Longitudinal Analysis of Strategies for Improving Biomedical Engineering Student Knowledge of Career Paths and Desired Skillsets

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Introduction

Across the United States, biomedical engineering (BME) undergraduate programs have deliberately designed curricula with a broad and diverse scope [1], [2]. This intentional approach affords students the ability to pursue a wide array of career paths upon completing their education; however, programs have faced criticism for their efficacy in adequately preparing students for careers in the field of biomedical engineering (BME) [3], [4]. Stakeholders (i.e., employers) in the biomedical field have reported BME graduates' expertise and technical skills to be limited, compared to other engineering majors. Importantly, recent efforts have been made to determine the professional and technical skills that stakeholders in the biomedical field deem required or expected of engineers in their workplace [5]; however, it is unclear if BME students are aware of the full spectrum of desired or required skillsets.

Similarly, BME students appear to have a limited perception of possible careers that BME graduates can pursue and hold post-graduation [6], [7]. For example, previous reports indicate that BME students tend to overly emphasize research and design positions within industry [6]. Importantly, BME career perceptions and skills development may naturally broaden over a student's course of study from in-class or co-curricular activities [7], [8]; however, most students do not know where gaps in their knowledge exist, and it remains unclear when expansion of career paths knowledge occurs during student progression toward graduation.

To remedy student challenges associated with career paths perceptions, several programs have devised interventions using extensive classroom discussions or seminar courses [6], [7]. However, similar efforts may not be reproducible for many programs, where alterations to degree credit hours or substantial deviations from core course content are unrealistic. Previous work has demonstrated that the use of specific, targeted lectures to deliberately train students in skillsets, such as teamwork, can prove effective [9]. Using a similar approach, this study investigated whether a short takeover lecture series focused on BME career paths and skillsets could increase knowledge of BME careers and desired skills across undergraduate students. The career paths takeover lecture series was implemented within an established BME sophomore-level course.

In this study, student understanding of potential career paths, industry job titles and roles, and desired skillsets (i) during degree progression and (ii) in response to deliberate instruction were analyzed. This study was specifically guided by the following educational research questions:

1. How does undergraduate understanding of career paths, industry job titles and roles, and desired skillsets and experiences change throughout major progression?
2. Can undergraduate understanding of career paths, industry job titles and roles, and desired skillsets and experiences be augmented following direct instruction on career and skillsets topics?
3. Is undergraduate understanding of career paths, industry job titles and roles, and desired skillsets and experiences retained over time?

Cohorts

This study was performed within a biomedical engineering (BME) undergraduate program at a R1 university in the southern United States. Historically, the biomedical engineering undergraduate cohort size has been ~50 students. The undergraduate program is ABET accredited. In academic year 2022-2023, 18 freshmen, 37 sophomores, 42 juniors, and 43 seniors, all of whom were BME majors, completed consent forms to be part of our IRB-approved study **(**IRB # 14861; **Table 1**).

Table 1. Cohorts included in the research study. x- students completed one survey in that course. y- students completed two surveys in that course.

	Graduation Date (Expected)	**Survey(s) administered as**			
		Freshmen (BME 1421)	**Sophomores (BME 2333)**	**Juniors (BME 3143)**	**Seniors (BME 4713)**
Cohort 1	(2026)	x			
Cohort 2	(2025)		y	x	
Cohort 3	(2024)			x	
Cohort 4	2023				x

Online Surveys

Four cohorts of biomedical engineering students, who had progressed through the major at varying degrees, completed surveys as part of homework assignments for specific courses within the biomedical engineering major (**Table 1**). Specifically, surveys were implemented in four courses: BME 1421 (optional course, freshman year), BME 2333 (required course, sophomore year), BME 3143 (required course, junior year), and BME 4713 (required course, senior year). Surveys for cohorts 1, 3, & 4 were administered online via the Qualtrics platform as part of a homework assignment during the first week of classes in Fall 2022 (cohorts 3-4) or Spring 2023 (cohort 1). Surveys for cohort 2 were administered via Qualtrics as part of a homework assignment during the first and fourteenth week of classes in Fall 2022, as well as the first week of classes in Fall 2023. While all students enrolled in the aforementioned courses completed surveys, data were analyzed only for those students who consented to participate in this IRB-approved research study.

Survey questions (**Appendix A**) focused on two major aspects: (i) student understanding of the career options available for biomedical engineering graduates and (ii) their understanding of the skillsets and experiences needed for career options. The surveys used were the same for all students and across courses. One survey question was adapted from previously published surveys [6], while two others were original. In this study, student responses to three open-ended questions were analyzed. Written responses to open-ended questions were blinded and analyzed manually to identify frequently mentioned keywords and themes, as well as unique responses across the student cohorts.

BME 2333

BME 2333 is a one-semester course specifically for biomedical engineering students. The lecture-based course focuses on applying mathematical principles to material, energy, and charge balances within biological systems. Enrolled students complete weekly in-class quizzes and homework

assignments, as well as take two midterm exams and one final exam. Surveys for this research study were assigned as portions of select homework assignments during first and fourteenth week of the course. In addition to completing surveys, students in cohort 2 participated in a four-part career paths takeover lecture series in BME 2333 in Fall 2022. The career paths takeover lecture series was offered by a BME professor who was not affiliated with (i.e., not the instructor for) the course. BME 2333 content was streamlined to make room for the career paths takeover lecture series; however, no major course topics were removed.

Career Paths Takeover Lecture Series

The career paths takeover series was implemented over four lecture periods (75 minutes each), and the lectures were spread out across the semester. The takeover series included four lectures (one per class period) that focused on: (1) the breadth of the BME field, (2) common BME career paths and industry job titles and roles, (3) skillsets & experiences desired by BME career sectors, and (4) an alumni panel (**Table 2**). The first three lectures of the career paths takeover series lectures were developed using available resources [5], [10], [11], [12], [13]. Lectures can be downloaded via the corresponding Figshare link: 10.6084/m9.figshare.25733268. The final lecture of the career paths takeover lecture series was an alumni panel that took place virtually over Zoom. Seven alumni, all of whom had graduated with their B.S. in biomedical engineering between 2019-2021, participated in the panel and had jobs in industry (3 alumni), were currently in graduate school (1 alumnus) or medical school (2 alumni), or working in the government sector (1 alumnus). The list of questions asked to panelists was created by the instructor following input from students enrolled in the course (**Appendix B)**. As mentioned above, surveys for cohort 2 were administered online via the Qualtrics platform as part of homework assignments in BME 2333 during the first and fourteenth week of classes in Fall 2022, as well as the first week of classes in Fall 2023.

Table 2. Career paths takeover lecture series information.

Lecture	Week #	Focus	Description	Resources
1	4	BME Overview	BME innovation milestones, current challenges in BME, areas of specialization	[10], [11]
2	8	Career Paths	BME workforce statistics, common career pathways, job titles & roles	[11], [12]
3	12	Skillsets & Experiences	Skillsets desired by future employers, experiences to help gain skillsets	[5], [13]
4	14	Alumni Panel	Panel featuring alumni from industry (3), academia (1), healthcare (2), and government (1)	---

Data Analysis

Data were deidentified (i.e., personal identifiers were removed so that a link between an individual and their data would be difficult to reestablish) prior to analysis to effectively blind coders during data analysis. Data analysis comprised two stages: open coding and code categorization to identify trends. Open coding was used initially to complete systematic review of survey responses. Codes (i.e., words and/or short phrases) were created, based on input from multiple researchers to

concisely represent and/or summarize the meaning of survey responses. Similar codes were then categorized into themes following coding of survey responses. A code was counted if it appeared at least once within the participant's response and any given code was applied only once per survey question per participant within a single survey. If the participant mentioned the same code across multiple surveys (i.e., a mention of the same code in the Fall 2022 survey and again in the Fall 2023 survey), then the code was applied once to each survey question per participant across the surveys in which the code appeared.

Statistical Analysis

Data are expressed as the mean ± standard error of the mean, unless otherwise noted. All statistical analyses were performed using non-parametric tests. A Kruskal-Wallis test was used to compare data obtained from cohorts 1, 2, 3, and 4 on week 1 of the Fall 2022 semester. A paired Wilcoxon test was used to compare data obtained from cohort 2 on week 1 and week 14 of the Fall 2023 semester. A paired Wilcoxon test was used to compare data obtained from cohort 2 on week 14 in the Fall 2022 semester and on week 1 in the Fall 2023 semester. A significance of $p < 0.05$ was assigned for all tests. Statistical interpretations and graphs were made using Prism 10.1.2 (GraphPad). Data are presented as box-and-whisker plots with mean (+), median, 25% and 75% percentiles (box boundaries), and range (whiskers extending to most extreme data points not considered outliers) depicted. Outliers (defined as 1.5 times the interquartile range) are indicated by ● and were not removed to keep the analysis conservative.

Results

Research Question 1: "How does undergraduate understanding of career paths, industry job titles and roles, and desired skillsets and experiences change throughout major progression?"

To generally understand the types of jobs and careers that undergraduates think a graduate with a B.S. in BME can pursue, students in cohorts 1-4 were surveyed. Written responses for unique jobs were analyzed and coded (**Appendix C**). Codes were first categorized into four common career path themes: industry, academia, healthcare, and government. The percentage of students who could identify at least one job within one of the four career path themes was analyzed (**Table 3**). Approximately 22%-39% of students in cohort 1 articulated that BME graduates can hold jobs in industry, academia, and healthcare. An increased percentage (71%-81%) of students in cohorts 2, 3, and 4 indicated that BME graduates can pursue careers in industry, while an increased percentage of students in cohorts 3 and 4 indicated that BME graduates can pursue careers in academia. Interestingly, a decrease in the percentage (3%-12%) of students in cohorts 2, 3, and 4 identify that BME graduates can pursue careers in healthcare was observed, compared to cohort 1. Importantly, all cohorts faced challenges with identifying that BME graduates could pursue careers in government.

Student perceptions of jobs that can be held by BME graduates were further assessed by examining written responses for unique job codes. In general, the number of unique job codes identified by each student increased from cohorts 1 to 4, where students in cohorts 1, 2, 3, and 4 named, on average, 1.17 ± 0.19, 1.59 ± 0.20, 1.74 ± 0.20, and 2.33 ± 0.23 codes per student, respectively (**Figure 1A**). In particular, the number of academic and industry codes were observed to increase

from cohorts 1 to 4, while no marked changes in the healthcare and government were observed (**Appendix C, Table 4**). Importantly, the percentage of students who were able to communicate that BME graduates can hold jobs in two or more career pathways following the career paths takeover lecture series increased across cohorts, where 33% of students in cohort 1 and 49% of students in cohort 4 communicated multiple career path opportunities.

Table 3. Percentage of students identifying at least one code in career path themes.

	Industry	**Academia**	**Healthcare**	**Government**
Cohort 1	55%	22%	33%	0%
Cohort 2	78%	11%	3%	0%
Cohort 3	71%	38%	7%	0%
Cohort 4	81%	49%	12%	5%

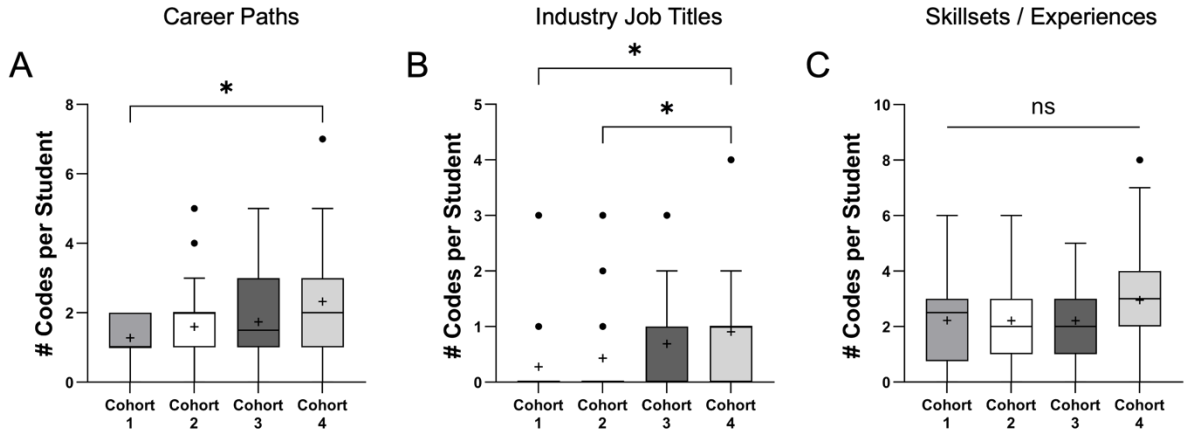

Figure 1. (A) Cohort 4, which had progressed the furthest through the degree program, could better articulate unique jobs for BMEs, compared to Cohorts 1, 2, and 3. (B) Cohort 4 could better articulate specific industry job titles and roles, compared to Cohorts 1 and 2. (C) Cohorts 1, 2, 3, and 4 demonstrated similar abilities toward identifying relevant skillsets and experiences that undergraduate students should obtain or pursue during their undergraduate tenure. * = $p < 0.05$; ns = no significance.

To assess student knowledge of specific industry job titles and roles, students were asked to describe the job titles and roles for biomedical engineers working to develop a new medical device. The average number of codes, each representing a unique job title or role in industry, generally increased from cohorts 1 to 4, where students in cohorts 1, 2, 3, and 4 named on average 0.28 $\pm$ 0.18, 0.43 $\pm$ 0.15, 0.69 $\pm$ 0.14, and 0.91 $\pm$ 0.02 codes, respectively (**Figure 1B**). Research and design engineer was the most named job title/role by students across cohorts; however, project/program manager, manufacturing engineer, design quality engineer, and clinical field specialist were also named, albeit at a lower frequency (**Appendix D, Table 7**). Importantly, many students in cohort 1 (82%) and cohort 2 (83%) specifically reported in their survey responses they "don't know" of any industry job titles or roles. A decrease in the percentage of students indicating that they "don't know" of any industry job titles or roles was observed as students progressed

through the program, where only 43% of students in cohort 3 and 42% of students in cohort 4 indicated they "don't know" of any industry job titles or roles in their survey responses.

Student knowledge of the skillsets and experiences that undergraduate students should obtain or pursue prior to graduation was further assessed. Skillsets and experiences were coded and focused on technical skills, professional skills, knowledge, and experiences. The average number of codes, each representing a unique skillset or experience, was similar for cohorts 1 to 3, where students in cohorts 1, 2, and 3 named 2.22 $\pm$ 0.39, 2.41 $\pm$ 0.26, and 2.21 $\pm$ 0.62 skillsets and experiences on average respectively (**Figure 1C**). The number of skillsets and experiences identified by students in cohort 4 was increased, albeit not significantly, to 2.95 $\pm$ 0.31 skillsets and experiences per student. Importantly, technical skills, professional skills, knowledge, and experiences were identified across all cohorts (**Appendix E, Table 10**). The number of technical and professional skills codes named per student was observed to generally increased from cohort 1 to cohort 4 (i.e., as students progressed through the degree program). The number of knowledge codes named per student remained similar across the four cohorts. Interestingly, the number of experience codes named per student decreased from cohort 1 to cohort 4 (i.e., as students progressed through the degree program).

Research Question 2: "Can undergraduate understanding of career paths, industry job titles and roles, and desired skillsets and experiences be augmented following direct instruction?"

To assess the impact of the career paths takeover lecture series on student understanding of the career paths in which BMEs can hold jobs, students in cohort 2 were surveyed during the first and fourteenth week of classes (i.e., prior to and following the conclusion of the career paths takeover lecture series) in Fall 2022. Prior to the career paths takeover lecture series, 0%, 3%, 11%, and 78% of students in cohort 2 identified that BME graduates can pursue jobs in government, academia, healthcare, and industry, respectively. Importantly, the percentage of students in cohort 2 that identified that BME graduates can obtain jobs in government, academia, healthcare, and industry increased to 11%, 27%, 22%, and 95%, respectively, after completion of the career paths takeover lecture series.

Student perceptions of careers that BME graduates can pursue were further assessed by examining written responses for unique job codes. Prior to the career paths takeover lecture series, the average number of unique careers that students in cohort 2 were able to name is 1.59 $\pm$ 0.20. The number of unique careers that students in cohort 2 were able to identify significantly increased to 3.03 $\pm$ 0.22 following the takeover series (**Figure 2A**). In particular, the number of academic, industry, healthcare, and government codes were observed to increase following the takeover series (**Appendix C, Table 5**). Moreover, 51% of students were able to communicate that BME graduates can hold jobs in two or more career pathways following the career paths takeover lecture series, compared to only 32% of students prior to the takeover lecture series.

Figure 2. (A) Cohort 2 could better articulate unique jobs for BMEs following the career paths takeover lecture series (Week 14) compared to before (Week 1). (B) Cohort 2 could better communicate specific industry job titles and roles following the career paths takeover lecture series (Week 14) compared to before (Week 1). (C) Cohort 2 could better identify relevant skillsets and experiences that undergraduate students should obtain or pursue during their undergraduate tenure BMEs following the career paths takeover lecture series (Week 14) compared to before (Week 1). *** = $p < 0.001$; **** = $p < 0.0001$.

Industry jobs titles and roles were specifically discussed in lecture 2 of the career paths takeover lecture series. To assess the knowledge of specific job titles and roles, students were asked to describe the job titles and roles for biomedical engineers working to develop a new medical device in the survey. Prior to the career paths takeover lecture series, the average number of unique job titles or roles that students in cohort 2 were able to name is 0.43 ± 0.15. The number of unique job titles or roles that students in cohort 2 were able to identify significantly increased to 2.45 ± 0.24 following the takeover series (**Figure 2B**). Research and design engineer was the most named job title/role by students both prior to and following the career paths takeover lecture series; however, substantial increases in the number of students who identified project/program manager, manufacturing engineer, design quality engineer, and clinical field specialist as possible codes were observed (**Appendix D, Table 8**). Importantly, the number of students in cohort 2 indicating that they "don't know" any job titles or roles decreased from 82% to 11% following the takeover series.

Skillset and experiences were specifically discussed in lecture 3 of the career paths takeover lecture series. Skillsets and experiences were coded and focused on technical skills, professional skills, knowledge, and experiences. Prior to the career paths takeover lecture series, the average number of career relevant-skillsets or experiences that students in cohort 2 were able to name was 2.41 ± 0.26 (**Figure 2C**). The average number of career relevant-skillsets or experiences that students in cohort 2 could name increased to 3.57 ± 0.36 after the takeover series. Importantly, increases in codes for technical skills, professional skills, knowledge, and experiences were observed (**Appendix E, Table 11)**.

Research Question 3: "Is undergraduate understanding of career paths, industry job titles and roles, and desired skillsets and experiences retained over time?"

To assess the retention of career paths knowledge, students in cohort 2 were again surveyed in the first week of the Fall 2023 semester (i.e., one year after the career paths takeover lecture series). Twenty-two students in cohort 2 completed the survey in week 1 of Fall 2023. The survey responses of the 22 students obtained in Fall 2023 were then compared to those obtained at the end of the takeover lecture series in Fall 2022 (i.e., week 14) for the same 22 students to assess retention of knowledge. Analysis of survey responses from Fall 2022 revealed that 3%, 14%, 19%, and 100% of students in cohort 2 identified that BME graduates can pursue jobs in government, academia, healthcare, and industry, respectively. In Fall 2023, 0%, 9%, 50%, and 73% of students in cohort 2 identified that BME graduates can pursue jobs in government, academia, healthcare, and industry, respectively.

Immediately following the career paths takeover lecture series in Fall 2022, students in cohort 2 were able to identify 3.27 ± 0.22 unique career codes, on average (**Figure 3A**). The average number of unique career codes that students in cohort 2 were able to identify remained similar one year after the end of the career paths takeover lecture series, where, on average, students identified 2.36 ± 0.30 unique career codes. In particular, the number of academic and healthcare codes were observed to decrease over time, while no marked changes in the industry and government codes were observed (**Appendix C, Table 6**). In addition, 50% of the 22 students were able to communicate that BME graduates can hold jobs in two or more career pathways both immediately following the completion of the career paths takeover lecture series and again one year later.

To assess retention of knowledge of specific job titles and roles, students were asked to describe the job titles and roles for biomedical engineers working to develop a new medical device in the survey. Immediately following the end of the career paths takeover lecture series, the number of unique job titles or roles that students in cohort 2 were able to identify was 2.53 ± 0.24 per student (**Figure 3B**). One year after the career paths takeover lecture series, students in cohort 2 were still able to name 1.94 ± 0.30 titles/roles per student. Research and design engineer was the most named job title/role by students both prior to and following the career paths takeover lecture series; however, substantial increases in the number of students who identified project/program manager, manufacturing engineer, design quality engineer, and clinical field specialist as possible codes were observed (**Appendix D, Table 9**). Importantly, 18% of students in cohort 2 indicated they did not know of any industry job titles or roles one-year post-takeover series, compared to 9% of students who indicated a lack of industry job titles or roles knowledge immediately following the career paths takeover series.

Retention of knowledge of desired skillsets and experiences was analyzed. Immediately following the end of the career paths takeover lecture series, the number of career relevant-skillsets or experiences that students in cohort 2 were able to identify was 3.55 ± 0.42 codes per student (**Figure 3C**). One-year post-takeover, the average number of career relevant-skillsets or experiences that students in cohort 2 could name was 3.09 ± 0.27 codes per student. Importantly, increases in codes for technical skills, professional skills, knowledge, and experiences were observed (**Appendix E, Table 12)**. Importantly, the distribution of codes across areas remained similar to that of before the takeover series.

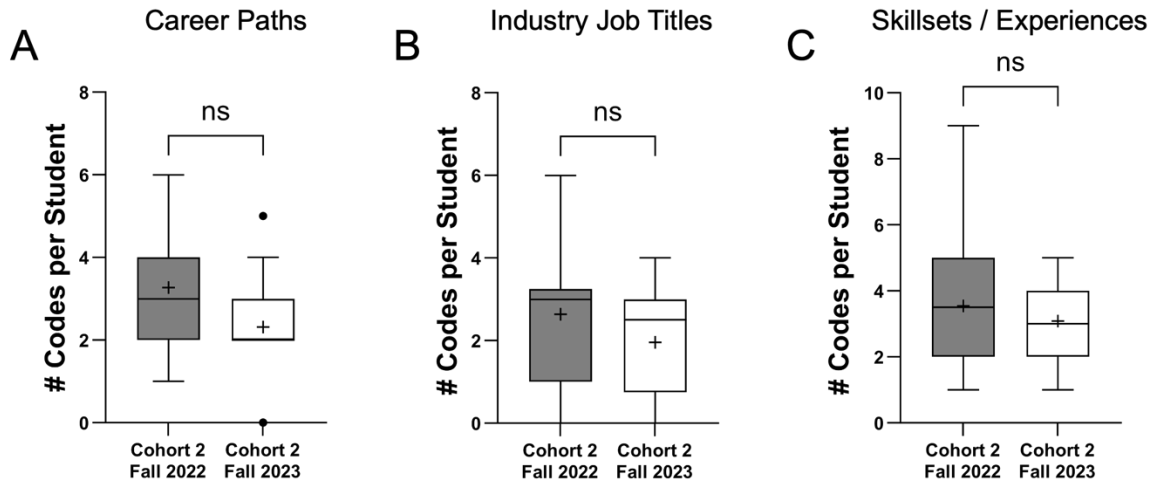

Figure 3. (A) Cohort 2 could articulate a similar number of unique jobs for BMEs immediately following the career paths takeover lecture series (Fall 2022) compared to one year later (Fall 2023). (B) Cohort 2 could communicate a similar number of specific industry job titles and roles immediately following the career paths takeover lecture series (Fall 2022) compared to one year later (Fall 2023). (C) Cohort 2 could identify a similar number of relevant skillsets and experiences that undergraduate students should obtain or pursue during their undergraduate tenure BMEs immediately following the career paths takeover lecture series (Fall 2022) compared to one year later (Fall 2023). ns = no significance.

Discussion

BME graduates pursue a variety of career paths, including those in industry, academia, healthcare, and government, among others. Unfortunately, student perception of BME career paths, and knowledge of the skillsets and experiences desired by future employers, is often reported as narrow; however, exploration of how BME student perceive career paths and desired skillsets across education levels and in response to target interventions is limited. As such, the perceptions of career paths, job titles and roles, and needed skillsets and experiences by students progressing through the BME major, as well as following intervention from a career paths takeover lecture series, were analyzed in this study.

Student perceptions of career possibilities were initially limited early in their undergraduate education. These findings are consistent with a previous report which demonstrated that student views at the start of their undergraduate education are narrow [6]. Importantly, student views on career options increased as students progressed through the BME major, both in terms of the number of career paths that students could name and the percentage of students who were able to communicate that BME graduates can hold jobs in more than one career pathway. Similarly, previous work has demonstrated that BME students do expand their knowledge base of possible careers throughout their undergraduate tenure [7]. These results are not surprising as the broadening of BME student perceptions across varying education levels has been reported before, with students of different education levels viewing the field of BME with subtle distinction [14].

In addition to general perceptions of career paths, student knowledge of specific industry job titles and roles was limited early in their undergraduate education but increased as students progressed within the major. However, even students in their last year of undergraduate (cohort 4) could, on average, name one industry job title or role. This result may speak to the larger disconnect that exists between academia, where BME students are trained, and industry, where many BME students are employed post-graduation. Many BME graduates have reported challenges with finding industry jobs, which has been hypothesized to result from the lack of knowledge of what biomedical engineering is by industry and the broad training of biomedical engineering students [1]. The results of the current study also suggest that a lack of awareness of the specific job opportunities and roles that BME graduates can pursue within industry may also contribute to awareness of employment opportunities.

Students across cohorts were able to articulate a variety of professional and technical skillsets, as well as experiences necessary to obtain said skillsets, in their survey responses. However, the number of skillsets and experiences identified by students as important to pursue during their undergraduate tenure was low and did not substantially increase with increased education level. These results suggest that students are generally unaware of what skillsets they should be pursuing and, perhaps more importantly, what skillsets are valued by stakeholders. Previous research documented the professional and technical skills required or expected of engineering from a variety of stakeholders across academia, industry, healthcare, and law [5]. While the current study examined student cohorts at a single university, direct and uniform translation of the professional and technical skills valued by stakeholders within academic programs would be of significant value to BME students.

As student perceptions of career possibilities and desired skillsets were indeed limited, particularly early in undergraduate student education, we hypothesized that a short series of targeted lectures could increase student understanding. As such, the career paths takeover lecture series was strategically implemented in BME 2333, a core sophomore-level BME course. The career paths takeover lecture series included four lectures exploring (i) the breadth of the BME field, (ii) common BME career paths and job titles/ roles, (iii) skillsets & experiences desired by BME career sectors, and (iv) an alumni panel. Importantly, the inclusion of the takeover series into BME 2333 in Fall 2022 did not detract from student success in course content, as the attainment of course outcomes by students in Fall 2022 was similar to that of Fall 2021 when no takeover series was offered.

Following the takeover series, knowledge of BME career possibilities, industry job roles and titles, and desired skillsets and experiences by students in cohort 2 increased significantly compared to their knowledge at the beginning of Fall 2022 (i.e., prior to participating in the takeover series). Further, the percentage of students unable to communicate career possibilities, industry job roles and titles, and desired skills substantially decreased. These results are perhaps expected as similar strategies have been previously used to successfully train students in skills such as teamwork [9] or to increase student abilities to use and apply tools, such as engineering standards [15]. Surprisingly, the knowledge of BME career possibilities, industry roles and titles, and desired skillsets and experiences noted by students in cohort 2 following the conclusion of the takeover series surpassed the knowledge exhibited by students in cohorts 3 and 4 (i.e., students who had

progressed further within the major). Further, knowledge of BME career possibilities, industry roles and titles, and desired skillsets and experiences by students in cohort 2 was retained one year after the culmination of the career paths takeover lecture series. Our findings align with previous research demonstrating that student perceptions of careers can be strongly influenced by a single experience [16].

Some limitations of this study include that the data were collected as part of a larger study and collected from students at a single institution. Further, this study focused on generating as many career paths, job titles or roles, and desired skillsets as possible and did not assess the specific careers that a specific student might be interested in pursuing or their knowledge of skills relevant to their chosen career. Future work on how knowledge of career paths and desired skills translates into the pursuit of career preparation endeavors and student career path choice is of interest to the broader BME community.

Conclusions

This study demonstrates that undergraduate understanding of biomedical engineering career paths and industry job titles and roles increases naturally during major progression; however, knowledge of skillsets and experiences desired by future employers appeared similar across education levels. Further, implementation of a short career paths takeover lecture series early in the curriculum can substantially increase knowledge of career paths, industry job titles and roles, and desired skillsets/experiences by BME underclassmen to a level that exceeds that of BME upperclassmen. Importantly, knowledge was observed to be obtained one year after the conclusion of the career paths lecture series.

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Appendix A: Survey Questions

1. What kinds of jobs do you think a graduate with a B.S. in Biomedical Engineering could hold after graduating? If you don't know of any, please type "don't know".

2. Scenario: You recently graduated from the University of XXX with your B.S. in biomedical engineering and have begun to work at Company A. Company A is seeking to develop a medical device that designed to detect the electrical signals of a life-threatening condition within the brain and treat the condition. Company A employs a variety of biomedical engineers, each with specific job titles and roles, that will work on this endeavor.

   Describe the job titles and roles for the various biomedical engineers who would aid in the development and translation of this proposed medical device. If you do not know of any, please type "don't know".

3. What experiences and/or skills do you think you (i.e., an undergraduate) should plan to pursue/obtain during your undergraduate tenure to prepare for a career? If you don't know of any, please type "don't know".

Appendix B: Alumni Panel Questions

1. How/why did you choose the post-graduation route that you did?

2. For those who went into industry, why did you choose to go into industry directly with a B.S. or after obtaining your M.S.? How difficult was it to find a job?

3. What kinds of extracurriculars (clubs, research, volunteering, etc.) were you involved in during the school year, and do you have any advice for balancing extracurriculars with schoolwork?

4. What did you do during your summers? How did you find/pursue these summer opportunities?

5. For those who participated in research or design projects, how did it benefit and/or influence your career path?

6. How can I leverage my BME degree to help me stand out when applying for health professional programs, jobs, graduate school, law school, etc.

7. How did you determine what area of BME you were most interested in and do you have any recommendations for how to tease out interests in specific topics/fields?

8. Are there opportunities to continue building my engineering knowledge, skills, opportunities, etc. in my career? Or how do you translate your engineering skillsets into your career outside of engineering?

9. What are some crucial skills you have discovered that you need in your current career path? Do you have any advice for how/where current students can acquire these skills?

10. Where do you see yourself in 5-10 years?

11. What is one piece of advice that you wish you had before you graduated?

Appendix C. Possible Career Path Codes Raw Counts.

Table 4. Possible Career Path Codes Raw Counts for Cohorts 1, 2, 3, and 4 from Week 1 in Fall 2022 or Spring 2023.

Codes		**Cohort 1** (N=18)	**Cohort 2** (N=37)	**Cohort 3** (N=42)	**Cohort 4** (N=43)
Academia	Education	0	1	2	5
	General	0	0	0	0
	Research	4	9	15	24
	Total	**4**	**10**	**17**	**29**
Industry	Bioinformatics	0	0	1	0
	Biomaterials	1	2	2	1
	Biomechanics	0	0	0	0
	Biotechnology	0	0	1	0
	Clinical Specialist	0	5	4	7
	Consulting	0	1	1	1
	General	1	3	5	6
	Human Factors	0	0	6	0
	Manufacturing	1	1	3	1
	Medical Devices	3	11	17	22
	Operations	0	1	1	0
	Pharmaceuticals	0	1	1	2
	Project Management	1	1	1	4
	Quality	0	4	1	2
	Regulatory	0	0	0	3
	Research & Design	4	12	5	13
	Technical Sales	0	0	0	1
	Technical Support	0	2	0	2
	Total	**11**	**44**	**49**	**65**
Government	General	0	0	0	0
	Law	0	0	0	2
	Total	**0**	**0**	**0**	**2**
Healthcare	General	3	3	2	2
	Medicine	1	1	0	3
	Physician Assistant	0	0	0	0
	Prosthetist	2	0	1	0
	Total	**6**	**4**	**3**	**5**
Grand Total		**21**	**58**	**69**	**99**

Table 5. Possible Career Path Codes Raw Counts for Cohort 2 from Week 1 and Week 14 in Fall 2022.

Codes		**Cohort 2 Week 1** (N=37)	**Cohort 2 Week 14** (N=37)
Academia	Education	1	3
	General	0	2
	Research	9	12
	Total	**10**	**17**
Industry	Bioinformatics	0	1
	Biomaterials	2	2
	Biomechanics	0	1
	Biotechnology	0	1
	Clinical Specialist	5	3
	Consulting	1	0
	General	3	10
	Human Factors	0	1
	Manufacturing	1	6
	Medical Devices	11	6
	Operations	1	1
	Pharmaceuticals	1	1
	Project Management	1	5
	Quality	4	7
	Regulatory	0	1
	Research & Design	12	22
	Technical Sales	0	4
	Technical Support	2	3
	Total	**44**	**75**
Government	General	0	4
	Law	0	0
	Total	**0**	**4**
Healthcare	General	3	5
	Medicine	1	2
	Physician Assistant	0	1
	Prosthetist	0	0
	Total	**4**	**8**
Grant Total		**58**	**104**

Table 6. Possible Career Path Codes Raw Counts for Cohort 2 from Week 14 in Fall 2022 and from Week 1 in Fall 2023.

Codes		**Cohort 2 Week 14 Fall 2022** (N=22)	**Cohort 2 Week 1 Fall 2023** (N=22)
Academia	Education	2	2
	General	2	0
	Research	7	10
	Total	**11**	**12**
Industry	Bioinformatics	0	0
	Biomaterials	1	1
	Biomechanics	0	1
	Biotechnology	2	0
	Clinical Specialist	3	4
	Consulting	0	0
	General	4	4
	Human Factors	1	0
	Manufacturing	4	2
	Medical Devices	3	3
	Operations	0	0
	Pharmaceuticals	1	0
	Project Management	5	3
	Quality	3	5
	Regulatory	1	1
	Research & Design	17	9
	Technical Sales	2	5
	Technical Support	2	1
	Total	**49**	**39**
Government	General	1	0
	Law	0	0
	Total	**1**	**0**
Healthcare	General	2	0
	Medicine	2	0
	Physician Assistant	1	1
	Prosthetist	0	0
	Total	**5**	**1**
Grant Total		**66**	**52**

Appendix D. Possible Industry Job Titles and Roles Codes Raw Counts.

Table 7. Possible Industry Job Titles and Roles Codes Raw Counts for Cohorts 1, 2, 3, and 4 from Week 1 in Fall 2022 or Spring 2023.

Industry Job Titles & Roles	**Cohort 1 (N=18)**	**Cohort 2 (N=37)**	**Cohort 3 (N=42)**	**Cohort 4 (N=43)**
Project/Program Manager	1	3	6	11
R&D Engineer	2	7	14	16
Manufacturing Engineer	0	2	4	2
Design Quality Engineer	1	4	1	3
Regulatory Affairs Specialist	0	0	0	3
Clinical Field Engineer	1	1	3	3
Technical Sales Engineer	0	0	1	1
Procurement Engineer	0	1	0	0
Total	**5**	**18**	**29**	**39**

Table 8. Possible Industry Job Titles and Roles Codes Raw Counts for Cohort 2 from Week 1 and Week 14 in Fall 2022.

Industry Job Titles & Roles	**Cohort 2 Week 1** (N=37)	**Cohort 2 Week 14** (N=37)
Project/Program Manager	3	13
R&D Engineer	7	27
Manufacturing Engineer	2	13
Design Quality Engineer	4	11
Regulatory Affairs Specialist	0	10
Clinical Field Engineer	1	8
Technical Sales Engineer	0	9
Procurement Engineer	1	0
Total	**17**	**91**

Table 9. Possible Industry Job Titles and Roles Codes Raw Counts for Cohort 2 from Week 14 in Fall 2022 and from Week 1 in Fall 2023.

Industry Job Titles & Roles	**Cohort 2 Week 14 Fall 2022** (N=22)	**Cohort 2 Week 1 Fall 2023** (N=22)
Project/Program Manager	10	7
R&D Engineer	17	16
Manufacturing Engineer	7	4
Design Quality Engineer	6	8
Regulatory Affairs Specialist	6	2
Clinical Field Engineer	6	4
Technical Sales Engineer	6	3
Procurement Engineer	0	0
Total	**58**	**44**

Appendix F

Table 10. Possible Skillsets & Experiences Raw Codes Counts for Cohorts 1, 2, 3, and 4 from Week 1 in Fall 2022 or Spring 2023.

Codes		**Cohort 1** (N=18)	**Cohort 2** (N=37)	**Cohort 3** (N=42)	**Cohort 4** (N=43)
Technical Skills	Design Skills	1	2	2	5
	3D Printing	0	2	0	5
	Computational Modeling	0	1	0	0
	Laboratory Skills	2	2	6	4
	Research Skills	1	5	5	5
	General	0	1	7	8
	Programming	0	2	6	7
	Circuits	0	1	1	7
	CAD	0	1	1	9
	Total	**4**	**17**	**28**	**50**
Professional Skills	Leadership	1	2	1	5
	Communication	1	4	6	10
	Time Management	0	2	2	1
	Organization	0	1	0	0
	Creativity	1	2	0	0
	Critical Thinking	1	2	2	4
	Problem Solving	3	4	1	8
	Teamwork	2	6	2	14
	Responsibility	3	0	0	2
	Project Management	0	1	1	0
	Flexibility	0	0	0	1
	Motivation	0	0	1	1
	People Skills	1	1	0	0
	Total	**10**	**25**	**17**	**46**
Knowledge	Medical Field	0	1	2	1
	General BME	2	3	6	4
	Basic Math & Science	0	2	1	4
	Biomechanics	0	2	0	1
	Electrical Principles	0	2	1	0
	Advanced Chemistry	0	1	0	0
	Tissue Engineering	0	1	2	0
	Statistics	0	1	0	1
	Biomaterials	0	1	0	0
	Bioinstrumentation	0	0	4	1
	Anatomy	0	0	3	1
	Neuroengineering	1	0	0	0
	Immunoengineering	1	0	0	0
	Genetic Engineering	1	0	0	0
	Pharmaceutics	1	0	0	0

	Bioimaging	0	0	0	1
	Nanomedicine	0	0	1	
	Bioinformatics	1	0	0	0
	Total	**8**	**15**	**20**	**16**
Experiences	Minor	0	0	0	0
	Clinical	5	6	4	1
	Internship	3	6	8	2
	Research	9	10	16	11
	Student Organizations	1	3	0	1
	Total	**18**	**25**	**28**	**15**
Total		**40**	**82**	**93**	**127**

Table 11. Possible Skillsets & Experiences Codes Raw Counts for Cohort 2 from Week 1 and Week 14 in Fall 2022.

Codes		**Cohort 2 Week 1 Survey** (N=37)	**Cohort 2 Week 14 Survey** (N=37)
Technical Skills	Design Skills	2	4
	3D Printing	2	2
	Computational Modeling	1	0
	Laboratory Skills	2	3
	Research Skills	5	7
	General	1	2
	Programming	2	6
	Circuits	1	2
	CAD	1	6
	Total	**17**	**32**
Professional Skills	Leadership	2	4
	Communication	4	11
	Time Management	2	1
	Organization	1	0
	Creativity	2	0
	Critical Thinking	2	2
	Problem Solving	4	8
	Teamwork	6	7
	Responsibility	0	2
	Project Management	1	2
	Flexibility	0	1
	Motivation	0	1
	People Skills	1	1
	Total	**25**	**41**
Knowledge	Medical Field	1	2
	General BME	3	2
	Basic Math & Science	2	3
	Biomechanics	2	2
	Electrical Principles	2	1
	Advanced Chemistry	1	1
	Tissue Engineering	1	1
	Statistics	1	1
	Biomaterials	1	1
	Bioinstrumentation	0	2
	Anatomy	0	1
	Neuroengineering	0	0
	Immunoengineering	0	0
	Genetic Engineering	0	0
	Pharmaceutics	0	0
	Bioinformatics	0	0

	Total	**15**	**17**
Experiences	Minor	0	1
	Clinical	6	4
	Internship	6	16
	Research	10	19
	Student Organizations	3	2
	Total	**25**	**42**
	Grand Total	**82**	**132**

Table 12. Possible Skillsets & Experiences Raw Counts for Cohort 2 from Week 14 in Fall 2022 and from Week 1 in Fall 2023.

Codes		**Cohort 2 Week 14 Fall 2022** (N=22)	**Cohort 2 Week 1 Fall 2023** (N=37)
Technical Skills	Design Skills	2	2
	3D Printing	1	2
	Computational Modeling	0	1
	Laboratory Skills	1	1
	Research Skills	5	3
	General	0	2
	Programming	3	2
	Circuits	1	3
	CAD	4	1
	Total	**17**	**17**
Professional Skills	Leadership	2	2
	Communication	7	3
	Time Management	1	1
	Organization	0	0
	Creativity	0	1
	Critical Thinking	0	3
	Problem Solving	4	1
	Teamwork	4	4
	Responsibility	1	0
	Project Management	0	0
	Flexibility	1	0
	Motivation	1	0
	People Skills	0	1
	Total	**21**	**16**
Knowledge	Medical Field	0	0
	General BME	2	2
	Basic Math & Science	3	5
	Biomechanics	2	1
	Electrical Principles	1	0
	Advanced Chemistry	1	0
	Tissue Engineering	1	0
	Statistics	1	0
	Biomaterials	1	0
	Bioinstrumentation	2	6
	Anatomy	0	1
	Neuroengineering	0	0
	Immunoengineering	0	0
	Genetic Engineering	0	0
	Pharmaceutics	0	0

	Bioinformatics	0	0
		14	**16**
Experiences	Minor	1	0
	Clinical	2	2
	Internship	11	4
	Research	11	13
	Student Organizations	0	0
	Total	**25**	**19**
Grand Total		**77**	**68**