Biomedical Engineering Education (2024) 4:171–173
https://doi.org/10.1007/s43683-024-00155-5

BMES BIOMEDICAL ENGINEERING SOCIETY

EDITORIAL

Overview of Biomedical Engineering Graduate Education Landscape

Jennifer R. Amos[1] · Katherine E. Reuther[2,4] · Mia K. Markey[3]

Published online: 26 June 2024

Introduction

Graduate education in biomedical engineering has existed longer than most undergraduate programs [1]. However, there is a lack of publications in the graduate education space with a Google Scholar search showing 256 undergraduate education-focused articles in biomedical engineering or bioengineering published between 2019-2023 and only 7 graduate education-focused articles in biomedical engineering or bioengineering in the same period. At the same time, national reports of graduates produced over 2019-2022 showed a 3-year average of 2777 graduates in biomedical engineering at the MS level (4% of all MS engineering graduates) and a 3-year average of 1062 at the Ph.D. level (8% of all Ph.D. engineering graduates) with an average 10% growth per year [2].

In response to this need for publication in the graduate educational space for biomedical engineering, Biomedical Engineering Education announced a special call for papers focused on graduate education in biomedical engineering. Graduate education was broadly defined as formal education, such as masters and doctoral programs, and also broader topics that surround graduate or postdoctoral training. The guest editors suggested topics of interest including graduate curricular elements, graduate program types, graduate professional and psychosocial support programs, admissions and promotion criteria, career placements, bridge programs or lifelong learning programs for alumni, mentoring programs, programs that develop graduate diversity, inclusion, and equity culture, extracurricular activities, and research or professional development training programs. This Special Issue presents recent innovations in these topics as highlighted below.

Uncovering Hidden Curriculum

In recent years, graduate education in biomedical engineering has seen a transformative shift, with an increasing emphasis on comprehensive professional development and the cultivation of skills necessary for success in both academia and industry [3, 4]. Formalizing these aspects of graduate student education, as a supplement to technical coursework and research experiences, is motivated by the needs and aspirations of graduate students. “Hidden curriculum”, encompassing the unspoken or implicit aspects of a student’s education not specifically addressed in formal instruction, is evident in higher education, including for graduate studies in biomedical engineering. These students often come from diverse backgrounds and experiences, and are navigating a new environment while also balancing other academic demands. The hidden curriculum, if not unmasked, has the potential to influence a student’s learning experience and professional identity, contributing to potential inequity and diminished feelings of belonging [5]. Several papers introduce coursework that develop graduate students' research, interdisciplinary, and professional development skills [6–8] and attempt to address and overcome “hidden curriculum” observed in biomedical engineering educational environments.

Teaching experience continues to be a cornerstone of many graduate programs, allowing graduate students to gain valuable experience in instruction and mentoring while also enhancing their communication skills and fostering a

✉ Jennifer R. Amos
jamos@illinois.edu

Katherine E. Reuther
kreuther@seas.upenn.edu

Mia K. Markey
mia.markey@utexas.edu

1 Department of Bioengineering, University of Illinois Urbana-Champaign, Champaign, USA

2 Department of Bioengineering, University of Pennsylvania, Philadelphia, USA

3 Department of Biomedical Engineering, The University of Texas at Austin, Austin, USA

4 Center for Health, Devices and Technology, University of Pennsylvania, Philadelphia, PA, USA

deeper understanding of the subject matter. Across higher education, there has also been a growing focus on updating teaching practices to foster a more inclusive and equitable learning environment. Jaimes et al. [9] discusses the integration of graduate students alongside faculty in creating and implementing inclusive teaching concepts across the biomedical engineering curricula. It is possible that these types of teaching experiences may have the added benefit of enabling and empowering graduate students to uncover aspects of the observed hidden curriculum for themselves and their peers.

Unique Areas for Focus in BME Graduate Programs

Several niche topics in graduate education also emerged, including the need for graduate training in Responsible Conduct of Research, convergence of research approaches, and developing trainees' understanding of the regulatory agency landscape. Topics related to the Responsible Conduct of Research (RCR) are often not covered in undergraduate education yet they are an expectation of graduate-level training according to national funding agencies including the NSF [10] and NIH [11] In Kreeger et. al. [7], requirements and formats for instruction of RCR topics are discussed along with exciting outcomes that promote additional benefits for graduate training.

Another featured article asserts the importance of including a convergence training framework for graduate students to help them develop their skills and abilities to collaborate across multiple fields to solve a problem where teammates may come from very distinct fields (e.g., computer science, biological sciences, engineering) [12]. This training is presented as a case study of a pilot program that leveraged training in artificial intelligence and machine learning approaches to solving biological research questions. Lerner et.al.[13] aims to address the lack of successful translation of medical devices by sharing a curriculum to train graduate students in the regulatory landscape including business environment consideration, regulatory obligations, and the protection of intellectual property. These papers show a variety of approaches including formal coursework and workshop approaches that any graduate program could leverage to enhance the learning outcomes for trainees.

International Biomedical Engineering Graduate Education

Biomedical engineering education outside of the United States is increasingly recognized, with many countries acknowledging the pivotal role of this field in advancing healthcare in their regions. International collaborations with US institutions, including student exchanges and faculty collaborations, have also fostered a global perspective for biomedical engineering students. One article highlights the opportunity to partner globally and spread innovations to graduate education in Nigeria [14] though we have much to learn from other international institutions and look forward to more submissions in this area.

Future Directions

The articles published in this Special Issue form a strong base for increasing scholarly attention on identifying and disseminating effective practices in biomedical engineering graduate education. However, there remain many opportunities to advance graduate education that would be of great interest to the readership of this journal. For example, comparisons of different approaches to common graduate curricular elements, such as physiology, could facilitate programs in adopting practices most likely to meet their students' needs. Transitions in and out of graduate training are also key topics for future work. Many students seek opportunities for integrated bachelors-masters degree programs, so it would be helpful to know more about the most beneficial structures and practices for such programs. In general, postbaccalaureate and summer bridge programs can provide additional pathways to graduate education and thereby broaden participation in postgraduate training. A deeper understanding of the role of postbaccalaureate and summer bridge programs specifically in biomedical engineering would advance our field. Likewise, postdoctoral training is essential preparation for future faculty. More systematic study of impactful training practices could increase equity in persistence from graduate education to postdoctoral training to early career faculty for those interested in an academic career. An important factor in a graduate student's educational experience is the mentorship received from faculty [15]. Defining effective relationships and interactions between faculty and their graduate students, such as incorporating inclusive behaviors, could contribute to unveiling the hidden curriculum and warrants further progress and attention. As a final example, reports on lifelong learning programs for alumni and mechanisms for alumni to contribute

to the educational environment of current graduate trainees would benefit the biomedical engineering education community.

Data availability Not Applicable.

References

1. Linsenmeier RA, Saterbak A. Fifty years of biomedical engineering undergraduate education. Ann Biomed Eng. 2020;48(6):1590–615.
2. American Society for Engineering Education. (2023). Profiles of engineering and engineering technology, 2023. Washington, DC.
3. DiMeo AJ, Afamefuna CJ, Ward SJ, Weilerstein P, Caro E, Germer M, Carroll AJ. Biomedical engineering professional skills development: the RADx SM tech impact on graduates and faculty. IEEE Open J Eng Med Biol. 2021;2:163–9.
4. Wickramasinghe, L. C., Borger, J. G. (2020). The new age of the PhD: transforming the PhD from a product to a process. J Life Sci. 2(1). https://www.journaloflifesciences.org/archives/1521/editorial-the-new-age-of-the-phd-transforming-the-phd-from-a-product-to-a-process.htm#
5. Sellers V, Villanueva Alarcón I. From message to strategy: a pathways approach to characterize the hidden curriculum in engineering education. Studies Eng Educ. 2023. https://doi.org/10.21061/see.113.
6. Acuña S. A practical research methods course that teaches how to be a successful biomedical engineering graduate student. Biomed Eng Educ. 2024;20:1–10. https://doi.org/10.1007/s43683-024-00135-9.
7. Kreeger PK. Rethinking the responsible conduct of research (RCR) course. Biomed Eng Educ. 2024. https://doi.org/10.1007/s43683-023-00131-5.
8. Lightsey S, Dill M, Temples M, Yeater T, Furtney S. Leveraging near-peer and collaborative learning for a graduate student-led cell culture workshop. Biomed Eng Educ. 2024. https://doi.org/10.1007/s43683-023-00132-4.
9. Jaimes P, Bottorff E, Hopper T, Jilberto J, King J, Wall M, Pinder-Grover T. The IT-BME project: integrating inclusive teaching in biomedical engineering through faculty/graduate partnerships. Biomed Eng Educ. 2024. https://doi.org/10.1007/s43683-024-00137-7.
10. NSF Responsible and Ethical Conduct of Research https://www.nsf.gov/od/recr.jsp Accessed 21 March 2024.
11. NIH FY 2022 Updated guidance: requirement for instruction in the responsible conduct of research https://grants.nih.gov/grants/guide/notice-files/NOT-OD-22-055.html Accessed 21 March 2024.
12. Zylla JL, Bomgni AB, Sani RK, Subramaniam M, Lushbough C, Winter R, Gnimpieba EZ. Convergence research and training in computational bioengineering: a case study on AI/ML-driven biofilm–material interaction discovery. Biomed Eng Educ. 2024;20:1–12. https://doi.org/10.1007/s43683-024-00146-6.
13. Adamo JE, Keegan EL, Boger JW, Lerner AL. Just-in-time education of FDA regulation and protection of intellectual property for medical products: a course review after our first 10 years. Biomed Eng Educ. 2024. https://doi.org/10.1007/s43683-024-00134-w.
14. Casserly P, Dare A, Onuh J, Baah W, Taylor A. Leveraging an open-access digital design notebook for graduate biomedical engineering education in Nigeria. Biomed Eng Educ. 2024. https://doi.org/10.1007/s43683-024-00136-8.
15 Lechuga VM. Faculty-graduate student mentoring relationships: mentors' perceived roles and responsibilities. Higher Educ. 2011;62:757–71.