks based on positive (or negative) experiences with professors and classes. We did not identify a relationship between influence factors and specialization track.

While our study inquired about the influences on student intra-major specialization decisions, the study did not capture whether these were positive or negative influences. Thus, future research is needed to unpack the specific quality of the influences we explored in this study. For example, while our study did ask about the influence of peers on track selection, this influence could be in the form of peer support or peer pressure. While previous research finds that peers can be a positive source of support for engineering students' specialization track selection [8], one student in our study shared that the BME major was "very competitive" with "peer pressure" from students who are intending to pursue medical school after graduation. The student explained that in an effort to avoid that pressure, they selected a track that enrolled less premed students, explaining that "sometimes those students are the ones to make me feel as though I am not doing enough." Similarly, average grades in prerequisite courses or elective courses could persuade or dissuade students from selecting a particular intra-major specialization. In the open response section, one student mentioned how exam scores have influenced their track choice. Another student mentioned feeling "stuck with a certain path" that "restricts their ability to explore engineering." Multiple students expressed feelings of being "stuck" in their track due to already having taken courses or not being able to choose their desired elective course because they conflict with core classes that are often only offered at one time once a year. These results highlight additional factors in understanding student intra-major specialization decisions that should be explored in future research.

RQ2: What are students' outcome expectations associated with track selection? Do these expectations vary by gender or track?

Overall, undergraduate students rated all track outcome expectations highly. The most influential on average were that the specialization track would provide an opportunity for work that is compatible with one's interests and work that would help the student achieve their desired professional success. On average, students rated expectations that their track would allow them to pursue a job with a good income and that their track would allow them to pursue a job with good colleague interactions as the lowest, yet still as a modest influence. The influence of opportunity for good colleague interactions was the most variable among respondents.

With respect to gender differences, interestingly, women students in our sample indicated a higher rating for the expectation that their track selection would provide them with a good income. While outside the scope of this study, this finding raises interesting questions about the reasons for this relationship. Prior research suggests that women anticipate bias upon entering engineering and other STEM careers (e.g., [56, 57]) and that one reason for both male and female students' choice of engineering major is because of expected pay and job security [9]. Positive collegial interactions are often a main source of job satisfaction for many [58], thus it is logical that many students hope to find this in a future career. Combining these findings, it may be that women who choose engineering careers (over other STEM or non-STEM careers) may feel that the high pay potential of engineering overrides the negative anticipated potential of bias. Thus, women may make decisions within the major with the expectation of capitalizing on the high pay potential of engineering in their future careers. This is but one of many potential explanations, and future research is needed to tease apart the reasons for this difference in good income expectations based on gender.

RQ3: What career sectors do BME students report most interest in pursuing? Do these career interests vary by gender or track?

The most common career sector for which BME students indicated interest was industry, followed by medicine. Some students described that their desired career sector (e.g., industry or medicine) had an influence on which track they selected, indicating that students perceived that certain tracks would be better suited to specific career sectors. For example, one student shared:

> I came in debating between industry biomechanics and medical school with the goal of building medical devices. But to follow the medical school track I would choose a different track like cell and tissue and to commit to industry I would take biomechanics.

While the sample size for individual tracks was limited, we did observe trends that suggest that students in some intra-major specialization tracks were more interested in industry careers than non-industry careers. For example, the intra-major specialization tracks most linked to industry were Biomechanics and Computational Systems Biology. By contrast, the intra-major specialization track least linked to interest in industry careers was Cell and Tissue Engineering. Future research is needed to understand if interest in the career sector guides intra-major specialization track choice or if selection of an intra-major specialization track influences plans to pursue a specific career sector. For example, in the case of Cell and Tissue Engineering where fewer students indicated an interest in industry, it would be interesting to know whether students who plan to pursue industry careers do not select this specialization and for what reasons (e.g., perceived lack of industry jobs in this space) or if students who choose Cell and Tissue Engineering subsequently develop less interest in an industry career and for what reasons (e.g., they learn there are less industry careers in this area). Related, future studies might adopt a longitudinal approach whereby they might assess student job placement rather than student interest in different career sectors to improve the predictive validity of the relationship between intra-major specialization track selection and career outcomes. Consistent with prior research suggesting challenges in the BME-to-industry pipeline [59], one student wrote that there is "smack talk" from other engineering majors that students in BME will not get jobs after graduation and that BME students need additional career support related to industry jobs. The student expressed concern that within the major, students are more often exposed to research and academic careers and that students need additional career guidance about industry opportunities, stating that the program does not "prepare students for industry/career search." This suggests that students may benefit from curriculum that highlights industry opportunities across intra-major specialization tracks. Women in our study were more likely to be interested in industry and less likely to be interested in medicine. It may be that women students believe industry to hold more opportunities to make more money faster than medicine, which may be a reason that women, who tend to rate a good income expectation as high, show more interest in industry.

Educational Implications

This research carries with it several implications for BME educators and decision makers. First, our finding that professors/classes were the most influential factor in student intra-major specialization decisions suggests that BME departments may benefit from ensuring that introductory and pre-elective classes and teaching are structured so as not to increase the chances of turning students off to particular areas of study. For example, a bad class or a bad professor may have the effect of reducing the interest of students who might otherwise be interested in exploring a wider array of specialization areas.

Second, the finding that alumni were not particularly influential in student intra-major specialization selection suggests that alumni may be an untapped resource when it comes to student learning about career paths and opportunities. Alumni interactions could be increased by hosting seminars and networking events for current students. This may be an important oversight given that alumni are individuals working in wide variety of roles and career sectors and may thus be in the best position (more so than professors and academic advisors) to speak to job and career opportunities associated with particular specialization tracks.

Third, our finding that most students connect their intra-major specialization track to positive outcome expectations raises potential questions about how informed students might be about these outcome expectations. Thus, it might benefit BME career counselors to provide students with more information about careers and career paths linked to particular intra-major specializations or about BME career paths in general to maximize the potential for students to make informed decisions.

Finally, at a broad level, future work that investigates how students learn about intra-major specializations and make decisions about these specializations will inform curriculum design. Further, an increased understanding of how intra-major specializations influence student career decision-making and outcomes will benefit student career advising. Finally, additional research that seeks to understand the role of social identities in intra-major specialization choice will support recruitment and retention in BME programs.

Limitations and Future Work

The present study has some limitations that suggest avenues for future research. First, we were limited in our ability to analyze influences by track due to the relatively small sample size for individual tracks. Although we purposefully analyzed a subset of survey participants to understand the relationships associated with intra-major specialization within BME, future research could replicate our findings with a larger sample and additional engineering majors. Second, our sample is composed of students at various academic levels from a single institution thereby limiting the generalizability of the findings. First-year students often take more general math and science courses outside of the BME department than upper-year students, who take more courses specific to BME. It is possible new students may be less influenced by general courses because they can seem to not relate to specializations. We do not specify whether the professor/classes influence is coming from within the BME department. Additionally, first-year students may be less likely to hold internships or have held fewer internships at the time of this survey, influencing the perception of this influence. While the findings are nevertheless informative, future studies may examine the relationships explored here in other BME educational settings. Third, although we assessed gender with a non-binary option (in addition to options to select man and woman), the small number of students identifying as non-binary in our sample limited our ability to analyze gender as a moderator in a non-binary way. Future studies may address this issue by purposefully sampling engineering students who identify as non-binary. Fourth, the data collected are self-reported by students. Although this approach fits with our interest in student perceptions of factors, such as outcome expectations, future research could attempt to collect objective intra-major specialization decision data (based on department records) and may use a longitudinal approach assessing job placement instead of interest. Fifth, our focus on intra-major specialization within BME raises larger issues about the benefits and limitations related to the necessity for students to select specific specialization tracks in their second year of education (or earlier), as is common in many programs. On one hand, these tracks help students to develop specialization in a particular area of interest, but on the other hand, rigid tracks may limit student options if students make uninformed decisions about tracks and/or if they get "stuck" in a particular track due to lack of requisites to switch tracks. Additionally, future work would be benefitted by collecting information about who is completing internships, as participating in an internship may impact the perceived influence of internships for intra-major specialization.

Conclusion

Given the importance of intra-major specialization on student career preparation and outcomes, understanding how students make decisions about intra-major specialization will inform curriculum development, policy, and academic advising. Our study examined undergraduate student influences and outcome expectations associated with intra-major specializations within BME. Overall, most students indicated multiple different influences on their intra-major specialization choice, with professors/classes rated highest of the influences studied. Additionally, students indicated multiple outcome expectations for their intra-major specialization selection, although good income and colleague interactions were rated slightly lower than other outcome expectations on average. While the sample size of the study limited some group analyses, differences were identified by gender and specialization choice, indicating that these factors may be important to consider in future work. Future research that further explores factors on student intra-major specialization decisions will benefit the BME community to support student career preparation and selection.

Appendix

Complete Survey

What elective track have you selected or are you planning to select? If your major doesn't have elective tracks, what area, if any, do you plan to specialize in with your elective courses? (Short answer)

How important were/are each of the following in your choice of elective track/specialization (1=not at all important, 5 = very important)

Advisors

Peers/Friends

Alumni

Professors/Classes

Extracurricular activities (e.g., clubs, RSOs)

Internship(s)

Other (describe other factor(s) that were important)

To what extent does the elective track/specialization area you selected, or are planning to select, provide the following (1 = not at all, 5 = to a great extent)

· Allow you interaction with your colleagues
· Let you practice skills that best suit your perceived abilities
· Provide you with a good income
· Allow you to perform a broad spectrum of work
· Be compatible with your interests
· Allow you to achieve your desired professional success

Which of the following best describes the career sector you are most interested in entering once you finish your education (check all that apply)?

· Industry
· Medicine
· Academia/Professor
· Government
· Other:

(If selected #Industry or Government, proceed to the next question)

If you think about you career in the next 5-10 years, which of the following is your most desired career path.

· Technical path (you want technical activities to be at the center of your career)
· Managerial path (you want to take on roles that are increasingly managerial, organizational and supervisory)
· Project-based path (you want to work on a series of technical projects to broaden your technical skills)
· Hybrid path (you want to do a mixture of technical and managerial work)
· Entrepreneurial path (you want to start your own company)

What is your engineering major?

What is your [institution] email address?

What gender do you most identify with? (Male, Female, Non-Binary)

What year are you in your program? (1st, 2nd, 3rd, 4th, 5th, Other)

What is your cumulative GPA?

What is your technical/major GPA?

Socio-Economic Status

What is your race/ethnicity? (Check all the apply)

What is your age in years?

In the space provided, please tell us any additional information about your experience in your engineering major with your elective track/specialization area that you think it would be helpful for us to know. (Short answer)

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Code Availability Not applicable

Declarations

Conflict of interest None

Ethical Approval The questionnaire and methodology for this study was approved by Institutional Review Board of the University of Illinois Urbana-Champaign (IRB #19580).

Consent to Participate Informed consent was obtained from all individual participants included in the study.

Consent for Publication Identifying information not present.

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