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TEACHING TIPS

A Practical Research Methods Course That Teaches How to Be a Successful Biomedical Engineering Graduate Student

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Abstract
Should your department offer a course on how to be a scientist and a successful graduate student? We offer this course at George Mason University as a mandatory part of the graduate curriculum, but this is not common practice for graduate biomedical engineering programs. Graduate education in biomedical engineering is evolving rapidly, with an increasing demand for fundamental research skills, interdisciplinary skills, and professional development. We believe that graduate students will be more successful in their research activities if they are explicitly taught these skills at the beginning of their graduate coursework. This paper describes the design of this course in our bioengineering department.

Keywords Research skills · Graduate curriculum · New graduate students · Scientific training · Professional development · Interdisciplinary skills

Challenge Statement

MS and PhD graduate students in biomedical engineering are often expected to conduct scientific research, including formulating hypotheses, conducting studies, and disseminating findings. For many, the pursuit of knowledge through rigorous research endeavors is not just a program requirement or stipulation for funding, but a profound opportunity to shape the future of healthcare, diagnostics, and medical technology. Although eager to participate, new graduate students may not yet know how to conduct scientific research, which includes the practical and logistical realities of working in a research lab and within an academic institution. Complicating this further, new graduate students also need to learn how to navigate the competing priorities and expectations of graduate student life, balancing coursework, teaching, outreach, and research while not losing sight of their own professional development to meet their goals. Students know that to become good researchers and contribute to the field during graduate school, it is essential that they quickly acquire and develop proficiencies in fundamental research skills and learn to navigate the demands of graduate school.

Where might a new student learn fundamental research skills and how to be a successful graduate student? Although considered a fundamental component of graduate training, the process of teaching research and professional skills (and which ones) is not consistent across departments, research labs, or cohorts of students. Students may not know which skills they should even be pursuing or do not realize the importance of pursuing them [1]. Even if students think they are knowledgeable enough, this opinion may not be shared by their research directors [1]. One way for graduate students to learn these critical skills is through direct mentorship with their research advisor. However, not all graduate students are provided an advisor (e.g., some master's programs), and not all advisors have the time, resources, or ability to teach their students the fundamentals of the research process, even if they want to. Some research advisors will take a more hands-on approach to teach their students some or all the necessary research skills, some advisors will delegate this to other lab members (i.e., peer learning), and some advisors will expect their students to learn the fundamentals elsewhere. In fact, professors tend to choose students who already have research experience [2]. Another mechanism for learning these skills can be through university resources, such as libraries, graduate student associations, and writing centers. Although they can provide helpful workshops

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and even one-on-one feedback, these mechanisms can still require that students take the initiative to seek out instruction on their own, with topics offered à la carte instead of as a comprehensive whole. However, some institutions are now trying to organize and coordinate workshops and trainings from the various campus centers and offices to form supportive networks to meet all the graduate student needs [1]. Another mechanism for learning research skills and how to be a successful graduate student can be through formal courses, which may teach these skills explicitly or implicitly alongside coursework for various topics in biomedical engineering. However, these classes might not be a required part of a graduate biomedical engineering curriculum, taken late in their graduate school career, or only focus on certain skills (e.g., how to teach [3]).

Complicating this further, the unspoken expectations for which party is responsible for teaching certain research and professional skills might also vary across departments, labs, and students. Some departments may be expecting their faculty to teach fundamental research skills to their mentored students, while some faculty may be expecting their department to prepare their students for conducting research. Some students might expect to learn these skills explicitly in their lab, but the lab does not have a system of mentorship in place or provide a trusted community of peers to teach best practices. Thus, there is a need for biomedical engineering education as a field to define consistent training opportunities that teach students how to be successful researchers and succeed in graduate school.

We believe that graduate students will be more successful in their research activities if they are explicitly taught the fundamental research skills at the beginning of their graduate coursework. This paper describes a mandatory course at George Mason University that teaches new graduate students in a bioengineering department how to be successful researchers and how to be successful in graduate school. We advocate for the adoption and development of similar courses in the field of biomedical engineering.

Novel Initiative

To address the challenge of preparing new graduate students to conduct research and succeed in graduate school, we developed and taught a graduate-level course titled "Bioengineering Research Methods." This course introduces students to the scientific research process and teaches the skills required for scientific research during their graduate studies. There is also a strong emphasis on the essential, transferrable skills they must develop in school (e.g., time management, communication, and interpersonal skills), as well as planning for their own professional development and living a fulfilling life (e.g., work-life balance, mental health, and finding a job after graduation). One of the major goals of the course is to help students optimize their time while in graduate school so that they take full advantage of the graduate experience and are prepared to reach their desired career goals. Unofficially, the course is referred to by students as "How to be a Scientist 101" and "How to be a graduate student in Bioengineering."

Course Design

A version of this course has been offered annually since 2017 but has undergone considerable refinement and development over the last two years to become the course presented in this paper. The 3-credit class meets once a week over 15 weeks, which is the standard duration of a semester at George Mason University. Over the last two years, course enrollment has grown from ~12 students to 25 students. The students are generally composed of MS and PhD students in their first two years as well as a few senior undergraduates. This class is a mandatory part of the bioengineering department curriculum for PhD students, and as such is mostly made up of students from the bioengineering department but occasionally receives students from other related engineering disciplines as well. The course is advertised that it is intended for new graduate students in the bioengineering department but is broadly applicable to a variety of scientific and engineering disciplines. Students with all levels of previous scientific training are welcome to participate in the course.

This course is meant to be practical and directly applicable to the needs of graduate students (Table 1) and thus the class is designed to provide a collegiate space for professional development and camaraderie [4]. To foster active participation and create a collaborative and engaging environment, chairs and tables are arranged in a circle so that students can see each other during group discussions [5]. The instructor is also seated in these circles, at the same eye level as the students [5]. When students enter the classroom, there is music playing — students

Table 1 Course learning objectives

Learning objectives
1. Create new knowledge through scientific research.
2. Assess knowledge presented within the scientific literature.
3. Interpret research data to support or refute hypotheses.
4. Write scientific manuscripts and proposals.
5. Effectively argue their research findings through writing and oral presentations.
6. Plan for their long-term professional development.
7. Navigate the demands of graduate school life.

know immediately this class will be different from a traditional engineering class! Music for each day is provided in advance by one of the students, providing a good way for students to get to know each other while also making the class environment more relatable and comfortable [6, 7]. This fun activity also reinforces a repeated theme of the course: Students should live a whole and balanced life and not spend their lives solely in pursuit of academic success.

Due to the practical nature of this course, activities and assignments use transparent teaching and learning methods [8, 9]. Using the Transparency in Learning and Teaching framework [10], the instructors can be very upfront as to why certain topics are or are not covered based on their experiences as active researchers and academics. They can also elucidate why course content is taught in a certain way, why the assignments/activities are relevant to the course, and how students will actually use the course material in their lives. The spirit of the class is not to give busywork or engage in unnecessary learning activities but to turn students into successful researchers and thrive in graduate school. In return for this transparent and practical instruction, students are expected to actively participate in all the class activities and discussions. To promote active engagement, a combination of lectures, active-learning strategies, interactive workshops, group discussions, and guest speaker sessions are employed. Assessment methods include individual and group assignments, oral presentations, and reflective essays. These assessments are designed not only to evaluate skill acquisition but also to encourage students to apply the concepts learned to their own research and academic journey [11].

A potentially controversial aspect of the course design is the approach to grading. Early in the course, students engage in reflective discussion on which would be most helpful for their personal growth: quantifiable grades from the instructor on submitted assignments or critical feedback throughout an assignment (from both peers and the instructor) that highlights what a student is doing right and steers them away from what they are doing wrong. Students have unanimously chosen the latter and in return have agreed to enthusiastically participate in their own learning process. Students receive a final course grade based on their course participation and their own self-assessment at the end of the semester. Through this approach, students have opportunities to take chances in class and make mistakes on assignments without worrying about hurting their grade point average. We acknowledge that this grading scheme would not fit every course but given the practical and accessible nature of the material we find it a good fit. However, we do caution students that if they take advantage of this grading scheme by coasting through the course in hopes for an easy A, they will not receive a stellar grade.

Course Content

The course content is generally divided into two categories: research skills and professional development as a graduate student (Table 2).

For research skills, topics include identifying a research question, reviewing scientific literature, formulating hypotheses, designing studies, statistically analyzing data, interpreting data to support or refute hypotheses, and effectively arguing research findings through written and oral presentations. It is important these topics are not taught in an abstract or hypothetical way, they must be grounded in the actual, day-to-day practices of experienced researchers. For example, when teaching students how to conduct a literature review, the instructor shows them the websites they personally use to search the literature (e.g., PubMed, Google Scholar), and how they organize their own PDFs in their reference software (e.g., Zotero, Mendeley). Students get to practice designing robust experiments (including designing alternative approaches to studies the instructor already conducted) and engage in a class discussion regarding the benefits and drawbacks of their various approaches. Statistical analyses are not focused on the formulas and abstract concepts that often accompany a statistics class. Instead, students are shown how to use statistical software (e.g., R, SPSS, Stata) to understand actual study data and interpret the significance of results. Actual manuscripts in progress and conference presentation drafts are shown to the class so they understand how real researchers start messy and then refine to polished and professional publications. To keep the topics grounded and practical, the instructor can also draw upon the experiences of other faculty and advanced graduate students to provide insight and best practices.

A major focus of the course is to teach scientific writing. Unlike traditional courses, where students write a paper by themselves and then the professor reads the final version, students engage in collaborative and iterative writing projects throughout the semester. Students co-create mock journal articles with other students based on their own research topics and get regular feedback as the manuscripts evolve with each draft. Like academic writing in practice, students learn how to write with co-authors and incorporate text changes using collaborative writing software (e.g., Microsoft Teams, Google Docs). Communal writing and accountability have been shown to help graduate students reduce feelings of isolation and meet their writing goals [12]. Writing assignments are scaffolded to encourage drafting, editing, and re-writing as separate and iterative stages. The course covers the drafting of original research articles (introduction, methods, results, discussion) and how to craft a compelling narrative to tell good research "stories." Sharing the craft of storytelling is crucial for teaching students to write strong manuscripts, make good arguments, and give compelling

Table 2 Example schedule of course content

Week	Lesson name	Topics to discuss
1	Introduction to course	Course expectations. Peer introductions.
	What is scientific research?	The research process. Difference between research and development. Valid research projects.
2	Research objectives	Difference between goals, objectives, and tasks. Writing specific aims.
	Research questions 1	Hypothesis testing. Writing a valid research question.
3	Research questions 2	Giving feedback on research goals, objectives, and approaches. Writing competitive objectives in grants.
	How to read a journal article	How to find scientific literature. Story structure of a journal article. Evaluating an article. Using a citation manager.
4	Be a healthy researcher	Work-life balance. Imposter syndrome. Fixed vs growth mindset. Mental health. Finding good mentors. Dealing with stress in graduate school.
	Scientific writing 1	Characteristics of good scientific writing. The writing process. Collaborative scientific writing. Seeking feedback on your writing. Making templates for articles. Writing introduction sections to ask research questions.
5	The business of academics	How a university is organized for research and education. Research from the PI perspective. Getting funds to run a research lab. How to pay for grad students & postdocs. Indirect costs. How research projects are chosen.
	Scientific writing 2	Re-writing and editing. Simplifying your message and cutting clutter. Give peer feedback on writing. The role of AI text generation.
6	Scientific writing 3	Feedback on draft introductions. Writing a discussion section to answer research questions.
	Forms of scientific writing	Journal articles. Review articles. Grants & proposals. Conducting peer review for journals. Structure of a thesis/dissertation.
7	Storytelling	Using story structure to guide writing and make arguments. How to tell a compelling scientific story.
	Strategic messaging	Crafting a story to meet a communication goal and appeal to a target audience. Simplifying your message.
8	Job searching while in graduate school	Networking as a tool to find desired industries, companies, and roles. Hiring from an employer's perspective. Reaching out on LinkedIn. Job search strategies.
	Informational interviews	Best practices & etiquette. Asking great interview questions. Seeking referrals for more people to speak with. Maintaining your network.
9	Interpreting data & results	Role of interpretation in the research process. Data does not speak for itself. Ethics of manipulating data to influence interpretation. Safeguarding against misleading data. Research bias & conflicts of interest.
	Study design 1	Quantitative vs qualitative research. Experimental factors & outcome measures. Confounding variables. Assumptions & limitations. Randomization. Navigating the IRB approval process.
10	Study design 2	Randomized controlled trials, cohort studies, case–control studies, and case reports. How study design affects the quality of evidence. Cross-sectional and longitudinal studies. Factorial designs. Between-subjects vs within-subjects factors.
	Statistical thinking 1	Representations of observed data. Types of distributions. P-values and statistical significance. Statistical power & analysis.
11	Statistical thinking 2	Which statistical tests you should use to answer your research questions. Using statistical software to conduct descriptive & inferential statistics. Associations & predictions. Group differences. Non-parametric statistical tests.
	CVs vs Resumes	Plan for updating CV during your career. Drafting guidelines.
12	Statistical thinking 3	Repeated measures ANOVAs. Two-way ANOVAs. Interpreting main effects and interaction effects.
	Scientific posters & presentations	Best practices for poster and slide design. Creating reusable templates. Making posters to effectively teach an audience. Storytelling with slides. Plans for improving your designs.
13	Making publication-worthy figures	Vector vs raster graphics. Using a vector graphics editor to make compelling diagrams, schematics, and plots. Cleaning up & polishing generated plots of data. Annotating figures and indicating statistical significance.
	Managing your projects	Treating graduate school as a full-time job. Optimizing check-ins with research advisor. Planning your work week and being responsible for your time.
14	Communication	Email best practices. Maintaining a calendar & sending calendar invites. Scheduling & running group meetings. Agendas and action items. Advocating for yourself & learning to say no.

Table 2 (continued)

Week	Lesson name	Topics to discuss
	Working in a research lab	Managing your manager. Setting a lab culture. Mentoring. Importance of outreach & service. Navigating interpersonal conflicts. Strategically choosing your dissertation committee.
15	Next steps after a PhD	Surviving in a research career. Why continue as a postdoc or research scientist. Obtaining a faculty position at a university. Process of getting tenure.
	Course review & debrief	How to continue developing skills. Getting the most out of your graduate school experience. Developing your identity as a PhD.

An example schedule of content covered during a semester is provided as an example, but the content of the course should be tailored to meet the needs of the students in the class. Professional development and research topics can be omitted, rearranged, or added to provide the student with the most relevant content based on their goals.

presentations. Telling clear, concise, and impactful stories also form the narrative backbone of writing grant proposals, also introduced in the course.

In tandem with scientific writing, visual communication is also emphasized in the course. Students get to practice making beautiful and impactful figures for use in their publications. Grounded in real-world publishing experiences, the instructor teaches students to use vector graphics editors (e.g., Adobe Illustrator, Inkscape) to clean up and refine figures generated during data analysis from statistical software. Students also learn to use this software to create publication-worthy flowcharts, diagrams, and annotated images that best communicate their research activities. Students also learn to craft clean and impactful presentation slides and regularly give short (i.e., 1–2 min) presentations throughout the semester to practice their storytelling and get feedback on their visual and oral presentation skills.

Students also learn about the realities of conducting scientific research in the academy. There are political and administrative obstacles unique to any department that senior faculty can explain. Students can learn how to prepare and submit protocols for ethical approval of human subjects research, a paperwork process unique to each institution. A helpful topic for students to learn is the business of academics, and why professors must constantly be writing grants to continue their research program and fund their students. This helps clear up common misconceptions from new graduate students who might naively think they can show up and engage in whatever research project they want when they are actually less aware of the funding, space, and time constraints behind real-world scientific research. Students are also taught how to advance through academic positions, moving from graduate student to postdoc to assistant professor and securing tenure [13].

Course content regarding professional development is focused on providing students with the essential, transferrable skills necessary to be successful in graduate school and enter the modern workforce. Because the needs of individual students will vary and it is not feasible to address every professional development topic in class, an important aspect of the course is teaching new graduate students how to be responsible for their own growth and acquisition of professional skills [14, 15]. Early in the course, students are tasked with assessing their current research skills, career interests, and values (e.g., using https://myidp.sciencecareers.org) so that they can form a strategic plan that maps out the key steps, skills, and knowledge they need to acquire during graduate school and eventual career (i.e., an Individual Development Plan). This strategic plan helps students decide who they are today, who they want to be (e.g., in 5, 10, 20 years), and what they need to do to get there. Strategic planning is an essential activity to becoming a successful graduate student [14]. It is okay if students do not know all the details because their strategic plan is a living document that will be adapted as they progress through graduate school. It also helps them keep an open mind and be willing to incorporate new milestones. The strategic plan assignment is scaffolded throughout the semester (Fig. 1). Students are to discuss their initial drafts with their faculty advisor and at least two senior graduate students and then update their plans based on the feedback they receive. After the semester is half over, students will revise their plans after completing informational interviews with at least three working professionals, strategically chosen based on their individual career goals. By the end of the semester, students then discuss their latest strategic plan with the course instructor before submitting it as a final course deliverable. Ultimately, the goal of the strategic plan assignment is to help students optimize their time while in graduate school so that they seek out and participate in the activities that help them reach their career goals. This is helpful because students often do not realize the opportunities they should be taking in graduate school and could regret not taking advantage of them sooner. For example, if a student aspires to be a professor they must develop a skill for teaching, which is not necessarily a standard part of a biomedical engineering curriculum. However, because they have carefully considered their professional development as part of their strategic plan, this student can strategically choose

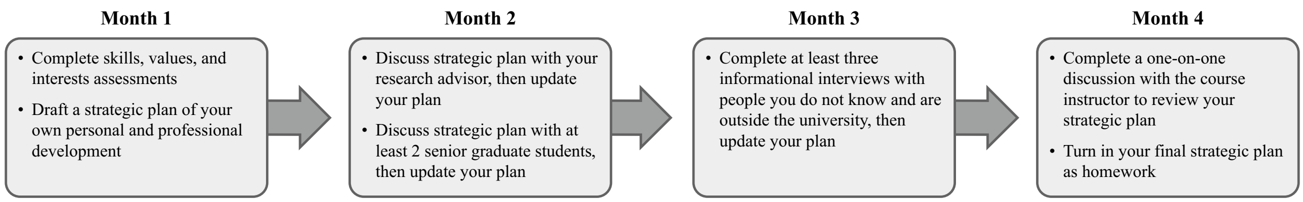

Fig. 1 Timeline for the srategic planning assignment. A strategic plan maps out the key steps, skills, and knowledge that a student needs to acquire during graduate school and eventual career. It answers the questions: Who are you today? Who do you want to be? What skills/experiences/careers will get you there?

extracurricular courses and university workshops to build up this skill early and throughout graduate school so that they are prepared and qualified to teach as a professor in their career. Through this strategic plan assignment, students become the architects of their own careers.

The professional development topics explicitly covered in the course will be chosen based on the needs of the current students [16]. By completing the skills assessment early in the course, the class can determine which topics are most relevant to cover in class that year. Through this process, students become co-designers in the course curriculum and take an increased interest in their own education [14, 17, 18]. Selected topics have included many basic transferrable skills, such as time management, project management, public speaking, crafting emails, and running meetings, but students have also chosen topics more related to their graduate school experiences, such as dealing with toxic advisors, publication ethics, finding work-life balance during school, advocating for yourself when talking to authority figures, and considerations for managing mental health.

Teaching students how to find a job through networking is another key professional development topic taught in the course. By building a professional network through references and informational interviews, students are taught the best practices to not just find *any* job, but find *the* job that best aligns with their career interests by exploring potential career paths and job market trends. This content is reflected in the scaffolding of the strategic plan assignment, which requires informational interviews to help students plan their careers.

Reflection

This Bioengineering Research Methods course was designed to introduce foundational skills essential for thriving in the dynamic field of biomedical engineering and prepare students for their professional careers. This course is well aligned with graduate student recommendations for improving graduate school to prepare them for research careers, including providing regular feedback, structured opportunities to work with peers, and strategic planning to meet professional goals [4, 14, 19]. By focusing on the practical aspects of graduate student development, the class is transformed into an intentional learning community that brings students together almost like a cohort model of graduate student learning [20] (our department does not use a cohort model of graduate education [21]). Students learn to treat each other as colleagues who all engage in scientific research. This socialization encourages the pursuit of academic careers [22] and helps promote an identity shift to someone who creates knowledge and is resemblant of a PhD [18, 23, 24]. It also can help prepare the participating undergraduates for a graduate program [25].

This course is mandatory for bioengineering PhD students at George Mason University, but offering a class on “how to be a graduate student” or “how to be a scientist” does not appear to be common practice for graduate biomedical engineering programs [16, 26]. However, studies are finding that graduate students are eager for this type of in-person instruction [1, 4, 19, 27]. The reality is that stress is at the core of the modern graduate student experience, rooted in internal conflict (e.g., unrealized expectations, a sense of responsibility to others, compromised standards, and guilt) and made worse by conflicting demands [28, 29]. It is even harder for international graduate students who face additional personal and professional obstacles [28]. We hope this course offers students a holistic and comprehensive roadmap of the skills they need to acquire in graduate school, how to acquire them, how to thrive during their graduate education, and how to prepare for their future after graduate school.

Offering a course like this can help address disparities in access to previous research training and foster a more equitable learning environment [30, 31]. This course may be especially relevant for first-generation college students, international students, as well as for students whose undergraduate degree was not in biomedical engineering [32]. By assessing the unique needs and motivations of students early in the course, the curriculum topics can be tailored to overcome limitations in prior training and address possible barriers [33]. Some topics covered in the course might seem relatively simple (e.g., time management, email etiquette), but the students who have not yet learned the required skills for the professional workforce will be approaching graduate school with a disadvantage [15, 19]. This course attempts to democratize explicit research training, providing more students insight into the hidden curriculum of a graduate program [19, 34–36]. By making this course required as part of graduate training, this course provides a uniform and comprehensive experience for all students in our program, not just the ones who proactively seek out research training.

It is important for students to receive messaging that they can be living rich, fulfilling, and balanced lives while in graduate school [37]. The expectations for success are high [38], and academic role models may not set the most positive examples [39, 40]. It is crucial for students to recognize that their "real life" is happening now and not defer their desired life experiences until after their graduate training is over [41]. Graduate school can be approached like a full-time job, and they should expect to have a healthy work-life balance. This messaging can support students in meeting the demands of graduate school, and it is especially powerful to hear it from their professors. By investing in the holistic development of graduate students, a department can help create a more inclusive academic environment.

Students' perceptions of the course content and delivery were assessed through a post-course survey in 2022 and 2023 (Fig. 2). Of the students surveyed, 25% were enrolled in PhD programs, 53% were enrolled in master's programs, and 21% were senior undergraduates (N = 28). Most students strongly agreed (71%) that the course had helped prepare them to be scientific researchers. Nearly all students agreed (93%) that the course should be mandatory for all new graduate students. Student comments (below) also demonstrated the positive impact of the course.

- "I really appreciated the debriefs and strategic plan meetings, it helped boost my confidence and more clearly defined how I wanted to pursue graduate studies and a career in science."
- "This class really helped me from a mental standpoint. It helped me realize that the feelings and struggles I'm going through are normal and don't make me a bad grad student compared to my peers."
- "I really liked the way you organized the class. Thank you for taking the pressure off the students. Keep doing it this way please."
- "I wouldn't change a thing. This course was refreshing and engaging to be a part of compared to the typical bioengineering coursework."
- "I really appreciate how you asked us what we wanted to learn from the course and actually incorporated our suggestions."

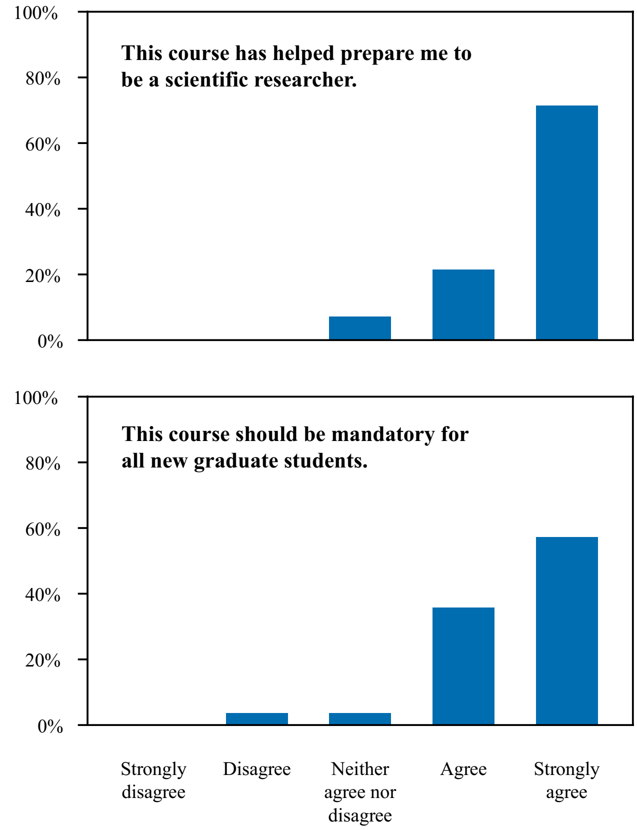

Fig. 2 Post-course anonymous survey results show that the course helped prepare students for scientific research and should be mandatory for new graduate students. Data were collected from courses taught in 2022 and 2023

- "As a first-year PhD student, this was the best time for me to take this class. It was very helpful as I started."

The major weakness of the course is that it is not feasible to cover every research skill and professional development topic. However, by tailoring the curriculum to the needs of the current students the instructor can attempt to make the biggest impact with the most relevant content. Students will obviously not master all the research skills during a single course, but at least students will be aware of the fundamental concepts and have made a strategic plan for their own development. This course also might be dependent on having an engaging and passionate instructor to deliver the content effectively. In less capable hands, it could be a very boring course that keeps topics abstract and not connected to the real-world experiences of researchers and the needs of the current students. Another potential weakness of this course is that to be effective, class sizes must be relatively small so that it fosters intimate discussions and allows the instructor to provide regular, quality feedback on student assignments. This might not be feasible with large class sizes (> 30) that often accompany the mandatory seminar courses taken by first-year graduate students. For class sizes of 10–15, a single instructor can feasibly provide targeted and substantial feedback for each student (especially on writing assignments) and students can engage the entire class for group activities (e.g., giving a speech to the entire class). For class sizes of 25–30, a single instructor will be limited in the amount of feedback they can give and will have to rely on students giving feedback to each other (e.g., as a homework assignment to provide comments on the writing of three of their classmates). Students will have to engage in small groups for most in-class activities (e.g., giving a speech to a group of students) and limit whole-class discussions (e.g., debriefing what was learned in groups). Enrollment priority should be given to PhD and master's students doing a thesis option because they require the student to conduct scientific research but is open to all graduate students and senior undergraduates. From the instructor's perspective, the course assumes everyone is a new PhD student and treats them as such—along with the assumption that each student is going through a multi-year graduate program and is invested in becoming a stellar scientific researcher.

For those interested in implementing a course like this, we have some recommendations based on our experiences. First, we recommend that the course be taken early in the graduate student's career and that the program curriculum should be structured to accommodate this. Second, we recommend this course be taught by younger faculty who still remember the struggles of the graduate school experience, which may help students identify with the advice being shared. Third, the course should provide practical instruction based heavily on a diverse set of lived experiences. Experienced guest speakers should supplement the core instruction, including senior faculty and industry professionals. Fourth, the course should leverage former students as part of the professional networking. Former students who are now working in industry will be assets in expanding the current student's professional network. Fifth, the instructor should see themselves as a lifelong mentor to these new graduate students and offer themselves as a student resource even after the class is concluded. This helps reinforce a collaborative and engaging research culture within the department and graduate program.

While traditional biomedical engineering curricula primarily focus on technical knowledge, the necessity for fundamental research skills, interdisciplinary skills, and professional development is becoming evident [19, 42]. The demands on graduate students in today's evolving scientific landscape extend beyond technical competencies. Successful researchers in academia and industry are expected to possess a diverse skillset encompassing effective communication, critical thinking, research methodology, and project management. Teaching students the skills to be successful researchers is not trivial, and we believe that integrating courses like ours into standard biomedical engineering graduate curricula could greatly impact the preparedness and success of biomedical engineering graduate students. By offering a course like this, a department can help manage the often unspoken expectations of who is responsible for teaching students to be successful graduate students and help prevent promising students from being left behind. There is a need to establish the students in our field with the proper tools to conduct their own research projects for their dissertation and to prevent frustration from having to figure out these skills on their own on a delayed timeline. We advocate for departments to adopt courses like ours to expose their students to skills and frameworks needed to be successful in research, which should supplement their learning in their own individual research labs.

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Declarations

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Consent for Publication Not applicable. The presented data does not constitute human subjects research as determined by the IRB of George Mason University and hence consent to publish is not applicable.

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