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Biomedical Engineering Master's: Aligning Programs with Industry and Academic Stakeholder Needs

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Introduction

Biomedical Engineering (BME) is a broad topic that has many subfields. The breadth in BME undergraduate curricula ensures that BME graduates are well-prepared to interface with both engineering and clinical professionals. However, they often have less depth in specific engineering topics due to the constraints and variations on the BME curriculum[1]. As a result of ambiguity in their academic training, it has been reported that BME graduates can experience barriers to career attainment as compared to those majoring in other engineering disciplines[2], [3].

In light of these barriers, many students pursue a BME master's program to gain deeper knowledge into a specific sub-field of BME and learn new skills associated with this subfield[4]. This enhanced knowledge can help students attain their career goals, whether it is advancement in industry positions or pursuing advanced degrees such as the MD and PhD. However, there is a gap between the knowledge and skills BME master's graduates gain during graduate study and the expectations of potential employers in both industry and academia. Alignment of BME master's program curricula with expectations of those who hire BME master's graduates will improve student outcomes, lead to satisfied master's program stakeholders, and will better distinguish the unique skill set of biomedical engineers.

The goal of this research is twofold: (1) Identify the expectations of those that hire BME undergraduate and master's graduates and (2) Generate specific ideas master's programs can implement to align their programs with employer expectations. To identify ways to enhance BME master's programs and share these recommendations with the broader BME master's community, the research team conducted two surveys and hosted two workshops over the course of about six months. These surveys and workshops discussed the perspectives of both senior industry professionals that hire BME graduates and those of established Ph.D. faculty advisors that select students to work in their lab. The surveys and discussions highlighted important professional skills hiring managers and advisors are looking for in employees, gaps in the BME undergraduate and master's curricula regarding professional skills, and the need to provide an assessment framework for BME master's programs. Overall, we hope that BME master's programs will address skill gaps by integrating targeted professional skills into their curricula.

Current Industry Perspectives of Biomedical Engineers

There are several recent studies that have discussed industry needs compared to current BME undergraduate and master's curricula. Overall, industry has reported interest in graduates who have desired general competencies such as problem solving, communications, teamwork, design, and project management[5], [6]. Additionally, there are more specialized competencies that are requested by particular sub-fields of biomedical engineering such as mechanical design, wet-lab skills, and manufacturing.

The majority of studies discussing industry needs have asked industry representatives to complete surveys with pre-defined skills for responders to choose from. For example, Stukes et al. reported specific skills and knowledge needed for BME-related jobs from an employer's perspective by surveying alumni of 9 BME master's programs using a list of 30 skills and knowledge terms from a labor & employment database. In general, industry representatives indicated that general skills such as writing, communication and teamwork were more important than specialized technical skills such as prototyping or regulatory affairs[7].

While Stukes and similar studies focused on surveying the industry about pre-defined skills, we opted for an open-ended survey to allow more freedom in responses. The research team also recognizes that many biomedical engineering undergraduates pursue alternate career options to industry positions such as graduate school (master's or Ph.D.), medical school, and government positions. For example, a survey by a team from Ohio State University found that while 51% of graduates go to industry, the balance of 27% go to graduate school and 22% attend medical school following graduation[8]. In our analysis of gaps in the BME curriculum, we wanted to consider the perspectives of other potential employers of biomedical engineers beyond those in industry.

Current Graduate Advisor Perspectives of Biomedical Engineers

While many students, particularly those in professional master's programs, are interested in pursuing careers in industry, others view the master's degree as a way to gain additional experience and qualifications to enhance their prospects for doctoral studies. BME is an unusual field because a significant portion of our graduates pursue further education rather than directly entering into industry. There are surprisingly few studies assessing the needs of academic investigators recruiting doctoral students into their labs, with most of the published research focused on the needs of industry. Academic and industry stakeholders have some areas of distinct expectations for incoming BME students. Rivera et al. conducted a survey of both groups and discovered that academic stakeholders place a strong emphasis on motivation and communication. They observed that one major difference between academia and industry was the greater focus on the professional skills of motivation and independence by academic stakeholders. The authors also found that research skills are in the top three skills for both stakeholder groups[3].

Methods

To discuss ideas regarding aligning BME programs with the needs of industry and academia, the authors held two workshops: 1) "Discussions on the value-added proposition for BME master's programs and views from industry" held at the BME Council of Chairs Education Summit in May 2024 and 2) "BME master's programs: Aligning programs with student career goals" held at the Biomedical Engineering Society (BMES) Annual Meeting in October, 2024. Though participants in the workshops were largely BME faculty members (~120 participants total), both workshops included discussion of two IRB-approved surveys that assessed the perspectives of both senior industry professionals that hire BME graduates (both undergraduate and graduate) and established Ph.D. faculty advisors that select students to work in their lab. The cadence of when the surveys and workshops were launched can be visualized in Figure 1. These surveys

highlighted important professional skills hiring managers are looking for in employees, gaps in the BME undergraduate and/or graduate curricula regarding professional skills, and the level of understanding of the BME degree as a whole. After receiving survey results, workshop participants discussed: (1) Actions individual BME master's programs can take to better align with expectations of industry and academic stakeholders (2) Actions the BME community can take to provide a framework for aligning programs with stakeholder expectations (3) Assessment of BME Master's programs.

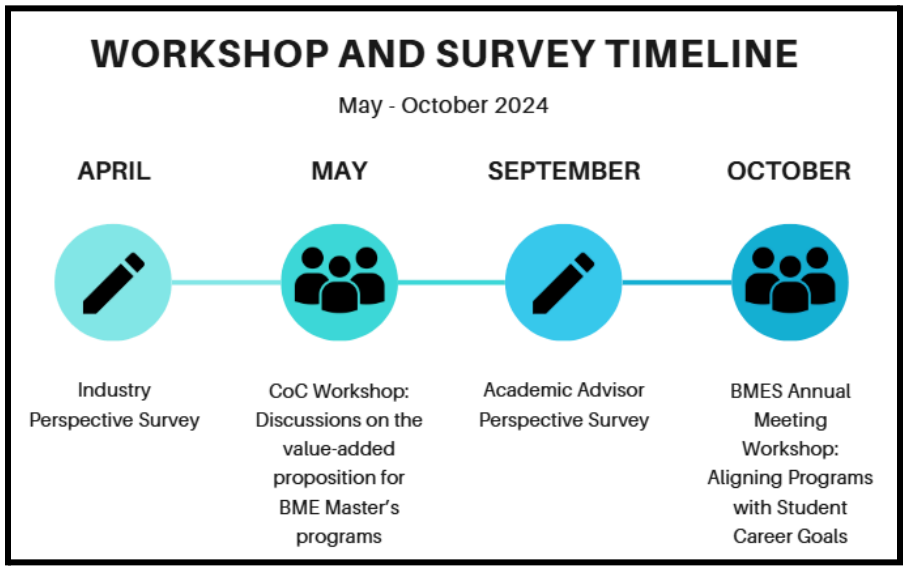

Figure 1: *Cadence of survey and workshop activities*

Survey Methods

First, to assess the needs of academic advisors who retain BME students and of industry hiring managers in recruiting students, an open-ended survey was sent to each group. The two surveys and overall methodology of this study were submitted to the IRB at Brown University (study number STUDY00000687 for the survey sent to industry representatives and STUDY00000693 for the survey sent to academic representatives). The IRB determined that the two surveys were not human subject research. These surveys asked very similar questions and included the following:

Table 1: Survey questions to industry hiring managers and academic advisors

Industry Manager Questions	**Academic Advisor Questions**
1. What are the 3 most important professional skills you are looking for in a new hire at your company?	1. What are the 3 most important skills you are looking for in a new PhD student into your research group?
2. Do hiring managers at your company understand or appreciate the differences in the curriculum behind a Biomedical Engineering	2. When would you recruit a PhD student with a biomedical engineering degree as compared to a student with a different educational academic background?

degree as compared to other engineering degrees?	
3. When would you hire a person with a biomedical engineering degree as compared to other engineering degrees?	3. In your opinion, are there skills that incoming BME PhD students are lacking that we could potentially address in BME bachelor's or master's programs?
4. In your opinion, are there gaps in professional skills for recent BME graduates we can address in our programs?	4. Do you prefer to recruit PhD students that have previously pursued a master's degree?

Rather than constrain responses to pre-determined key attributes, the survey was designed with open-ended questions so that responders could freely give their input. The survey language intentionally did not differentiate between graduates of BME bachelor's or master's programs as we wanted to know the skills gaps of BME programs in general. The surveys yielded results from 30 senior engineering leaders (average of 22 years industry experience) and 25 academic advisors (average of 18 years experience). Industry engineering leaders were primarily from the medical device field (77%) with 10% each from consulting firms or medical supplier manufacturers. The primary function of these engineering leaders was in product development (53%), with another 20% each in executive roles or research & clinical areas of responsibility. All responded that their firms actively hire biomedical engineers. Academic advisors were primarily of the full Professor rank (n=20) and represented 16 universities of various sizes, which ranged from enrollments of 6,400 students to 61,000 students.

This data was sorted and tabulated by each individual survey participant's input. To start the process, one- or two-word phrases were used to summarize the meaning of the open-ended responses, looking for common meaning or terms. At least two individuals on the research team sorted and agreed upon the recurring words or phrases and created a list of codes that were fed into a widely available word cloud generator (Word It Out; Enideo - Antwerp Belgium) to visualize the input from the surveys. Word clouds were grouped by question. Only words cited at least two times were presented in the word cloud.

Responses were tabulated and categorized into key terms. Word clouds were generated from these key terms for easy visualization of common responses. A word cloud is a cluster of words depicted in different sizes. The bigger and bolder the word appears, the more often it is mentioned within a given text and the more important it is. Word clouds can be an ideal way to pull out the most pertinent parts of textual data and to compare and contrast two different collections of responses to find the wording similarities and dissimilarities between the two.

Workshop methods

The authors prepared for and delivered two different workshops within 6 months of each other to foster discussion regarding specific actions master's programs and the BME community can take

to align programs with stakeholder needs. The first workshop titled "Discussions on the Value-added Proposition for BME Master's Programs and Views from Industry" will be referred to as the "CoC workshop" and was held at the BME Council of Chairs Education Summit in May 2024. The primary audience of this workshop was BME faculty and academic leaders, though there were some industry representatives also in attendance. Because of the large size of this summit, the workshop was delivered three times with approximately 30 participants per workshop. Prior to diving into breakout groups for guided discussions, the workshop organizers shared the results of the aforementioned industry survey. Copies of the word clouds created from the survey responses were provided to each discussion group. With the survey results and a review of the literature as an introduction, participants were instructed to self-select into groups of 4-6 participants to generate ideas according to the following prompts:

1. Discuss how the outcomes of the survey may influence how your own program is structured and administered.
2. Discuss how BME master's programs as a whole can better align with industry needs and expectations of BME graduates.
3. Discuss how access might be limited to BME master's programs, specifically among under-represented students and international students.

Discussions were limited to 30 minutes and all individual ideas were recorded via sticky notes. Groups then aggregated common ideas which were documented on a worksheet and submitted to workshop organizers. All information from worksheets were digitized and combined in one document. The research team viewed all responses across participant groups and workshops. Common themes were highlighted based on keywords and phrases. For example, a workshop idea of "contacting alumni in industry" was included in the "Alumni" theme when coalescing our results. Themes that were mentioned at least twice in the workshop results were included in our results summary.

One major discussion point that resulted from this workshop was the need for an "assessment framework" for BME master's programs. The workshop instructors wanted to further discuss this idea and decided to incorporate it into their next workshop.

The second workshop was titled "BME Master's Programs: Aligning Programs with Student Career Goals" and will be referred to as the "BMES workshop." It was held at the BMES Annual Meeting in October 2024. The primary audience was BME Master's Program Directors and there were approximately 20 participants and 4 breakout groups. Though we were focused on discussing industry needs of BME graduates in the CoC Workshop, the research team recognized that industry is only one career pathway for BME graduates. Therefore, the second workshop was focused on discussing the needs of industry hiring managers and academics who admit BME graduates as Ph.D. students. This focus on academia stems from a significant percentage of BME undergraduate and master's students continuing their education with a Ph.D. program. Also, we anticipated the audience of this BMES workshop to be primarily faculty in academia.

For this workshop, both the industry manager and the academic advisor focused surveys were shared with participants. Participants then self-selected into groups of 4-5 participants and recorded ideas to the following prompts:

1. Discuss current program elements that best align BME master's programs with the needs of industry and academia.
2. Discuss new program ideas that best align BME master's programs with the needs of industry and academia.
3. Discuss ideas surrounding assessment of BME master's programs that can be taken by programs themselves or the BME community as a whole.

Participants discussed these topics for approximately 45 minutes and recorded all ideas on large easel pads. After a brief wrap-up discussion with the large group, workshop organizers collected the ideas and digitized the information. Once the second workshop concluded, workshop organizers highlighted common themes and responses from both workshops.

Results and Discussion:

Survey Results and Discussion

Overall, top skills listed by industry responders were generally consistent with previous industry survey results reported in the literature with technical skills including CAD and design skills highly valued[3]. From our specific survey, the most common desired skills for industry stakeholders (shown in Figure 2a) included communication, mechanical design, problem solving engineering competency, teamwork, and project management. Top desired skills for academic recruitment (shown in Figure 2b) included research skills, communication, critical thinking, passion and curiosity. Both groups highly valued communication skills, teamwork, and problem solving & critical thinking, consistent with other reports in the literature[3], [9].

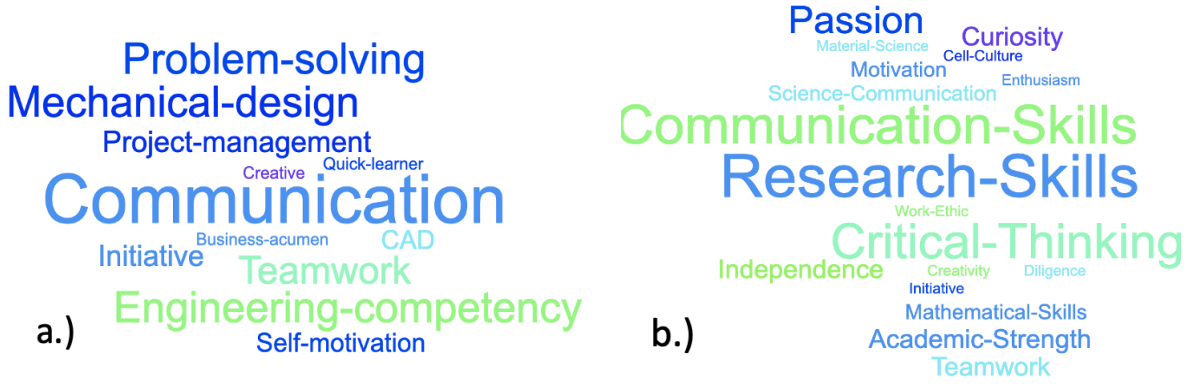

Figure 2*: Word cloud for industry hiring managers and academic advisor survey. a.)What are the 3 most important professional skills you are looking for in a new hire at your company? b.) What are the 3 most important skills you are looking for in recruiting a new PhD student into your research group?*

One survey question asked about hiring managers' awareness of the BME degree characteristics compared to other engineering majors. While 50% responded favorably, 33% felt that there was limited understanding and 17% felt that their hiring managers did not fully appreciate the

nuances of a BME curriculum. To assess where industry and academia particularly focus on recruiting BME majors, the survey asked about key skills desired. The industry respondents indicated they would hire BME graduates in roles such as product development, research, and quality, and into jobs requiring clinical understanding and a broad perspective. Academic recruiters' responses indicated that their particular research focus guided the need for BME students, as well as life science and interdisciplinary projects. Finally, academic recruiters valued a number of particular skills including computer programming, cell culture and mathematical capabilities.

Finally, areas not found to be well addressed in the BME curriculum for industry and academia were assessed in the survey. For industry, key areas that are not well represented by BME graduates include experience and understanding of manufacturing, design controls, drafting, regulation, and quality (shown in Figure 3a). Academic leaders reported key areas for additional focus would be increased technical depth and science communication (shown in Figure 3b). Additional skills desired by academia that are lacking include computer programming, mathematical skills, design of experiments and data analysis.

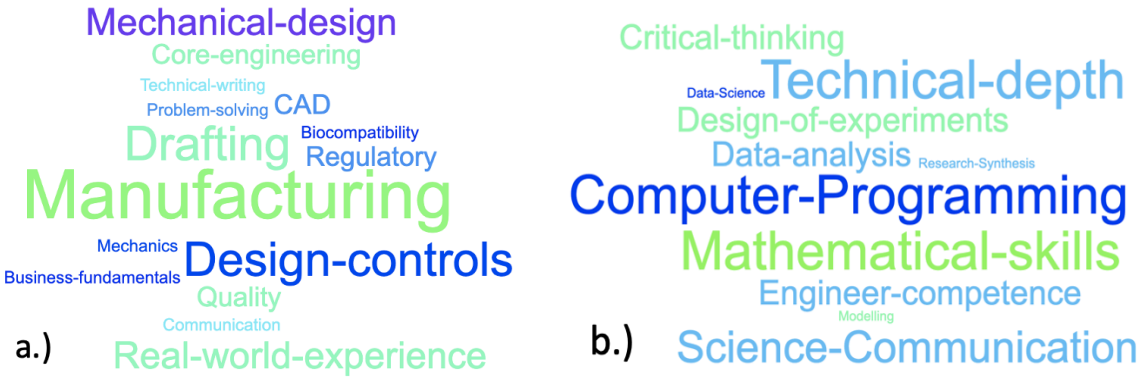

Figure 3*: Word cloud for industry hiring managers and academic advisors survey. 3a.) In your opinion, are there gaps in professional skills for recent BME graduates we can address in our programs? 3b.)Question 3 (right) : In your opinion: are there skills that incoming BME PhD students are lacking that we could address in BME bachelor's or master's programs?*

We do want to emphasize that there are some limitations to our survey responses, particularly the industry survey. Many of our respondents (77%) were in the medical device field and other industries that hire biomedical engineers were not well represented. These fields include the biotechnology and pharmaceutical industries. Though we expect responses regarding professional skills to be similar in those industries, we may also expect different responses in terms of technical skills.

Workshop Results and Discussion

Across both workshops, the enthusiastic participants had many ideas to better align programs towards both industry and academic needs. We organized common thoughts into 4 main categories:

1. Broad ideas to better align programs to ***both industry and academic needs***

2. Specific ideas to better align programs with ***industry needs***
3. Specific ideas to better align programs with ***academic needs***
4. Master's program ***assessment*** considerations

Aligning Programs to both industry and academic needs
During the workshops, participants brainstormed broad ideas that individual programs could take but also emphasized the need for the BME community to take action. Two main themes from the discussions around aligning programs with both industry and academic needs include (1) program structure and (2) professional development. Participants mentioned that master's programs should have a structure that directs students to a career focus such as industry, academia, or medical school. Developing or revising curricula for programs should be done with multiple stakeholders that represent different career options. Regardless of students' career focus, participants highlighted the need for hands-on learning master's courses for students to learn and practice essential skills. While most master's programs are tailored towards those recently graduated with their undergraduate degree, participants believed that programs should provide curricular options to those who are established in their career.

Because both industry and academic stakeholders highly value graduates with strong professional skills, a major theme in both workshops was the need for professional development courses. Courses that polish skills such as design, innovation, communication, teamwork, and leadership skills could be counted towards degree requirements. A more specific idea is to teach students persuasive communication skills for pitching ideas to different audiences.

Building off the need for professional development within the BME master's programs, participants suggested that the broader BME community could help with this endeavor. For example, BMES may gather and post a curated list of professional short-course offerings that include both technical skills and professional skills. These could be sessions that are already available or generated by the BMES community. Similarly, BMES could also sponsor a YouTube channel as a home for these educational videos. A great example discussed in the CoC workshop was the Kern Engineering Entrepreneurial Network (KEEN) which is a database of videos and resources surrounding engineering entrepreneurship [10].

Aligning programs with industry needs
The topic of aligning programs with industry needs generated the most ideas across workshops. This is not surprising, as industry is where the majority of undergraduate and master's students land after graduation. Faculty are regularly thinking about how to improve their programs and better prepare students for industry careers. Two main themes arose during the workshops surrounding this topic: (1) Specific curricular options (2) Actions to increase programs' exposure to industry.

Specific curricular options suggested by participants included the addition of industry skill-based courses that focus on topics such as quality, regulatory compliance, risk management, Computer Aided Design (CAD), design process, fabrication, manufacturing, and career progression. These suggestions include a mix of industry-specific technical skills and engineering-based professional skills. Another suggestion included the development of one year, project-based design programs with clinical or industry partners. These programs could include design

competitions sponsored by these partners. Regardless of program structure, it was recommended that institutions tailor their BME master's programs according to industries common in that region. To make programs more accessible to students regardless of location and career level, another common suggestion was to provide online opportunities for students.

Though BME faculty and academic institutions often come together through conferences, professional meetings, and other events, we connect less often with those in industry. There were many ideas vocalized at the workshops to increase students' exposure to industry. A common idea was the development of co-op and internship opportunities for career experience. These experiences could also include clinical experiences for those pursuing clinical roles. Other similar experiences that may not require as much time commitment for both parties include shadowing opportunities, informational interviews, and invited guests. Many faculty have found it difficult to form industry relationships, but others have found success by leveraging their program alumni. To ensure that programs are aligned to industry needs and meeting outcomes, master's programs should have advisory boards that include industry representatives. Again, these representatives could also be alumni of the programs. Lastly, an idea that may take a significant amount of negotiation on behalf of industry and the academic program is industry-sponsored scholarships. However, this idea could be mutually beneficial for companies, programs, and students.

These previous ideas are primarily for specific programs, but there are many suggested initiatives for the broader BME community. One major roadblock to aligning BME programs with industry needs is the lack of regular, longitudinal data from industry. To solve this issue, the BME community should compile an industry and sector-specific competency or skills list that is shared in a searchable way. To further connect institutions and industry, more industry-focused workshops could be offered at BMES and other regional and national meetings. Ideally, these workshops would focus on professional skills or be a panel format with Q&A sessions. It is clear that there is room for the BME community to improve its relationship with industry. One bold suggestion was for BMES to embark on a public relations campaign with industry representatives. This could be done at large engineering conferences such as the National Society of Black Engineers (NSBE) Annual Convention or the Society of Women Engineers (SWE) Annual Conference where there is a large industry presence. It is believed that the BME community needs to increase awareness and value proposition of our BME graduates. Key information that should be presented to industry partners include information about the degree itself, what differentiates biomedical engineers from other engineers, and what specific skills biomedical engineers could bring to their company.

Aligning programs with academic needs

The topic of aligning BME master's programs with academic needs was only discussed at the BMES workshop, but the resulting ideas have the potential to make a major impact on the BME field as a whole. As the Engineering and Biomedical Engineering Ph.D. landscape becomes more competitive, many prospective Ph.D. applicants are enrolling in master's programs with a goal of becoming a more competitive applicant. The academic survey results were somewhat surprising to workshop attendees as they highlighted the need for specific technical skills such as coding, data analysis, and application of mathematical concepts to research. Though professional skills were a focus for graduate advisors, the coveted skills were technical in nature.

Two main themes arose from discussions surrounding academic needs: (1) Curricular elements for individual programs with a focus on coding, mathematical skills, and Artificial Intelligence (AI) and (2) Dissemination of BME graduate program information by the broader BME community. In terms of curricular elements, participants encourage programs to integrate basic coding, data science, and AI into existing courses. The same could also be done with mathematical modelling and experimental design, two other skills highly valued by academic stakeholders. Another option is to have space in the curriculum for students to take these types of courses as an elective from other departments.

In terms of suggestions for the broader BME community, it is recognized that there is a need to demystify graduate school options for those interested in BME graduate programs. Students should be able to access information regarding the value of both master's and Ph.D. programs, the cost-benefit of both degrees, and the differences between degrees. Perhaps the community can generate a template to circulate to individual programs or create a fact sheet to post on the BMES website. One example of how the BME community is supporting this initiative was during the BMES Annual Meeting in October 2024: the BMES Education Committee organized a panel for student attendees entitled "Demystifying graduate school options and application processes."[11]

Assessment Ideas

The most recurring theme in both workshops was the need for assessment of master's programs. Assessment of BME master's programs will allow programs to develop and assess outcomes to assure they are meeting the needs of all stakeholders. While undergraduate engineering programs are largely accredited by ABET[12], BME master's programs are not generally assessed by a single governing body. Therefore, BME master's assessment varies widely between individual programs, with few programs having established assessment policies. There is very little information in the literature on assessment of BME master's programs, and workshop participants have implored the BME community to develop resources to share among master's programs. Compounding the problem is that specialized master's programs will need different assessment strategies according to specificity as these programs emerge. Despite the many different types of master's programs, there is a need to develop broad assessment guidelines. Workshop participants recommend that BME master's leaders find inspiration for assessment from professional science master's programs or even other engineering programs. In the meantime, participants did give assessment suggestions for individual programs.

One recommendation from workshop participants includes the use of instructional designers to follow Bloom's Taxonomy[13] when developing and assessing objectives for courses. Lectures, readings, assignments, and assessments should all be aligned with these course objectives. A key professional skill needed in both industry and academic careers is initiative. Programs should develop methods that assess students' ability to complete tasks with minimal assistance. Another assessment idea is the use of skill-based or more qualitative surveys to assess graduate skills. These surveys could even be given to employers after co-op or internship programs and after career fairs. Tracking outcome metrics through LinkedIn or other social media accounts is a great method to collect data regarding BME master's graduates. However, there is also a need to generate and circulate best practices for collecting outcome data among programs so they can

easily be compared. Overall, workshop participants urge that individual programs start their own assessment measures and work as a community to develop common assessment guidelines.

Conclusions

Biomedical engineering master's programs strive to align their programs with the needs of those that recruit BME master's graduates. Our research specifically focused on industry and academic stakeholders, as they are the primary employers of BME graduates. Surveys of both groups yielded a number of key needs and areas for improvement overall in the education and training of BME program graduates. This information functioned as a key prompt for workshop discussions by program leaders on ways to improve their efforts to prepare master's students specifically for industry roles and for further advanced education at the doctoral level. Key themes discussed in these workshops included the need for specialized master's programs and courses that focus on technical skills, methods to polish professional skills in master's programs, and BME master's program assessment options. Participants generated ideas for individual programs but also emphasized the need for the broader community to address issues such as industry relations and assessment. Overall, we hope the information presented here will help increase the impact and value of BME master's programs.

We recommend that BME master's stakeholders meet regularly at forums like BMES to drive these initiatives forward. Gathering resources and establishing a method to distribute them will be the group's immediate priorities.

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