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PERSPECTIVES

BME Master's Programs: Who Are They for and What Can They Offer?

Marissa Gray[1] · Jennifer R. Amos[2] · Soraya Bailey[3] · K. Jane Grande-Allen[4] · Celinda Kofron[1] · Sabriya Stukes[5]

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Abstract
Authored by six current and former Biomedical Engineering (BME) Master's Program Directors, this article aims to summarize the types of BME master's programs that are offered in the U.S., delve into the value of BME master's programs, and reveal concerns of BME master's students and directors that are exacerbated among international and under-represented populations. Using a combination of literature review, meta-analysis, and review of data collected from master's program websites, we provide a report of master's program types and characteristics. Based on the demographics of these BME programs, the authors use their collective expertise to outline common concerns of BME master's programs and propose solutions to these issues. There is a wide variety of BME master's programs that include those rooted in research, coursework, or medical device innovation. The value of a BME master's degree includes depth in the field beyond the undergraduate degree, eligibility for more specified positions in industry, pivot to another career path, or a gateway to professional programs. However, there are perceived disparities among BME master's students compared to Ph.D. and undergraduate students. These disparities typically fall under two main categories: lack of support for master's programs and financial concerns. To better support master's programs, the authors recommend (1) advocating for master's-specific resources for both students and program leadership and (2) advocating for master's-specific scholarships and assistantships at the institution-level. With this enhanced programmatic and financial support, BME master's programs will be more robust, equitable, and attainable for many students.

Keywords Master's programs · Support · Financial concerns · Thesis · Non-thesis · Translational programs

Introduction

In recent years, there has been an increase in the number and types of biomedical engineering (BME) master's programs. BME master's programs include thesis and non-thesis coursework-based programs, combined BS/MS programs, and specialty medical innovation programs that are focused on developing specific interests and career paths. Master's programs often have unique challenges compared to undergraduate and Ph.D. programs including student demographics; career development for students; and support for programmatic funding, student program progression, and development of faculty that play a large role in master's programs.

✉ Marissa Gray
marissa_gray@brown.edu

1 Institute for Biology, Engineering and Medicine, School of Engineering, Brown University, Providence, RI, USA

2 Department of Bioengineering, University of Illinois Urbana-Champaign, Urbana, IL, USA

3 Department of Bioengineering, University of Washington, Seattle, WA, USA

4 Department of Bioengineering, Rice University, Houston, TX, USA

5 Department of Biomedical Engineering, City College of New York, New York, NY, USA

Types of Programs

From data compiled in 2023 from the U.S. News and World Report top 50 (N=57) BME graduate programs in the U.S., 53 (93%) have some type of master's programs while 87% of those offer a program that requires a thesis [1]. 44 of 53 schools (83%) offer both thesis and non-thesis options. As of 2023, 23 of 53 schools (43%) had specialized programs related to medical innovation, translation, entrepreneurship, or project-based learning. Thesis-based BME master's programs are typically based on research and span a 2-year period. There are several types of non-thesis programs

including coursework-based programs, bridge programs to other professional degrees, and specialized medical innovation programs. These programs can take as little as one year and are typically cohort-based. In particular, specialized master's programs are rising in popularity. In 2018 a survey was conducted among nine of these programs that solicited responses from both program directors (n=9) and alumni (n=55) [2]. When asked to submit five keywords to describe their programs, 97% of respondents cited "design" and "innovation" while 73% submitted "regulatory." Based on responses, both faculty and alumni feel the most important themes of these programs are teamwork, industry, and hands-on design work. The increasing diversity of BME master's programs reflects the varying interests and career goals of BME students. More than ever before, master's programs are used to elevate and direct students toward a specific goal or career path.

Masters Program Demographics

According to the American Society of Engineering Education (ASEE), nearly 2971 master's degrees were awarded in Biomedical Engineering in 2022 compared to 8422 undergraduate degrees and 1129 doctoral degrees [3]. Only 336 master's degrees (11.3%) were awarded to those who meet the federal definition of Under-represented Minority (URM) which includes those who identify as Black or African American, Hispanic or Latino, American Indians, or Alaska Natives [4]. This is a significant decline from the 15.5% of URM-identifying undergraduate degree recipients while 7.9% of BME Ph.D. recipients identify as URM. The 2018 Status Report on Engineering Education from the Association of Public and Land-Grant Universities (APLU) concluded that though there has been an increase in URM students earning engineering undergraduate and master's degrees in the past 10 years, these students remain largely underrepresented in the field [5]. This is especially true as the level of education increases from the bachelor's to master's degrees. Alternatively, there has been an increase in the number of master's degrees awarded to international students since 2011 [3]. Nearly 60% of all engineering master's degree recipients are international students or those who do not have U.S. citizenship or permanent residency in the U.S. In contrast, the percentage of engineering master's degrees awarded to international students in 2009 was 44.1%. As more international students have been receiving master's degrees, there is a complementary decline in domestic students earning master's degrees. It should be noted that the BME discipline awards more master's degrees to women than any other engineering discipline except for environmental engineering (BME is 49.5% women while Environmental Engineering is 57.3%) [3].

Value of the BME Master's Degree

Though students have varying motives for entering a BME master's program, we attempt to distill the value of a earning a BME master's degree using four themes as outlined in Fig. 1: increased depth in the field beyond the undergraduate degree, eligibility for more specified or higher-level positions in the biomedical industry, pivot to a different career path, or gateway to Ph.D. programs, medical school, or other professional programs (such as law school, dental school or chiropractic programs).

Increased Depth in the Field

Undergraduate BME programs often provide a broad base of biomedical engineering that includes core coursework in math, physics, biology, and engineering. Because of the high number of courses this entails, students may only take a few courses specific to biomedical applications in their chosen subfield as an undergraduate [6]. Master's programs in BME provide the opportunity for students to broaden their knowledge and deepen their understanding of skills, tools, and real-world applications. Further, it has been found that

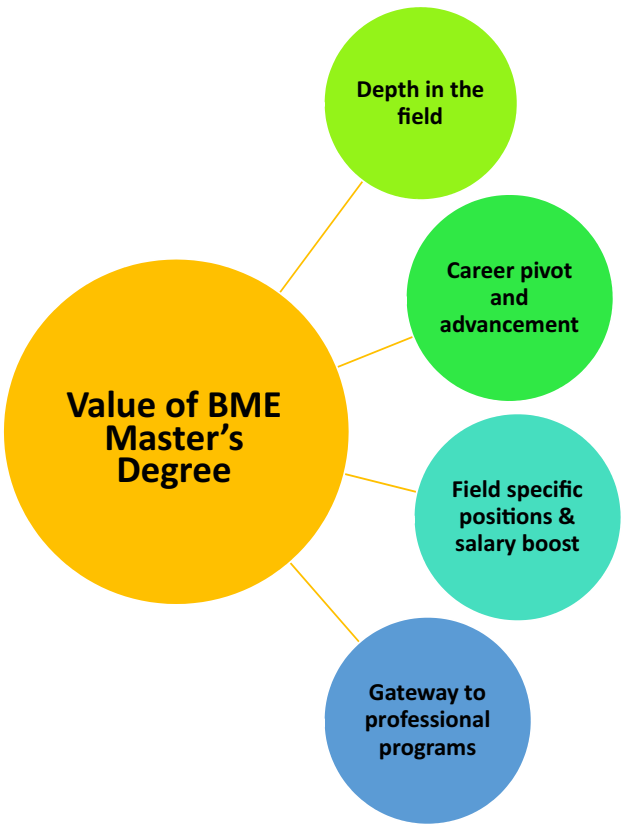

Fig. 1 The value of a master's degree is highlighted by four themes

there is a need for skills related to regulatory, quality, and commercialization to be taught in the classroom rather than on the job in industry [7]. Therefore, enrolling in innovation and industry-based programs enables students to gain these skills before applying them in the field.

Advancement Within or Pivoting Career Paths

BME master's programs are attractive to many students as a means for a career path that doesn't require the 5+-year time commitment of Ph.D. or M.D. programs. Students enter master's programs with a background already within BME or they are looking to pivot their engineering and science skills towards biomedical applications. Graduates from master's programs are typically trained for "integrator" roles within the biomedical and biotechnology industry and often interface with both science and business aspects of industry [8]. These roles often include project management, marketing, regulatory, and research and development positions. In 2020, researchers at Georgetown University analyzed 15 of their biomedical master's programs. They found that 69% of graduates entered industry, while 59% of those graduates had primarily research-based job functions [9]. Nearly 50% of employed graduates changed positions upon completing their degree. Graduates most often kept their same job function but switched companies, changed to an advanced position at the same or different companies, or changed to a different position at the same or different companies. Master's degrees also appear to enhance employment as master's degree recipients in the life sciences have lower unemployment rates than those who have bachelor's degrees [10]. In many companies, job postings often require either a master's degree, usually with experience, or a Ph.D. [11, 12]. This reflects well on master's programs, which produce candidates with both field-specific knowledge and complementary skills in business, communications, or product development. It is worth mentioning that compared to the Ph.D. application process, admission to a master's degree program is typically less competitive and the degrees can be earned in a shorter (1–2-year) time frame [13]. They do have a large cost associated with them as Ph.D. programs usually provide modest financial support and can provide training for specific sub-fields of BME or specific career paths. However, master's degree graduates enter the job market much quicker than Ph.D. graduates.

Field-Specific Positions and Boost in Salary

According to the National Science Foundation-sponsored 2013 National Survey of College graduates, those with STEM master's degrees generally earn a 13% higher salary in comparison with their non-master's degree counterparts [14]. This is dependent upon many variables such as type of industry, specific degree, positions in industry, and specific employee demographics. For both men and women, 70% of STEM master's degree recipients believe their work is closely related to their chosen degree, while only 50% of bachelor's degree earners feel the same. Additionally, among STEM master's degree recipients, there is a much higher percentage of those working in research and development (R&D) than those with a bachelor's degree. Therefore, according to this survey, STEM master's degree earners typically have a higher salary, are more likely to be employed in the field of their choosing, and master's programs may more adequately prepare students for an R&D position.

Gateway to Ph.D., Medical School, or Other Programs

Because of the competitive nature and experience needed for other professional degree programs, some students use the master's degree as a stepping-stone to programs such as medical degrees, Ph.D. or other professional schools such as law school or pharmacy programs [15, 16]. For example, some universities have gateway BME-related programs to prepare students for medical school or for the Ph.D. More often, students use these master's degree programs to gain more research experience or coursework so that they may build a stronger application to these professional programs.

Overall, there is a definite need for BME master's programs with regards to professional skills not covered during undergraduate education, advancement within the field, pivoting to another career path, or bridging to other professional degree programs. To fulfill this broad range of aspirations, there is a wide variety of types and structures of BME master's programs that cater to the individual needs and aspirations of each student. However, there are perceived disparities that affect BME master's students more than they do Ph.D. and undergraduate students that are exacerbated in under-represented and international populations. These disparities typically fall under two main categories: lack of support for master's programs and financial concerns. Lack of support of BME master's programs include insufficient resources for faculty, staff, and students as compared to those of undergraduate and Ph.D. programs. Financially, master's students are typically self-funded and have limited access to financial aid, while students in Ph.D. programs are often fully funded.

While four main themes are highlighted that could influence one's decision to pursue a BME master's degree, it is worth noting that each theme may carry more intrinsic value than the others depending on an individual's experience. Despite the decline in numbers of URM's pursuing BME MS degrees, they are still an increasingly important mechanism for upward mobility and professional development. Additionally, for first generation students (here defined as the first in their family to enroll in postsecondary education)

they may see earning degrees beyond a bachelor's as a way to provide substantial support for their families as well as themselves.

Observed Concerns

The group of authors are currently or were affiliated with universities with biomedical engineering master's programs and come from programs ranked in the top 100 by US News (#7 Rice, #13 University of Washington, #22 University of Illinois Urbana-Champaign, #41 Brown University, #74 CUNY City College). All have directed or managed master's programs in a range of 5–8 years at these various institutions and have observed similar patterns and concerns among our collective master's programs. Specifically, we have all received anecdotal feedback from our master's students that they feel as though they do not have the same types of resources and support as BME undergraduate and Ph.D. students. In discussing differences between master's and other BME degree programs as a group, we felt that the perceived disparities fell into two categories: lack of support and specific resources for the master's program and financial concerns surrounding the cost of master's programs compared to costs and aid given to those in B.S. and Ph.D. programs. These concerns are often exacerbated in URM and international populations. Here we attempt to distill these concerns and offer recommendations to BME master's program leadership in order to address these concerns.

Lack of Support for Students and Faculty

In most institutions, there are typically foundational support structures in place for students in both BME bachelor's and Ph.D. programs while reciprocal programs for BME master's students are often lacking or combined with another BME degree program. In describing "lack of support" we can divide support structures into two groups: support that is directed to the student and support that is targeted for faculty directing, teaching, or advising students in BME master's programs.

Student Support

Institutions themselves often provide graduate program support that impacts both students and faculty, but this support is often not sufficient to meet the needs of both parties at the master's level. Examples of student support resources at institutions include student affairs resources, financial aid, career advising, and wellness services. In many schools, there are no networks of master's deans or disability services [17]. For questions regarding financial aid, it has been observed that master's students are often directed to an institution's general Financial Aid Office, which typically specializes in undergraduate financial aid and gives only general advice for master's students. There is often not a separate career counselor for master's student career advising even though the need for career advising at this level is high. Moreover, though there are many international students in master's programs, we observe that there are often no separate resources for international master's students. International student-specific resources are certainly needed, especially at the career advising level when the needs of international students are very different compared to domestic students. It is important to note that unlike their undergraduate and Ph.D. counterparts, master's students are on-campus for a much shorter time (1–2 years vs. 4–6 years) and this may contribute to the perceived lack of support. International students particularly are just becoming accustomed to the culture and nature of the program and school when it is time to graduate.

Faculty Support

Directing a master's program often requires a Ph.D. in Biomedical Engineering and both teaching and advising experience. However, many faculty members who direct master's programs are Non-tenure Track (NTT) faculty and often do not have well-documented promotion timelines or career advancement opportunities. In STEM fields, women are more likely to hold NTT positions which typically yields lower salaries and job satisfaction as compared to tenured/tenure-track positions [18]. Because of the "niche" nature of their position, there is also little direct mentorship for individuals in this role. Further, it is perceived by the authors that tenure-track (TT) faculty who teach or advise master's students are not incentivized to do so with respect to teaching, research, and service requirements, in the way they are with bachelor's and Ph.D. students. Finally, while there are staff that support students, directors, and faculty of master's programs, in our experience the numbers of these staff are usually insufficient.

URM and International Students and Faculty

Though additional student and faculty support for BME master's programs is needed for all individuals, URM and international student populations could greatly benefit from more specific support. URM and international students are often isolated due to the relatively short duration (1–2 years) of master's programs compared to undergraduate and Ph.D. programs. Also, because engineering courses and content often have a lack of diverse instructors, speakers, authors, and other content, diverse populations may feel underrepresented and excluded [19]. Connecting with those like themselves is very important, particularly to understand unique

situations such as financial struggles and language barriers. For international students, immigration status can provide barriers to summer internships and jobs after they graduate. This is often an added stressor for international students on top of belonging and cultural differences. Overall, to address these issues for both URM and international students, there is often little clarity on where master's program constituents can go to voice their concerns.

Financial Concerns

Another major concern for Biomedical Engineering master's students is the cost of their master's education. In sharp contrast to both undergraduates and Ph.D. students, there is very little to no financial aid for the vast majority of BME master's programs based on publicly available data compiled from the top 50 BME master's programs. Even for those completing a thesis and conducting research in a lab, there is typically little financial support. The data compiled from the top 50 BME master's programs also reveals that tuition averages $49,788 per program, regardless of program length and varies widely from $12,646 to $116,068. Public institutions often have the most affordable programs for in-state residents with a mean of $31,602 (lowest: $12,646, highest: $63,920) for in-state residents and a mean of $54,710 (lowest: $24,798, highest: $116,068) for out-of-state residents. Engineering programs do tend to cost more than programs in other disciplines [20, 21]. This high tuition is coupled with living expenses, which vary widely on institution location. Tuition costs are often not instituted by the program, but rather decided upon at the institution-level where there is little direct interaction with program constituents. Furthermore, tuition revenue is often a primary source of income for schools and departments, but very little of that revenue is returned to the programs to help develop courses, resources, and facilities for their master's students.

The combination of high tuition costs and living expenses is a financial burden for students of all backgrounds as seen in Fig. 2. Many students may want to enter the workforce before taking out loans or adding to their existing debt. Additionally, student loan terms can be less advantageous than for undergraduate students, with the potential for higher interest rates and borrowing caps [22]. Master's programs themselves often cannot ease this financial burden as there are typically few scholarships, teaching assistantships, research assistantships, or other opportunities exclusively for master's students. These types of assistantships are often reserved for Ph.D. students. Also, master's students who would be competitive for outside and government-sponsored scholarships have a very small window to apply for these opportunities since they are in the program for a very short period compared to B.S. and Ph.D. students.

BME programs often have difficulty justifying the high financial cost of their program to prospective students. Because of the wide variability in BME master's programs in terms of content covered, presence or lack of thesis, and duration of program, it is difficult to explain the value of the degree compared to long-established degrees in traditional engineering fields with clear post-graduate pathways. The value of the education is also perceived to be of higher benefit earlier in the career than later, which is another financial barrier to early career (1–2 year post-undergraduate) prospective students who may already be paying their undergraduate student loans [23]. Additionally, this perception excludes more experienced engineers, those looking to change careers later in life, and those looking to attend programs part-time. For domestic students, there is often an option to enroll in a BME master's program part-time while working full-time, but often programs have limited course availability in the evenings, on weekends, or online. Though this model is often seen in business school programs, it is less common in BME programs. Overall, flexible programs with options for online and night courses may yield more students than programs with more rigid, on-campus structures.

URM and International Students

These financial challenges are largely amplified in URM and international populations. For URM students, there may be familial pressure to enter the workforce and earn a salary directly after receiving a B.S. Further, URM students are more likely to secure funding for graduate school from family members [24]. There is a major disparity in student debt for URM students, and private institutions often are the primary source of this debt [25]. Hidden costs, such as

Fig. 2 Cumulative costs of BME master's programs

transportation and health insurance costs may impact international students and URM students disproportionately. International students most likely will not have U.S. driver's licenses for travel or access to government-subsidized or parental healthcare which will be additional expenses [26]. International students may need to take extra courses as they acclimate to the U.S.-based higher education and courses taught in English. Though there may be some limited fellowships and scholarships available to BME master's students, many are restricted to domestic students. Finally, the urgency to find a position after completing the master's degree may be particularly high for URM and international students so that they can earn a salary and begin repaying student loan debt. International students have additional obstacles to finding positions, including the need for company sponsorship and application for Optional Practical Training (OPT) for temporary employment in the United States. Even during the master's program, international students who would like to gain off-campus industry experience must apply for Curricular Practical Training (CPT) as part of a course if their program offers this option. Throughout the span of the master's program, both URM and international students face unique and specific financial obstacles that they must overcome and need extra support navigating these obstacles.

Recommendations to BME Master's Program Leadership

In light of the authors' collective experiences directing and supporting BME master's programs, we propose recommendations to current BME master's program leadership to proactively address these concerns. These recommendations are not comprehensive, rather they are a starting point for program leaders to support BME master's students, faculty, and staff.

Recommendations to Support Students and Faculty

Our recommendations to enhance support structures for master's students, faculty, and staff fall in two categories: enhancing support at the broader institutional level and at the program level.

Enhanced Institutional Support

First and foremost, we recommend advocating for master's-specific resources at the institution-level for the benefit of all master's students, not only those in Biomedical Engineering or related programs. This can include working with Career Development Offices to provide more insight into employment opportunities for students post-graduation and possibly implementing discipline-specific resources. We believe it is important to identify points of contact at companies that would hire our graduates so that companies can become aware of the value our graduates can bring to their organizations. Career Development Offices can also help facilitate a more fluid pipeline between academia and industry.

Leadership at the institutional level can also help to build a more cohesive network within master's students to allow for familiarity and rapport among master's students. This could be in the way of events and activities or more discipline-specific programming. We recognize that the short program (1–2 years) can contribute to the perceived lack of support for master's students. In recognizing this, we believe that early and streamlined introduction to master's-specific resources is essential for master's students to feel supported.

Additionally, building robust master's alumni networks and being able to easily extract information and data from this pool can help programs measure outcomes and highlight success stories. To specifically retain URM students, institutions may want to invest in infrastructure to support 3+2 or 4+1 programs either in the same institution or partner institutions. We expect such programs will support the student pipeline through the master's program and potentially to the Ph.D. program.

Enhanced Support Within the Program

Many BME Master's Program Directors and department leaders have the latitude to increase support in their own programs. This typically comes at a time cost, but we recommend advocating for increased support staff or existing faculty members that can serve as master's advocates to help implement new support structures. At minimum, a dedicated master's program coordinator and/or academic advisor are staff positions that can help provide much needed individual support. The first step to build larger support structures is to assess which support mechanisms are needed. This can be done by surveys administered to master's students, town halls, and program director office hours. Master's students have enhanced academic performance when they study as part of a group [27], so it is essential that they feel welcome, supported, and are able to make connections. This cohort and community building can and should continue after completion of the program. An alumni network can be an essential component for career development in master's programs, but they may also serve as members of an advisory board for the program to help build the program for future cohorts. Alumni and program staff may also provide specific career development opportunities such as resume reviews and practice interviews. Another aspect to enhance career development and marketability of program graduates is to align the programs themselves with employer needs. Alumni networks may be a good first step in connecting employers with program directors in order to revise the

program curricula. It should be noted that we believe involving alumni in any BME program activities such as advisory boards, career fairs and events, guest speakers, or involvement in courses can strengthen all BME programs including undergraduate and Ph.D. programs.

Though both the institution and programs often have many resources for students, we as current or former Master's Program Directors believe it is important for programs to bridge and connect their students to those resources. This is particularly important for URM and international students. Programs should provide connections to identity, international, and other student groups on-campus and connect new students to current BME master's students already in those groups. Master's program directors should also be able to recommend wellness, counseling, and strategies to promote psychological safety among students [28]. Lastly, it is important for programs to provide diverse course instructors, content, and speakers to promote inclusivity in programs. Weaving inclusivity into the curriculum and student life can empower URM and international students to seek resources when help is needed.

In addition to students, Master's Program Directors themselves could benefit from additional support. They would greatly benefit from faculty mentoring from Biomedical Engineering program leadership or others that have managed graduate programs. Another idea is to form Master's Program Director communities both within universities (across disciplines) and external networks (within one discipline). Because many faculty that direct BME master's programs are non-tenure-track (NTT) faculty, promotion and pathways to career advancement are often unclear. We recommend clear pathways are established for NTT Directors and that they have access to support for their career. Further, we believe that Master's Program Directors with access to program and career resources will be more effective at advising their students and building cohesive master's programs.

Recommendations for Student Financial Support

Ideally, financial support for master's students should be administered both at the institutional and program level as is the case for undergraduate and Ph.D. students. However, in many institutions, the BME master's programs are responsible for administering any financial support through limited budgets for scholarships and availability of teaching assistantships (TA) or research assistantships (RA). Typically, TA and RA positions are limited to Ph.D. students. We recommend that there are increased financial support opportunities at both the institutional level and school or program level by way of merit-based scholarships, TAs or grader positions, and opportunities for RA positions in laboratories. Perhaps these opportunities can be funded through a portion of the tuition revenue that is generated by the master's programs. Other sources of funding could come from a donor campaign specifically to help fund master's students. Programs can indirectly financially support students by offering accommodations, evening courses, or hybrid courses for part-time or professional students. Programs may also wish to promote their master's programs as an immediate option after graduation with a bachelor's degree or an option for those already in the workforce and perhaps more financially stable. Another indirect way that programs can financially support their students is by providing early and ongoing opportunities to connect with industry representatives and recruiters. These ongoing connections can pave the way for internships and co-ops during the program and more permanent employment opportunities after graduation.

For URM and international students, there are other ways of supplementing costs if scholarships or assistantships are not available. Programs should highlight and provide resources for these methods which include budgeting, capitalizing on student discounts, researching different tuition costs and living expenses at schools they are interested in attending, using CPT to earn a salary (for international students), inquiring about home-country assistance, family funds, private loans, or scholarship opportunities for specific groups of people [29].

Conclusion

Our work highlights several best practices that are encouraging for master's program including (1) enhancing support structures for master's students, faculty, and staff, (2) providing financial support at the institutional and program levels and (3) diversifying modes of earning income to cover academic expenses, particularly for international students.

While we have raised several challenges that master's program and master's student face, we also want to acknowledge that many programs are beginning to take steps to address these challenges; however, little is published about these programmatic changes and their effect on master's students. There are also few venues focused on discussing master's programs, short of sporadic sessions conducted at the Biomedical Engineering Society Annual Conference, which led to a publication and review of types of master's programs in the field [2].

In writing this article, it is our hope that we can better understand the types of BME master's programs available, the value of these programs for their constituents, and how to address common issues in BME master's education. It is our hope that those in Biomedical Engineering leadership positions can use this article to better advocate for their programs at the program and institutional level. We anticipate that this article will spark a larger conversation

about BME graduate education in workshops, conferences, and additional publications.

Citation Diversity Statement

Recent work in several fields related to Biomedical Engineering has identified a bias in citation practices such that papers from women and other minority scholars are under-cited relative to the number of papers in the literature [30–32]. We recognize this bias and have worked diligently to ensure that we are referencing appropriate papers with fair gender and racial author inclusion, particularly due to the subject matter of this article.

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Data Availability The Biomedical Engineering master's program data that was collected for this manuscript was gathered directly from the websites of the top 50 BME master's programs according to U.S. News and World Reports. This data were recorded in an excel spreadsheet. Only the authors and two students collecting the data have access to the spreadsheet. Data collection began in Fall 2022 but was updated in Summer 2023. The collected data are available upon request.

Code Availability Not applicable: no code was generated for the development of this paper.

Declarations

Conflict of interest Dr. Jennifer Amos is the co-Editor of the Biomedical Engineering Education journal's special issue on graduate education. The authors would like this manuscript to be considered for the special edition on graduate education.

Ethical Approval Not applicable: no human subjects research, data, or material was collected as part of this manuscript.

Informed Consent Not applicable: no human subjects research, data, or material was collected as part of this manuscript.

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