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BME Career Exploration: Examining Students' Career Perspectives

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Biomedical Engineering Career Exploration: Examining Students' Career Perspectives

Abstract. *Historically, biomedical engineering (BME) undergraduate programs have been designed to expose students to the broad spectrum of knowledge required to adequately address problems in engineering and medicine. While students' resultant knowledge base has allowed for flexibility in the careers that undergraduate biomedical engineers can enter, many BME students also believe that the broad curriculum may lead employers to perceive them as underprepared to enter industry positions upon graduation. Recent studies have validated this concern, as BME students report fewer co-op and industry internship placements pre-graduation, enter the job market with fewer available jobs seeking BME graduates, and receive lower average annual salaries than other engineering disciplines. Despite the challenges, students continue to pursue and persist through BME undergraduate degrees. If the perception is that their options are limited in industry, it is important to identify and understand the careers that BME students consider pursuing. To explore what BME students perceived as possible for a career upon graduation, this study examined changes in BME students' career perceptions over the course of a year of their undergraduate program. Fourteen (14) undergraduate BME students were interviewed three times over the course of their third year at a large R1, public university. A qualitative analysis identified patterns of change at the individual and group levels. Findings indicated that most participants' initial view of possible careers in the field was narrow. Over the course of the study, some participants changed their view of career possibilities; for those who had not yet decided on a career, concrete exposures to possible BME careers contributed to more optimistic career outlooks. Suggestions for future research to more broadly understand BME students' career exploration are also presented.*

Introduction

Biomedical engineering (BME) degrees are often advertised as a means to pursue many career pathways upon graduation [1]; however, at the same time, their curricula has been criticized as being too broad and not deep enough to prepare students adequately for industry work [2]–[4]. Studies have explored these criticisms by looking at measures of industry competitiveness, such as co-op and internship placement pre-graduation, ratios of BME graduates to BME industry jobs, and average annual salaries of BME graduates. Reports indicate that BME students have fewer co-ops and internships pre-graduation [5], enter the job market with fewer job opportunities [2], [6], and receive lower average annual salaries than other engineering disciplines in industry [2], [5], [7].

While enrollment and graduation rates in BME undergraduate programs continue at a steady pace [6], knowledge about what students' career aspirations are, where they go upon graduation, and why, is limited. Some preliminary data collected from alumni of one large, R1 institution with a BME program indicated that while a good proportion of students (40%) may enter BME considering pathways like medical school or graduate school, many of those students (from 17% entering the degree to 45% upon graduation) end up pursuing industry positions after graduation [8]. Given the previous figures on students' career plan changes between entry and graduation, as well as the stigma that BME bachelor's degree graduates experience with industry career placement barriers, more research is needed to understand students' perceptions of BME industry career pathways, particularly at a later stage in the degree. Understanding these perceptions can help inform how BME programs are advertised, how programs help students explore industry

career options, and how programs strategize partnerships with industry employers. This qualitative study used an exploratory approach to examine third-year students' perceptions of an undergraduate BME degree as a means to pursue a career upon graduation, with particular analytical focus on career pathways. Most immediately, results can be used to make recommendations for how to better serve the needs of students at the institution where the study was performed. More broadly, this exploratory work proposes important areas for future research that can help educators understand how BME students' perceptions of the field change between their enrollment and their successful entry into a career.

Background

In the scholarly literature, BME is often viewed as a discipline characterized by its ties to both engineering and medicine, as well as the necessary work performed across those disciplines, to integrate knowledge and solve medical problems [9], [10]. With such a broad definition, BME is applicable in many professional contexts. For example, when tasked with describing what a BME does, one author posed a counter question: "What don't biomedical engineers do?" [1, p. 23]. BME bachelor's degree graduates can work in entry-level engineering positions in medical device or pharmaceutical companies, clinical engineering positions in hospitals, sales positions for biomaterials or biotechnology companies, research positions at academic institutions, and positions in government agencies (e.g., the FDA) [1]. With further education, those with BME undergraduate degrees have also gone on to work as physicians, business managers, patent attorneys, physical therapists, professors, research scientists, teachers, and technical writers [1]. With a wide array of possible careers, BME professionals must be prepared to perform a wide variety of job requirements [9]. Within their day-to-day tasks, a BME practitioner may be asked to design instruments, devices, or software, integrate technical knowledge from multiple sources, develop new procedures, or conduct research needed to solve clinical problems [9].

Historically, as the number of BME undergraduate programs grew, BME program directors viewed industry positions as a promising employment option for undergraduates. Researchers and educators cited positive statistics for the number of degrees compared to the number of industry jobs (i.e., involving the design, manufacturing, regulation, and sale of products and services in the biomedical sector) available for biomedical engineers in the 1970's and 1980's [9]. However, as more programs have developed and the number of graduates has increased, the ratio of graduates to the number of industry job openings has become less promising [6]. Further, research on student job placement shows that the history of BME program development as intentionally broad and unique to each institution's faculty strengths [9], may have had a negative impact on industry's perceptions of BME graduates, limiting BME student industry career placement upon graduation [5], [9], [11], [12]. These studies indicated a disconnect between industry desired skills and the training received by BME graduates [9], [13]. Other research discussions proposed that the lack of consistency in what is taught across BME programs has contributed to industry's limited understanding of the knowledge and competencies they can expect of BME graduates [10]. In acknowledgement of these issues, some programs have expressed a need to better market their students' abilities and prepare students to communicate their skills to address this perceived disconnect [11].

In examining industry jobs available to students within the BME field, it appears that BME industry placement with an undergraduate degree is difficult. Despite concerns surrounding industry job placement associated with a BME degree, students continue to pursue and graduate

with the undergraduate degree [6], which may be related to other motivations students have for pursuing BME. Research on engineering career pathways has indicated that completion of an engineering degree does not necessarily mean that students will pursue engineering work. In particular, a study of engineering students across disciplines at two universities showed that students who complete an engineering major are not necessarily committed to performing a traditional engineering job [14]. Along similar lines, a study by Rohde and colleagues [15] indicated that an interest in BME was negatively associated with entering an engineering industry career. Further, using the Academic Pathways of People Learning Engineering Survey (APPLES) dataset, Gilmartin and colleagues [7] also found patterns that indicate that BME students are less likely to pursue engineering industry positions when compared to other engineering degrees, interpreting their results as evidence that perhaps BME graduates see their degree as a bridge to other positions (e.g., medical school or other graduate schooling). While research suggests that not all BME graduates wish to enter industry careers, other motivations students have for pursuing a BME undergraduate degree are relatively understudied in the current literature. Some preliminary research indicates that BME may be attractive to students as a way to combine engineering with their other career interests (e.g., clinical careers [16] or a career that allow them to help others [17]).

Given the complexity of BME industry career placement upon graduation, institutional efforts to improve students' understanding of BME as a career should focus on improving communication of their career options upon graduation, including careers that may not be perceived as traditional engineering positions. Rohde and colleagues support a similar strategy in approaching engineering education more broadly, stating that research in engineering education frequently discusses students who do not enter the engineering industry, academia, or who leave after a few years as 'lost' [18]. They argue that earning an engineering degree gives students the necessary skills and ability to have a significant positive impact on the workforce, regardless of if they enter or persist in what is typically classified as an engineering career.

In conversations about what a BME career looks like, the voices of educators and industry employers have typically been included [10], [19]. Relatively few studies have incorporated the perceptions of students in discussions about what BME is [10]. When examining students' definitions of the field of BME, Ramo et al. argued the importance of incorporating student voices in conversations about BME to develop a "coherent field identity [10, p. 1]". Further, student perceptions of the BME field can provide important insights on a common understanding of the possible careers in BME, which can inform recruitment and career mentoring efforts within departments.

Study Design

This study was guided by the following research questions:

What do BME students perceive as possible careers in their field? How might their views change over time?

In order to answer these questions, the careers that students perceived as possible for BME's were first identified from the data. Changes in the students' perceptions of possible BME career paths over time and observed sources of career exploration were also studied. Data used in this study were collected as part of a larger longitudinal, qualitative study focused on how upper-

level BME students' experiences and professional development occur naturally, without researcher intervention, through co-curricular engagement. Qualitative research methods are commonly employed to explore participant motivations, interpretations of their experiences, and/or provide detailed descriptions of a given event or phenomena [20], [21]. The first author conducted interviews with fourteen BME students at three time points spanning their third year of undergraduate study. While performing the first interviews, the interviewer observed common discussions about students' perception of possible careers in BME. In order to explore how students were discussing these ideas further, follow-up questions were added to the remaining interviews. The practice of refining research questions, data collected, and/or analysis methods throughout a qualitative research study is common. The refinement acknowledges the interconnected nature of the stages of research, where the data collection and analysis process is not linear but rather permits each step to inform both the previous and succeeding stages in the research [22]. This view of research was particularly relevant for this study, which allowed for the examination of a spontaneous set of discussions observed in the interviews, but not originally in the scope of the study design.

Institutional Context

The study was conducted at a large, research-intensive, public university located in the Midwest United States. Students enrolled in the institution's BME program pursue one of three concentrations as a part of their undergraduate major: bioelectrical, biochemical, or biomechanical. Unique to the timing of this study, the university transitioned to a hybrid course format prior to the final interview, with the majority of classes offered virtually and a select few offered in an in-person format due to the COVID-19 pandemic.

Participants

Through purposeful and snowball sampling, 14 BME undergraduate students in the beginning of their third year were selected to participate in the study. The fourteen-participant sample utilized in this study is well within the range of a typical sample size for a qualitative study, as these studies rarely seek to generalize results but rather ask questions that allow for an in-depth understanding of a specific environment [23]. Participant quotes are denoted by "P(participant number)I(Interview number)," such that the first interview completed by the first student is referred to as P1I1 within the context of this study.

Interviews

Each of the participants completed a series of three 45- to 90-minute semi-structured interviews over the 1-year study period. Interviews were conducted by a BME graduate student (the first author) at the beginning of the first semester (Interview 1), near the end of the first semester (Interview 2), and towards the end of the second semester of the students' third year (Interview 3). The interviews for the third interview occurred during the early months of the COVID-19 pandemic. As a result, one participant did not complete Interview 3 and the remaining thirteen interviews were conducted virtually through video calls.

Semi-structured interviews were leveraged as a way to explore student perceptions about how their curricular and extracurricular experiences relate to their professional development as biomedical engineers. An advantage of a semi-structured interview in longitudinal studies is that while all participants are asked certain questions, allowing for comparisons across participants and time points, the interviewer also has the flexibility to add follow-up questions that allow for

further exploration of participants' views on a topic if responses are interesting or unexpected [20]. Within this study, the interviewer recognized patterns in how students were describing their perceptions of the BME job market, and chose to incorporate follow up questions in the interviews that could further explore this topic (see Appendix C for some examples). These discussions were extracted from the interviews for the analysis presented in this paper.

Data Analysis

A qualitative data analysis was performed to identify the careers that students perceived as possibilities within BME as well as to gather information on how they found information on possible career paths during their educational experience. Passages that mentioned career possibilities were selected from the interview transcripts and compiled into the NVivo 12 program. The first two authors identified common areas of discussion in the passages independently during the intensive reading process [24] that followed, noting that participants named multiple possible BME careers as well as how they learned about those possibilities. For instance, the mentions of "academia", "industry", and "medical school… pre-med track" in the excerpt below were noted as possible careers in the initial reading process.

"I think now I see that I could take my BME degree to a lot of different places, not just into academia or not just into industry, but I've heard that one third of people in BME are going into medical school or working towards, working in that pre-med track." ***P2I1***

The first two authors then read the transcripts a second time, creating codes for possible careers (second author) and opportunities for career exploration (first author). After discrepancies and patterns between the identified career codes were discussed, the scope and meaning of codes were refined to reflect observed patterns in the career possibility discussions in the data. Conceptually similar codes were grouped into a set of categories (Academia, Industry, and Other). Interview questions that probed relative importance or interest in specific career paths were not asked; as such, the coded mentions of a career path were considered to represent a student's awareness of a career possibility. Additionally, the research questions and analytic approach presented aimed to explore what students perceived as possible rather than plausible or most interesting.

A code was counted if it was mentioned at least once by a participant. Because the intensity of the students' awareness or interest was not the focus of this study, multiple mentions of a code by a participant within a single interview were coded just once per participant. However, mentions of the same code by a participant across multiple interviews were coded multiple times (e.g., two mentions of bioinformatics in P1I1 would be coded once but one mention of bioinformatics in both P1I1 and P1I2 would be two codes). Definitions for how the career possibilities codes were categorized (Academia, Industry, and Other) and applied can be found in Appendix A.

Results

The number of careers mentioned per participant suggested that students' overall knowledge of possible BME careers broadened over the course of the interview cycle, especially from Interview 1 (an average of 4.93 careers) to Interview 2 (an average of 8 careers). A closer examination of trends in the way participants discussed possible BME careers during the code application process also indicated that the number of possible careers mentioned by participants

was negatively related to the students' level of certainty about their own career aspirations throughout the interviews. This level of certainty was analyzed by examining the language by which the students described their personal aspirations throughout the interviews as well as the specificity of the career paths that were mentioned. For example, students whose responses displayed confidence in their personal career aspirations in Interview 1 exhibited less growth in the number of newly mentioned possible careers between Interviews 1 and 2 when compared to students who appeared less certain about their career aspirations. Along with our analysis of what careers BME students perceived as possible upon graduation, we found that many students mentioned the positive impact of opportunities that allowed them to explore the wide array of career possibilities with a BME degree. In discussing that career exploration, participants named multiple mechanisms at the university that they found helpful in navigating their own exploration process.

BME Career Possibilities

For the analysis of BME career possibilities, the number of unique careers mentioned by each participant in Interviews 1, 2, and 3 were calculated. The total counts for the *Academia, Industry, and Other* (e.g., business, consulting, healthcare, law, public health, and more) categories are summarized in Table 1. Since Interview 3 consisted of fewer participants (n=13) than both of the previous interviews (n=14), the values in Table 1 were also normalized in order to compare across interviews. The normalized number of unique careers mentioned in each interview was calculated by dividing the total number of career codes by the number of participants. The resulting values are displayed in parentheses. A table detailing the counts for each of the individual codes (i.e., specific careers) in Interviews 1, 2, and 3 can be found in Appendix B.

The number of careers mentioned per participant increased from Interview 1 to Interview 2. Participants mentioned an average of 4.93 different careers in Interview 1 and an average of 8 careers in Interview 2. The increase in careers mentioned between Interviews 1 and 2 came from the categories of *Industry* and *Other*. In *Academia*, the total careers mentioned by participants remained fairly constant. Comparing responses from Interview 3 to Interview 2, both the total and normalized values from Table 1 indicate that participants mentioned fewer careers in each category. Despite this decrease, the average total number of careers mentioned per participant in Interview 3 (6.54) remained higher than the average mentioned in Interview 1 (4.93).

Table 1. Total Number of Possible Career Path Codes

	Interview 1 (n=14)	**Interview 2 (n=14)**	**Interview 3 (n=13)**
Academia	11 (0.79)	11 (0.79)	10 (0.77)
Industry	28 (2)	43 (3.07)	38 (2.92)
Other	30 (2.14)	58 (4.14)	37 (2.85)
Total	**69 (4.93)**	**112 (8)**	**85 (6.54)**

The study was also interested in the total unique careers identified by students over the three interviews. Figure 1 demonstrates the growth in each participant's mentions of unique BME

careers over the course of the three interviews. The number of BME careers that students communicated in Interview 1 are represented as the leftmost points on the graph. To account for repeated career codes from Interview 1, the total number of unique careers that each participant mentioned in Interview 2 was calculated by adding the number of new careers mentioned in Interview 2 to the number of careers identified by the same participant in Interview 1. Similarly, the values for the Interview 3 time point were calculated by adding the previous number of careers mentioned by the participant (i.e., the unique careers in both Interview 1 and Interview 2) to the number of new careers mentioned in Interview 3.

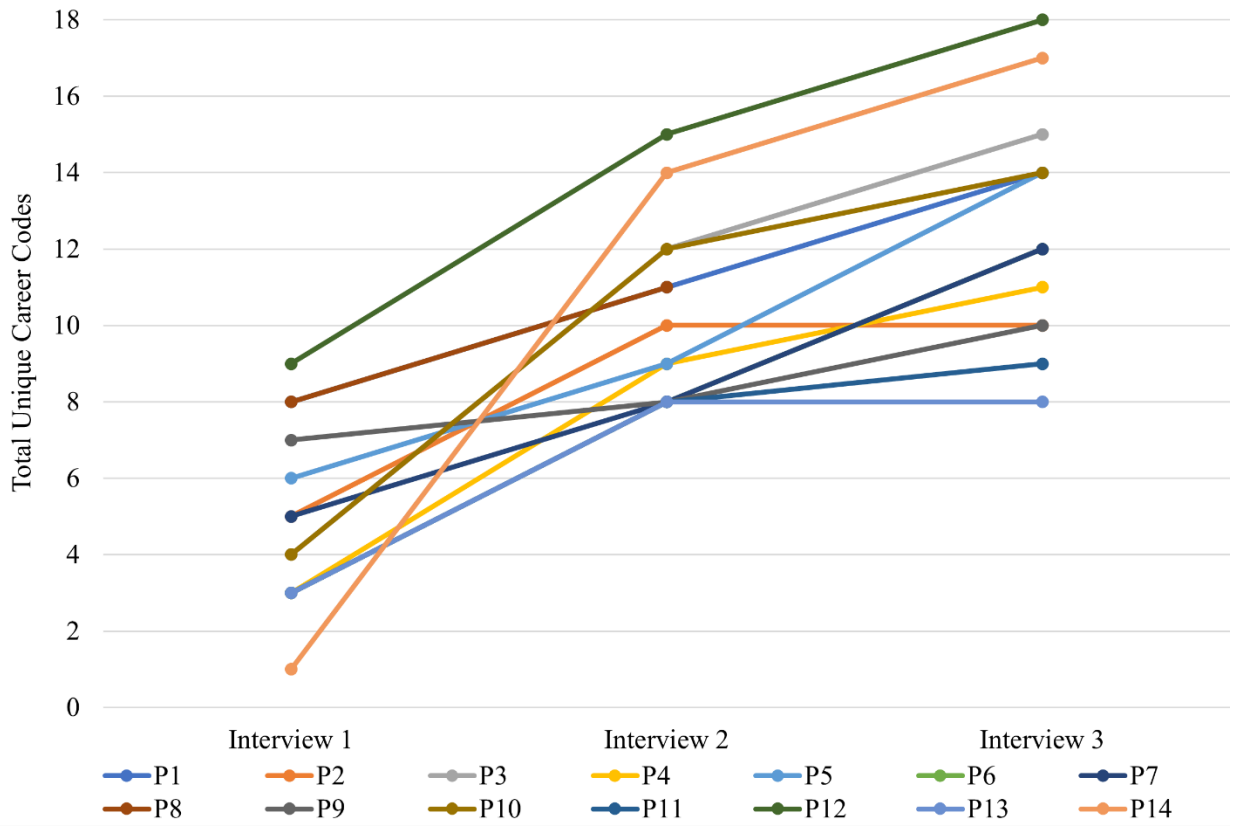

Figure 1. Total Unique Career Codes for Participants Over Time

All participants mentioned additional unique BME careers from Interview 1 to Interview 2 (Figure 1). All but two of the students showed continued growth (mentions of additional unique careers) into Interview 3. These two students, P2 and P13, repeated the same careers in Interviews 3 that they already had mentioned in Interviews 1 and 2. However, all interviewees displayed an overall increase in reported unique career paths over the course of the three interviews. Generally, for those who showed continual growth throughout the entire interview process, the increase in the number of unique careers mentioned was larger between Interview 1 and 2 compared to the increase from Interview 2 to 3. Participants 5, 7, and 9 were the only participants who had a smaller increase in reported unique BME careers between Interviews 1 and 2 than between Interviews 2 and 3. The patterns observed in Figure 1 were further explored by examining students' responses qualitatively. Table 2 shows example quotes from Participants 2 and 9 that illustrate how participants' discussions of possible careers could relate to their certainty of their own personal career aspirations at the time of the interviews. Compared to the

rest of the interviewees, P2, who appeared unsure of which career they wished to pursue upon graduation based on how they described possible careers in the interviews, named a typical number of career possibilities in their first interview (5 career codes) and showed a substantial increase in the number of new careers named in Interview 2 (5 additional career codes). However, they mentioned no additional careers in Interview 3. Alternatively, P9 who talked about personal career aspirations much more confidently in their interviews, mentioned 7 careers in their first interview but only named one (Interview 2) or two (Interview 3) new careers in the following two interviews.

Table 2. Examples of Discussions of Prospective BME Career Paths and Personal Aspirations Across Interviews with Participant 2 and Participant 9. underline = prospective BME career named; {} = career code applied

Identifier	Example Quote
P2I1	*I think now I see that I could take my BME degree to a lot of different places, not just into academia {Academia - General) or not just into industry {Industry - General}, but I've heard that one third of people in BME are going into medical school or working towards, working in that pre-med track {Other - Healthcare}.*
P2I2	*I've been struggling with that, with what I want to do in the future. Like I thought I wanted to go into industry {Industry - General} after graduating undergrad… but like this semester, I felt like job searching for me is really stressful and very difficult… and I thought about whether I would like to stay in the industry for 30 to 40 years. And I couldn't imagine myself… in the industry for that long… I think there's so many paths that BMEs can go into. And I think that's a blessing and a curse… I think I heard that one third of BMEs are pre-med, so definitely the healthcare kinds of things {Other - Healthcare}. Like, becoming a doctor. And then, going into industry. And that could be a lot of different roles like product development {Industry - Design, Research & Development} or I know someone who's going into human factors {Industry - Human Factors, IOE}. Or quality engineering, regulatory affairs {Industry - Regulatory, Quality Engineering}. And I feel like it could also go into government jobs {Other - Patent, Law, Politics} too, like FDA or my friend is interested in pursuing a public health {Other - Public Health} degree after undergrad.*
P2I3	*Starting last semester… I began to think maybe the industry {Industry - General} isn't the best option or best choice. I couldn't see myself working in the industry for 30 to 40 years even, so I began considering other options. Right now I'm thinking about… either pursuing PA {Other - Healthcare} or the regulatory {Industry - Regulatory, Quality Engineering} side of medical devices {Industry - Medical Devices}… Yeah. I'm not too sure what I will be doing in 10 years, but right after graduation I think I would be either working in providing patient care to apply for a PA school in the future, or preparing for a grad school, or patenting {Other - Patent, Law, Politics} or regulation side of things… I think that there is a wide range of*

	options [for BMEs], but I think it's sometimes harder for BMEs to enter into those. I feel like we have a wide option, but not everyone can have those jobs.
P9I1	*I would say that biomedical engineers can do a lot. So, so far in research, I've seen a lot of both like the wet lab side and analysis as well, even some development {Industry - Design, Research & Development} and troubleshooting {Other - Coding, Computational} and things like that… I would say that biomedical engineering gives you a wide base of knowledge, both as you get experience in the mechanical {Other - Other Engineering - Mechanical} side of engineering, but also you get experience doing electrical {Other - Other Engineering - Electrical} work and circuits. And then it also gives you an opportunity to really focus in on a specific area, which for me, I would definitely choose more of the chemical tissue engineering {Other - Other Engineering - Chemical} side.*
P9I2	*Biochemical {Other - Other Engineering - Chemical}… I'm really interested in more of the research and development {Industry - Design, Research & Development} side of BME. I'm not particularly interested in medical devices {Industry - Medical Devices} or circuitry or anything like that… I think I would like to start a PhD, either immediately after [undergrad] or maybe after a gap year for my kind of short term… but long term I'd like to be in the R&D industry… I have heard of people in BME going into things like consulting {Other - Consulting} or there's also a lot of development and engineering positions that people go into. Development of instrumentation and more the electrical {Other - Other Engineering - Electrical} side. I've also heard people who take their skills from BME and just apply them to a different field in general.*
P9I3	*Immediately after [undergrad] I'd probably like to take a gap year working in a research {Academia - Research} lab of some sort, but eventually I'd like to be in grad school, probably pursuing a PhD. So that's the five year plan. I would like to be in industry doing research {Industry - Design, Research & Development} [in the long term]... probably for a pharmaceutical {Industry - Pharmaceutical} company or something like that… [BMEs can do] a lot for sure. I was actually looking at LinkedIn yesterday for work and looking at [my university] alumni in BME doing all different kinds of things, obviously from medical devices {Industry - Medical Devices}, … to research, to consulting {Other - Consulting} to all different kinds of stuff.*

Opportunities that Exposed Students to BME Careers

The qualitative examination of students' career possibilities also demonstrated the importance students place on opportunities to explore what different careers look like in BME. These discussions often occurred simultaneously with students describing realizations of what they wanted to do or how they would fit into the BME career landscape. Students described the importance of the co-curricular activities that were the focus of the original interviews, but examples of exploration opportunities also included other co-curricular settings, department level programming, and experiences in a course where professors discussed examples of BME careers.

Students indicated that these opportunities gave them the ability to make professional connections, understand the types of jobs biomedical engineers have successfully obtained, get advice on how to talk about their undergraduate experiences in order to get a job in a company, and understand company cultures before entering the workforce. Students mentioned opportunities like attending programming from professional fraternities specifically for BME students, participating in BME design teams, talking with senior members of their labs (e.g., post docs and graduate students) through undergraduate research, volunteering in hospitals, attending alumni engagement socials, and hearing professors point out career paths that relate to the content taught in their courses. Further, some participants described these opportunities as ways to find out what they did not enjoy before entering the workforce. Some example quotes from interviews that demonstrate this theme are shown below in Table 3.

Table 3. Examples of Where Students Described Opportunities to Explore Careers in BME. underline = exploration opportunity

Identifier	Example Quote
P8I2	*I think that like personal goals, from doing the research have stayed the same of just gaining new knowledge of the field of biomedical engineering, and seeing what specific types I enjoy, and seeing where I should take, further my career. Also doing research has made me possibly consider doing a PhD. So, I guess seeing what I'm interested in, like I said. Seeing if I want to go to grad school or go to a career, which I think is always, doing anything outside of class, is like always just trying to see what I like and don't like, and what I can see myself doing in the future.*
P11I2	*I think they [the professional fraternity] have helped me a lot with progressing through the University, or just through my career here. Then, they also helped a lot with just figuring out what you want to do in the long run [...] I feel like the network is very close-knit and very approachable. Like, when I went to career fair, and I spoke to Stryker, the representative that I talked to was the founder of my professional fraternity. It all just comes full circle. And it's just really interesting to see where people are now that have been in my shoes kind of.* ***P11I2***
P13I2	*I think talking to professors and their experiences are also helpful, so hearing about them I think will help structure the career path as well. And I think there are also opportunities outside the university like getting internships for experience.*
P10I3	*There's a distinguished alumni awards lunch and one of the people who won the award she did undergrad in MechE, Masters in BME and then now she's a nurse. And so, I went to lunch, I talked to her and I was talking to another recruiter and they encouraged me to forget about an internship and just be a CNA. It was scary.*

Discussion

Upward trends in the number of possible BME careers named by students across the interviews were observed, indicating that BME students are still exploring different careers as they progress to their final year as an undergraduate. A deeper qualitative analysis of the responses indicated that students have varying levels of certainty in their own aspirations at an advanced stage in

their undergraduate career. Insights from the qualitative analysis also pointed towards the importance of career exploration at multiple levels of depth. Based on the results and the literature reviewed, the authors propose implications for changes in practice and suggest research topics that warrant further investigation.

Overall, as the participants progressed through their third year, they mentioned a greater number of careers in their interviews. The expression of new, unique BME careers in these later interviews and the growth in the overall number of careers mentioned in each interview indicated the broadening of the students' understanding of possible BME careers over the course of the study. Students' changing perception of BME as field has been studied previously [25]. In their 2019 study, Ramo et al. found that students at different education levels view the field in nuanced ways, which to some degree, could link to the career exploration process studied in this paper. Within the group of students interviewed, the correlation between the increase in the total number of codes (Table 1) between Interview 1 and Interview 2 along with the large number of new unique careers named by a majority of the students in Interview 2 (Figure 1) suggests that a great deal of career exploration occurred between the first two interviews. Moreover, the growth in the number of careers mentioned between Interviews 1 and 2 for careers in *Industry* and in *Other* fields (outside of *Academia*) signifies that the students' exploration of BME careers between Interview 1 and Interview 2 likely occurred in those fields and that their perception of possible careers within those areas expanded. Despite a decrease in the average number of careers named by interviewees between Interviews 2 and 3 (Table 1), continued growth in the total number of unique careers for a majority of the participants was observed (Figure 1). Additionally, nearly all of the participants mentioned new careers in Interview 3 which implies that the students continued in their exploration of possible BME careers between I2 and I3.

Interestingly, the few participants that did not show substantial increases in the number of unique careers mentioned throughout the interview process also expressed their interests and intended career aspirations clearly and confidently in the first interview. These interviewees, including P9, described their aspirations using language that conveyed certainty in their choices and interests (e.g., *"I'm really interested in [X]", "I'm not particularly interested in [Y]"*) and their personal aspirations remained consistent throughout the interviews. Any new career paths that were mentioned in the participants' later interviews were often discussed with reference to other individuals' pursuits and aspirations. However, the majority of participants, including P2, that demonstrated substantial increases in their total amount of unique codes during the interview process discussed their career aspirations differently. Though many of these students had also stated their intended career paths in the first interview, they were more likely to use language that conveyed doubt and uncertainty when expressing their interests (e.g., "*I'm not very sure*", "*I'm still deciding", "I think",* etc.) than the participants who did not show substantial increases (e.g., P9). These students used general terms when referencing possible career paths in Interview 1, often mentioning "academia" and "industry" as opposed to specific careers within those fields (e.g., "education" and "R&D"). The frequent use of these generalizations may indicate that they held limited understandings of possible BME careers at the time of the first interview. During the second interview, these participants referenced more specific BME careers and many also demonstrated an increase in their total number of unique codes, though they continued to express uncertainty about their own career aspirations. These patterns suggest that students uncertain of their career aspirations in Interview 1 had explored career options between Interview 1 and Interview 2. It seems possible that these explorations were driven by the students' desire to

achieve more certainty regarding their own career options, since these participants often emphasized their own relation to the mentioned career possibilities ("*I thought about whether I would like [X]", "I couldn't imagine myself [in Y]*"). By Interview 3, most of these participants appeared more certain in their professional goals, based on how they discussed career possibilities in the interview. While many participants had still not determined what career they would pursue upon graduation in Interview 3, they demonstrated a greater level of clarity regarding their BME career interests in Interview 3 than in Interview 2.

The observed trends between the number of reported career paths by participants and their level of certainty about their own career aspirations suggests that participants who have a clear understanding of their own professional aspirations likely mention fewer possible careers. Conversely, when a participant was questioning their future career aspirations, they were likely to mention a greater number of career paths, which appeared to link to their own career exploration efforts. Future research concerning students' exploration of possible careers may wish to focus on exploring how realistic or probable BME students perceive different careers to be as well as identifying the sources from which BME undergraduates obtain new knowledge about possible career paths.

This study identified a few possible mechanisms by which participants learned about possible BME careers. Additionally, in those discussions, participants emphasized the importance of exploring career options on the development of their views of the overall BME career landscape. Exploration experiences like internships, co-ops, and research opportunities have been previously implicated as important for BME students' career choices upon graduation [1], [9], [26]. The results of this study indicated that smaller career exploration opportunities, like attending the alumni networking lunch mentioned by P10, can also have a big impact on students' career perceptions. This finding aligns with previous research from Lichtenstein and colleagues that found that students' thoughts about careers can be strongly swayed by a single experience [14]. Lichtenstein's work and the current study provide strong support for the value of intentional development of career exploration opportunities for BME students, even if they are short or single time point events. Future research may wish to intentionally explore the impact that single time point career exploration opportunities have on students' career plans upon graduation to inform administrators' and educators' efforts to facilitate students' career exploration.

Limitations

The exploratory nature of this study poses some limitations on the conclusions that can be drawn from the results. First, data were collected as part of a larger study with only third-year BME students at one institution. Although qualitative research in general does not aim to be generalizable [21], [27] and the recommendations made based on the results of this study focus on posing questions for future research rather than making generalizable claims, including other age groups or BME students from other institutions in the study would have added to the overall understanding of BME students' experiences with career exploration. Furthermore, the work to explore what careers were possible was also limited due to the way the data were collected and analyzed. This study focused on identifying as many careers as possible, rather than exploring to what extent participants felt the careers were realistic or interesting for them personally. Though some information about this topic was able to be drawn from the data, future work in this area

could use the career codes identified in this study to develop a survey that examines students' perceptions (as realistic or interesting) on possible BME careers.

Conclusions

This study provides value to the field of BME education research by using the results of a qualitative, exploratory study on the career perceptions of a cohort of third-year BME students to inform future work. The results provide recommendations for future research that explores where students envision themselves going in a career and how educators and administrators can support students in career exploration.

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Appendix

Appendix A. Possible Career Path Codes and Definitions

Category	Subcategory	Description

Academia Employment at an academic institution.	*Academic Advising*	Provide students with educational and professional support. This includes helping students explore their academic interests, developing plans of study, and connecting students with resources for additional information and support.
	Education	A professor or faculty member at an academic institution
	General	References to academia as a career path without specification of a subcategory
	Research	Conducts studies and experiments with the aim of developing a greater level of understanding on the subject matter
Industry Careers involving the design, manufacturing, regulation, and sale of products and services in the biomedical sector.	*Bioinformatics*	Utilizes computational research methods and software to explore biological and genetic data
	Biomaterials	Specializes in the development of synthetic materials for use in biological systems
	Design, Research & Development	Responsible for the design and iteration of new products and systems for a company. This includes need assessment, design iteration, testing prototypes, and mentions of research with the goal of designing products, etc.
	General	References to industry as a career path without specification of a subcategory
	Human Factors, IOE	Involved in the design of machines, systems, and environments to allow for safe and effective use.
	Medical Devices	Jobs pertaining to the production and sale of medical devices. This includes prosthetics and other instruments that aid medical providers in the diagnosis and treatment of disease.
	Operations	Responsible for ensuring that the operations within a company are working properly and efficiently.
	Pharmaceuticals	Involved in the production and sale of medication and pharmaceutical drugs.
	Regulatory, Quality Engineering	Responsible for inspecting equipment and product safety, developing quality standards, and implementing quality control measures.

Other	*Business*	Roles in sales, human resources, PR, finance, accounting, marketing, and more.
	Coding, Computational	Utilize technical skills to solve computing problems or develop new softwares and programs.
	Consulting	Offer advice to organizations on methods to improve their business performance.
	Dental	Provides care for patients to ensure that their teeth and mouth are healthy.
	Healthcare	Jobs involving an active role in a clinical setting. Includes references to attending medical school, nursing, clinical engineering, etc.
	Management	Responsible for the recruitment, training, and management of a team or staff. Includes project manager roles in industrial settings.
	Other Engineering	References to other disciplines of engineering or roles traditionally filled by engineers belonging to other disciplines. Includes chemical, electrical, mechanical, and data engineering as well as neuroengineering.
	Patent, Law, Politics	Employment at a governmental institution or careers in public policy, legal and governmental affairs, or politics.
	Public Health	Careers that aim to improve the health of the community as a whole. Includes epidemiology, global health, biostatistics, etc.
	Social Work	Assist clients with everyday life problems and may also diagnose and treat patients with mental, behavioral, and emotional issues.
	Veterinarian	Diagnose, provide treatment for, and conduct research on illnesses and injuries of animals.

Appendix B. Possible Career Path Codes Raw Counts (Note: <u>underlined</u> = totals)

	Interview 1 (n=14)	***Interview 2 (n=14)***	***Interview 3 (n=13)***
<u>Academia</u>	**<u>11</u>**	**<u>11</u>**	**<u>10</u>**
Academic Advising	0	1	0
Education	2	4	3

General	1	2	2
Research	8	4	5
Industry	**28**	**43**	**38**
Bioinformatics	1	1	1
Biomaterials	1	2	0
Design, Research & Development	10	10	8
General	3	7	6
Human Factors, IOE	0	1	1
Medical Devices	7	10	11
Operations	0	1	1
Pharmaceuticals	5	6	5
Regulatory, Quality Engineering	1	5	5
Other	**30**	**58**	**37**
Business	1	3	5
Coding, Computational	1	3	1
Consulting	4	6	2
Dental	0	3	0
Healthcare	7	12	8
Management	1	3	4
Other Engineering	*14*	*19*	*8*
Chemical	2	5	1
Data Engineering	0	1	1
Electrical	4	3	3
General	0	3	0
Mechanical	8	6	3
Neuroengineering	0	1	0

Patent, Law, Politics	0	4	4
Public Health	1	3	3
Social Work	1	1	2
Veterinarian	0	1	0
Total Number of Codes	**69**	**112**	**85**

Appendix C. Semi-Structured Interview Example Questions Where Participants Discussed Possible Careers

1. Based on your educational experiences so far, what do you think biomedical engineers can do professionally?
2. How would you describe the value of your degree for entering the workforce?
3. What kinds of areas do you think biomedical engineers can enter professionally?
4. Based on your experience so far at [X] University, what are your professional aspirations short term? And long term?
5. What is the range of careers you think biomedical engineers can have?