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TEACHING TIPS

Leveraging Near-Peer and Collaborative Learning for a Graduate Student-Led Cell Culture Workshop

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Abstract

Hands-on laboratory courses seldom appear in biomedical engineering (BME) graduate programs, thus limiting graduate students' ability to acquire wet laboratory skills like cell culturing. At large, BME graduate programs rely on ad hoc training provided by senior graduate students; however, this method cannot be extended to new or non-BME laboratories, which generally lack senior personnel adequately trained in cell culture techniques. This paper describes a graduate student-led, five-session workshop that introduces cell culture fundamentals to interested students with little to no prior experience. The workshop employs novel teaching techniques, such as near-peer and collaborative learning, to enhance students' understanding and knowledge retention. To demonstrate the effectiveness of this initiative, students assessed their confidence levels with concepts and skills related to cell culture via pre- and post-workshop surveys, where significant improvements in cell culture-related concepts and skills were reported upon completing the workshop. Finally, this paper presents some challenges and reflects on insight gained from this initiative, thus providing a template for implementation at other institutions interested in enriching their graduate student education.

Keywords Near-peer learning · Collaborative learning · Professional development · Graduate education · Workshop series · Cell culture

Challenge Statement

Graduate-level wet laboratory courses are rare. An examination of the 25 top-ranked graduate biomedical engineering (BME) programs (27 total schools) shows that only 7 provide graduate-level laboratory courses covering cell culture [1]. Central to the multidisciplinary study of BME is the acquisition of a vast array of skills, ranging from computational modeling to biomaterials development [2]. Among these proficiencies, cell culture takes a prominent place [3]. At the University of Florida, 60% percent of our incoming BME graduate students indicated a research interest in either "Biomaterials & Regenerative Medicine" or "Molecular & Cellular Engineering" from the six research areas as defined by the department's website. While these research areas commonly require a mastery of cell culture techniques, many new graduate students have limited cell culture experience and must address this deficit during the first year of their graduate studies. Historically in our program, this deficit was addressed by ad hoc training provided by senior graduate students from the first-year student's matched laboratory. Although this ad hoc method is used by programs across higher education for training new students in facilities, we identified limitations. For example, the onboarding process was not an option for newly established laboratories, which had no senior personnel, and did not engage our Master's student population. In addition, this practice could have potentiated improper technique since there were no standardized training protocols across labs. Therefore, we identified an opportunity to create a scalable professional development solution that was both accessible and standardized.

Here, we detail a student-led, five-session workshop that serves as an introduction to the fundamentals and techniques of cell culture for graduate students with little to no prior relevant experience. The workshop objectives are to (1) provide valuable experience in cell culture techniques to current BME graduate students to advance their skill set

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and (2) strengthen their applications to match into BME laboratories.

Novel Initiative

Despite overwhelming evidence on the benefits of active learning [4–6], a common method for content delivery to graduate students is still lecture-based courses [7]. However, skill-based boot camps are rising in popularity, especially in multidisciplinary fields such as BME [8–10]. These workshops engage students with hands-on learning experiences and fundamental laboratory skills while improving technical competence to assist students in gaining a competitive edge when looking for research positions or industry jobs post-graduation [11]. In addition, an intensive workshop traditionally requires less time and money to equip students with the necessary fundamentals, which increases the likelihood of student participation. Efforts to move towards active learning thus far have largely focused on the undergraduate curriculum. Currently, the University of Florida provides a semester-long Cellular Engineering Laboratory course that teaches BME undergraduate students the basic principles of cell culture; however, no such paradigm exists for the BME graduate program. To address this, we created a five-session workshop that targets graduate students seeking to increase their familiarity with cell culture fundamentals.

Workshop Organization and Content

The workshop was organized and led by two senior-level graduate students who will be identified as graduate student instructors in the context of this article. These individuals were responsible for developing the budget and syllabus, coordinating with department leadership for financial support, and collaborating with the graduate academic team to develop the curriculum of the workshop. Additional graduate student volunteers were recruited as teaching assistants (TAs) to assist during the hands-on portion of the workshop sessions. TAs were required to have experience in cell culture to volunteer. The workshop utilized equipment and lab space borrowed from the undergraduate Cellular Engineering Course, including 8 biosafety cabinets (BSCs), 2 incubators, 2 centrifuges, a water bath, pipet-aids, and micropipettes. Consumables were purchased with departmental support and a registration fee from each attendee.

The workshop covered a range of cell culture techniques including aseptic technique, cell thawing, feeding, passaging, seeding, and freezing. Each student cultured their own set of cells over the 2-week workshop, and each workshop session built on skills learned in the previous session. In addition to basic cell culture maintenance, the students completed basic immunocytochemistry staining and a metabolic assay with their cell cultures. A more detailed breakdown of the topics covered in each workshop session is included in the workshop syllabus (Supplemental Material 1).

Each 3.5-h long workshop session was divided into two sections: a lecture and a practicum. During the lecture, graduate student instructors covered the necessary information to complete the experimental protocols and provided additional scientific background on methods. After the lecture, students transitioned to the practicum, which is the hands-on portion of the workshop. The laboratory and general workflow are shown in Fig. 1. First, two working students completed the experimental protocol in full in the BSC, while two observing students examined their peers' work and provided constructive feedback on the working student's techniques. After the working student completed their experiment, the working student and the observing student switched roles, which allowed all four students to gain hands-on experience. One TA with prior expertise in cell culturing oversaw experiments for two BSCs. Using this ratio, the TAs were available to answer any lingering questions regarding lecture material or experimental techniques while critiquing the working student's technique to ensure proper safety without hindering the roles of the observing student.

Rooted in the principles of active learning, this initiative amalgamates near-peer guidance and collaborative learning to enhance knowledge retention and overall student satisfaction.

Near-Peer Mentorship

Near-peer mentorship refers to a teaching approach where a more experienced individual, referred to as a near-peer, facilitates the learning of their peers [12]. The advantages of near-peer learning include enhanced understanding, increased approachability, immediate feedback, peer-led

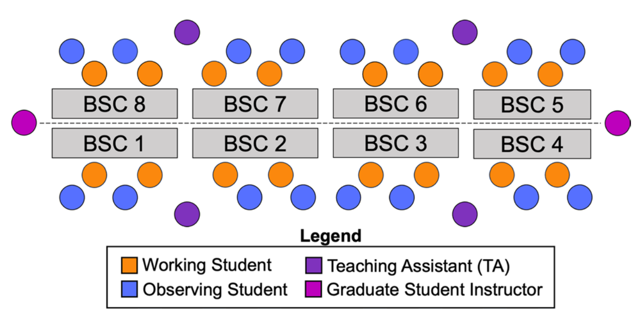

Fig. 1 Example classroom workflow for the hands-on portion of the graduate student cell culture workshop. The maximum capacity of this layout is 32 students

innovation, and cost-effectiveness [13]. Overall, near-peer learning leverages the power of peer connections and mutual understanding to create a supportive and effective learning experience. In this workshop, we utilized two instances of near-peer learning. As mentioned previously, we recruited a minimum of one student with previous cell culture experience to volunteer as TA for every eight students enrolled in the workshop. One drawback of near-peer mentorship is the lack of formal pedagogical training, which can result in the potential spreading of misconceptions. To combat this, the workshop utilized an additional two senior graduate student instructors who not only had a significant background in cell culturing but also had previously served as a TA for the undergraduate Cellular Engineering Laboratory. Being in a similar academic stage, the graduate student instructors create a comfortable space for TAs and enrolled students to seek guidance, ask questions, and discuss challenges.

Collaborative Learning

Collaborative learning involves students working together in groups to achieve common learning goals. It has been demonstrated that collaborative learning helps students retain information more thoroughly, deeply, and efficiently when compared to that done individually [14]. Through mentoring peers, students find new ways to articulate the research protocols as well as the purpose of each step in the process, which results in a deeper understanding of highly complex concepts [13, 15]. To facilitate collaborative learning, BSC groups were assigned based on pre-workshop self-assessment scores regarding laboratory confidence. This ensured that each BSC had students with varying laboratory confidence levels, allowing less confident students to learn from more experienced peers. While near-peer learning provides an opportunity for graduate student instructors and TAs to develop teaching and communication skills, collaborative learning allows for a student to receive constant feedback from peers on their technique and for groups to benefit from different confidence and experience levels of group members.

Demographics

To date, we have provided this professional development to three cohorts of participants. Briefly, we had 11 M.S., 10 Ph.D., and 1 post-doctoral student participate in 2020, 14 M.S., 10 Ph.D., and 1 senior undergraduate student in 2022, and 5 M.S. and 14 Ph.D. students in 2023. The majority of students enrolled were male, BME Ph.D. students. This workshop was originally designed to target graduate students in BME; however, students from other departments, such as chemical or mechanical and aerospace engineering enrolled due to the broad extent of cell culture applications (Fig. 2).

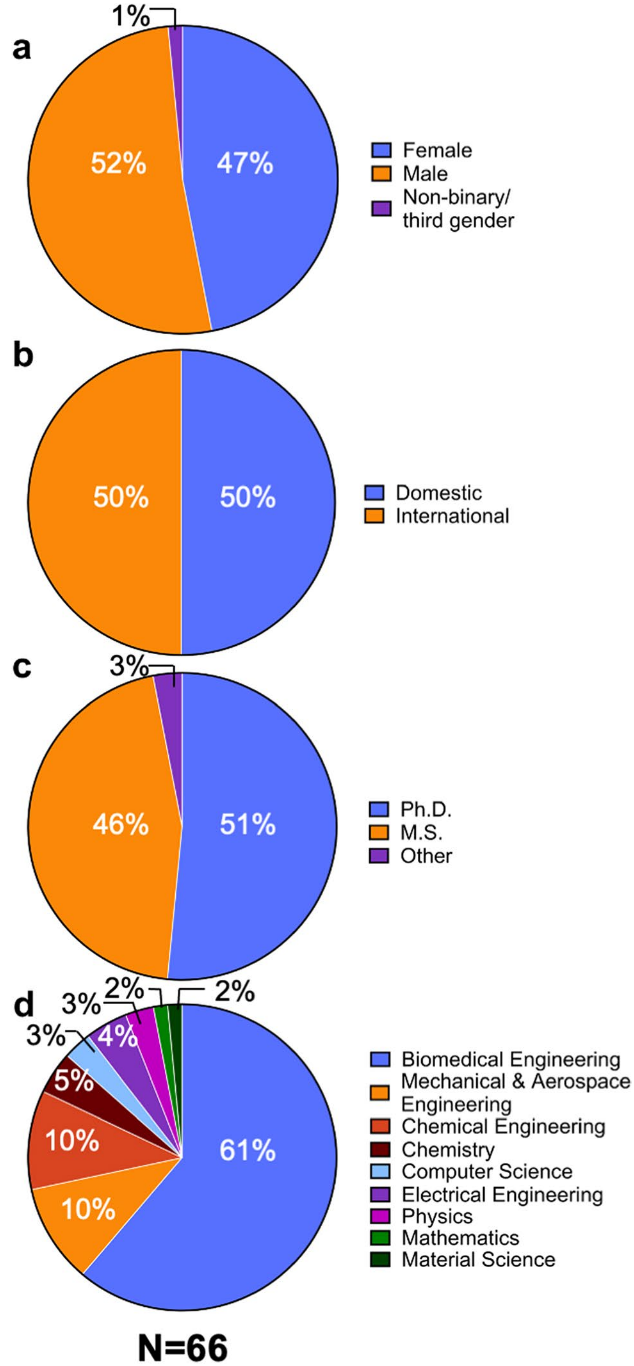

Fig. 2 Demographics of students enrolled in the Graduate Student Cell Culture Workshop. Distribution of enrolled students **a** gender, **b** residency status, **c** degree pursued, and **d** major

When asked why students wanted to take this workshop, a range of answers were received; however, themes such as improving knowledge, resume building, and developing good standard operating procedures were commonplace. Sample responses are shown from 10 students in Table 1.

Table 1 Representative responses from students who registered for the workshop when asked, "Why do you want to take this workshop?"

Why do you want to take this workshop?
"To learn basic cell culture techniques as I transition from dry lab to wet lab focus"
"I am potentially shifting to cell culture work in the lab, so prior familiarity would be nice and for resume building"
"To improve knowledge of cell techniques, particularly assays"
"The field of biomedical engineering is a wide variety of disciplines. As a biomedical engineer, I feel that it is important to learn as much as I can about the different aspects of the field so that I may better understand how everything works together. I currently do not have any experience working with cells, so I think this would be a good opportunity"
"To diversify my lab experience to wet labs"
"My undergraduate degree was in chemical engineering so as a first year Ph.D. student in biomedical engineering I am lacking these skills. My lab performs cell culture but many of the senior students are leaving within the next semester so I need additional practice to master these skills to be successful in my Ph.D."
"While I've done cell culture work before, I've never worked with mammalian cells or gone through official training. This course would help me learn the standard operating procedures in BME for cell culture work, which would help my research and make me more proficient in training my lab mates."
"My lab relies heavily on cell culture and I have very little practical experience"
"I want to learn more about cell culture and be able to develop good standard operating procedures for my starting lab"
"I would like to learn more about cell culture. I have never had the opportunity to learn about cell culture before, and I think it would help broaden my knowledge as a Masters student on lab work."

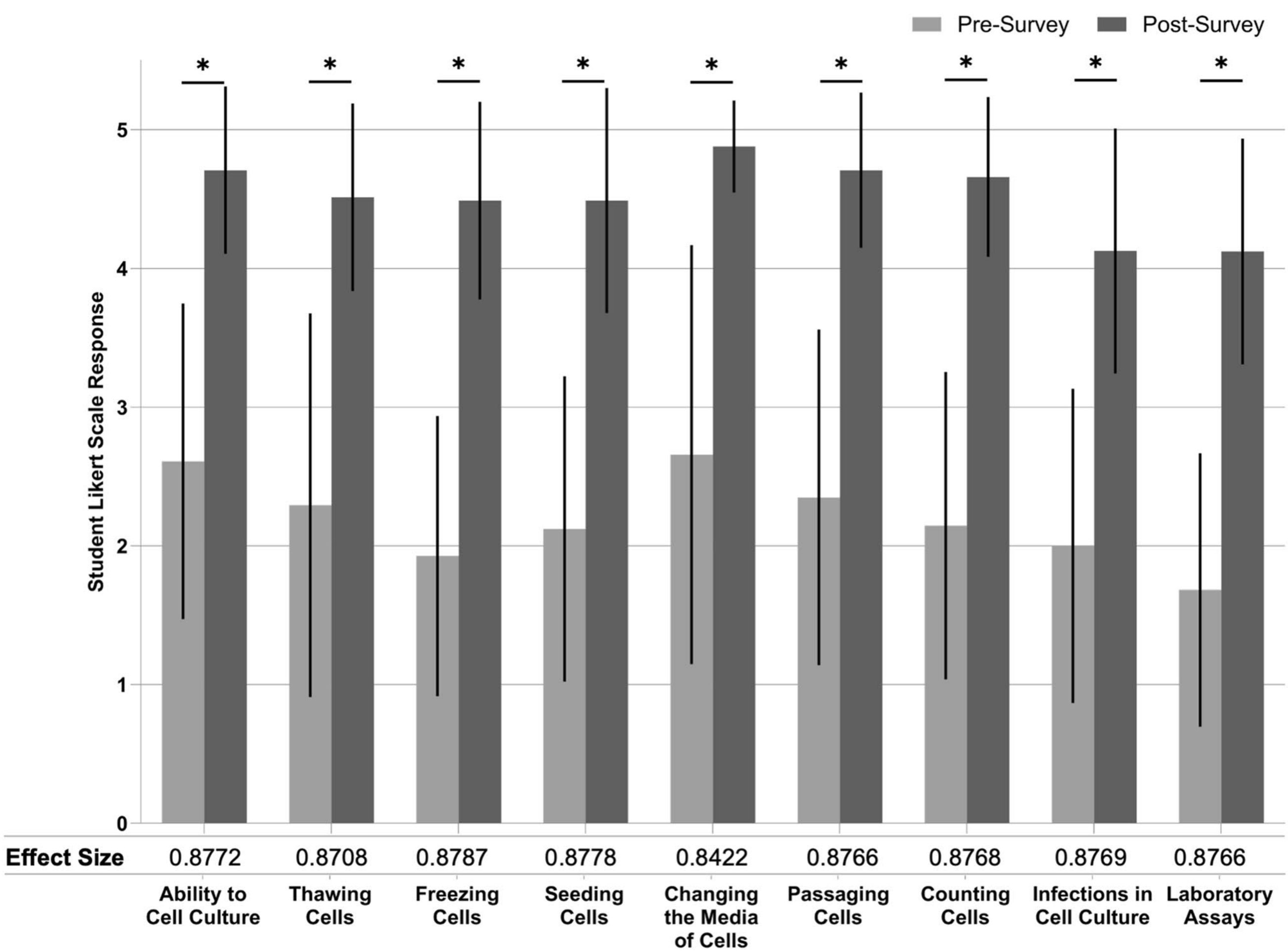

Fig. 3 Results of average student responses for pre- and post-surveys for cell culture-specific skills. Significance was determined using a paired samples Wilcoxon signed-rank test ($N = 41$, $*p < 0.0001$)

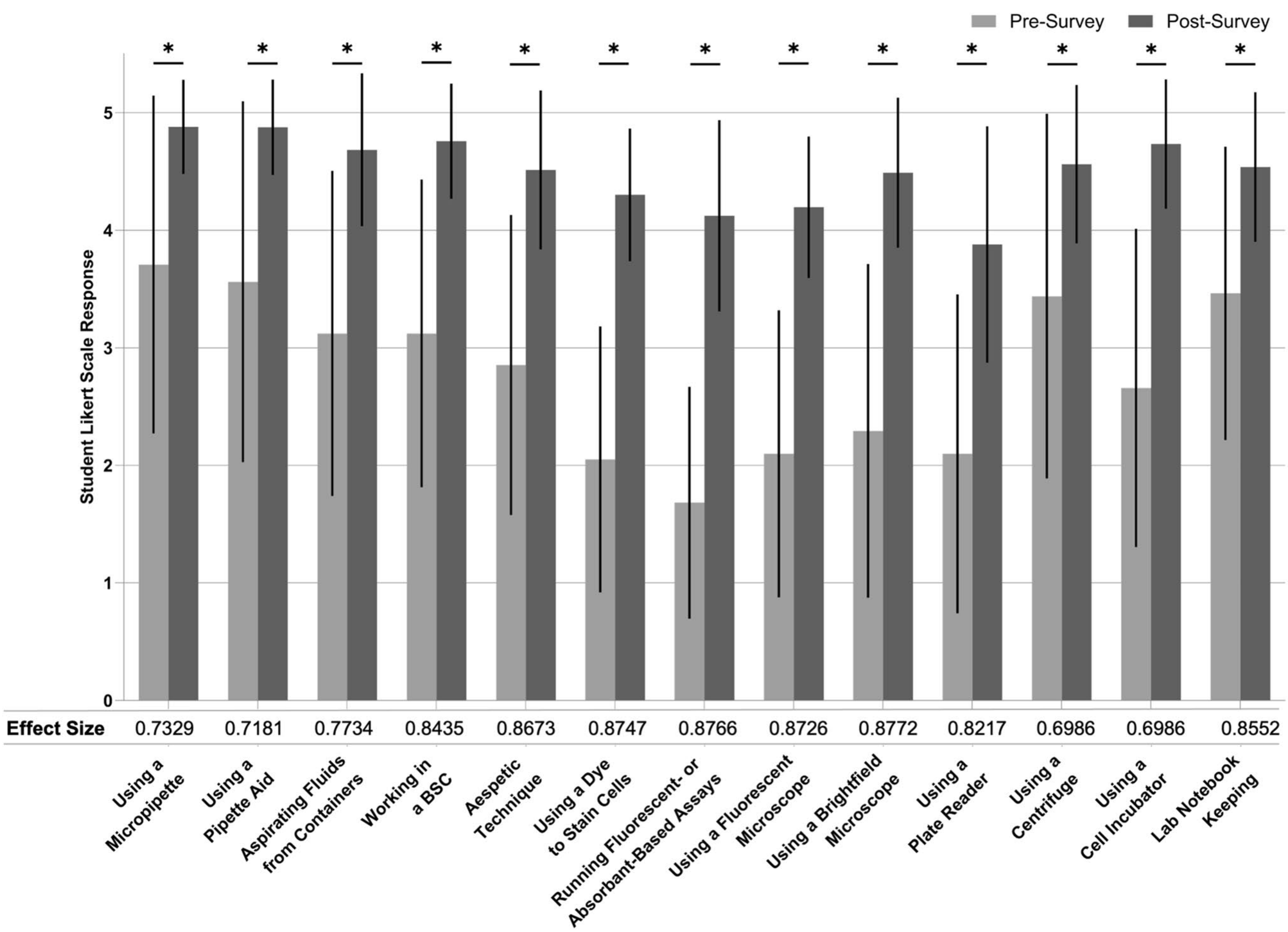

Fig. 4 Results of average student responses for pre- and post-surveys for other wet laboratory skills. Significance was determined using a paired samples Wilcoxon signed-rank test ($N = 41$, $*p < 0.0001$)

Assessment of Student Success

Learning outcome surveys were primarily used to evaluate the effectiveness of the workshop from cohorts 2 and 3. Pre- and post-learning surveys were administered online and contained a combination of open-ended and 5-point Likert-scale questions. Likert-scale questions probed students' confidence with skills and concepts related to cell culture. Qualitative questions asked the students for their perspective or opinion on the workshop (e.g., "Why did you take this workshop?", "Was this workshop a valuable experience for you, why/why not?", "Please provide feedback on what we could improve upon."). Data were analyzed only for students who completed both the pre- and post-learning surveys. All student responses were anonymous or de-identified.

After completing the workshop, students reported significant improvement in all cell culture- and wet-laboratory-related skills assessed (Figs. 3, 4). In addition to increasing laboratory skills, this workshop also bolstered students' confidence in laboratory safety and chemical and biological waste disposal (Fig. 5). These results quantitatively show the impact of leveraging near-peer and collaborative learning in a workshop series. Beyond increasing graduate students' cell culture competency, we also found that participants' confidence in instructing others on concepts learned in the workshop increased. Five participants from cohorts 1 and 2 returned as workshop TAs for future cohorts. While not directly measured, the impact of collaborative and near-peer learning was clear in post-survey follow-up questions. When asked "Was this workshop a valuable experience for you, why or why not?", student responses commonly cited the advantages of connecting with their peers and receiving individual feedback from instructors and TAs in a low-stress environment. Example responses from 10 students are shown in Table 2.

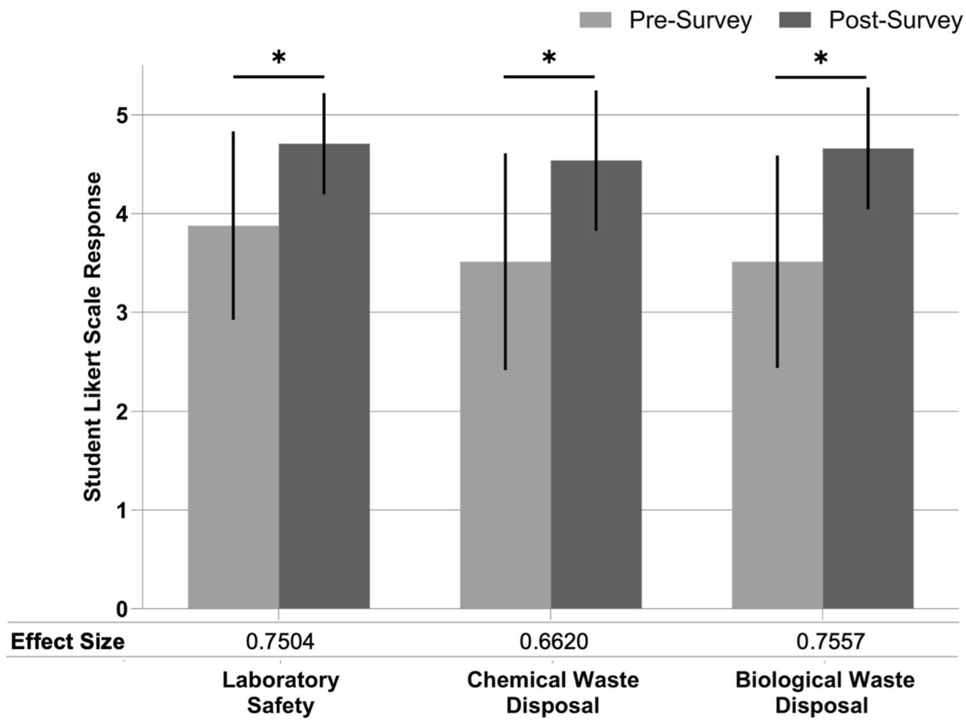

Fig. 5 Results of average student responses for pre- and post-surveys for general laboratory safety and waste management. Significance was determined using a paired samples Wilcoxon signed-rank test ($N = 41$, $*p < 0.0001$)

Table 2 Representative responses from students at the end of the workshop when asked, "Was this workshop a valuable experience for you, why/why not?"

Was this workshop a valuable experience for you, why/why not?
"This workshop was a gentle and fulfilling intro to cell culture. Performing cell culture in groups helped a lot since team members helped each other out with the steps and equipment"
"It definitely was. Cell culture always seemed like something extremely interesting but since it's not my field I never had the chance to learn until now"
"Yes! For one, I thought it was a great opportunity for me to connect with more of my BME peers. Second, it was valuable to get a refresher on key concepts of working on cell culture work that I can take into my lab"
"Yes. The teachers and TA spoke very well, were very patient and friendly, and helped to add a lot of useful experience. It was a very pleasant experience!"
"Definitely. Glad to learn more about the topic as I'm not in BME, so this was a great introduction to what the bio world of cell culturing looks like"
"Yes. I did have a lot of the skills already but it reinforced some gaps I had and the lecture portion did explain some of the things I just learned through experience"
"Yes, it was super helpful! This workshop solidified lab techniques I've learned but wasn't super comfortable in and it was great getting individual feedback from the TAs in a low-stress environment"
"Yes!!! It was a great hands-on way to learn about the process of cell culture and the reasoning behind the steps (which I mostly didn't know before this workshop)"
"Yes! I think I gained a lot of confidence in myself through this experience before I actually apply for jobs"
"This workshop was valuable to me as a refresher on cell culture techniques. I hadn't done cell cultures for a couple of years and this workshop gave me the confidence to start again"

Reflection

As instructors, from our vantage point, the most notable outcome of this workshop was building a community of students interested in cell culture-related research at the University level. Expanding enrollment to all graduate students, irrespective of their laboratory affiliation, facilitated greater accessibility to learning cell culture. This inclusive approach accommodated individuals interested in advancing either their professional development or research objectives. In addition, by employing standardized teaching practices for cell culture, students can better navigate learning a difficult skill and ensure more robust,

Table 3 Representative responses from students at the end of the workshop when asked to provide detailed feedback on what we could improve upon

Please provide detailed feedback on what we could improve upon
"Extend the timeframe or have it in 2 different labs so that there are more resources available and it can be conducted in the timeframe"
"I think maybe it's better to release the calculation tasks earlier, like before class so that we can do the calculations ahead of time"
"I think the workshop should be longer in weeks but less time for each session and do some more chemical assays"
"I think there could have been more consistency/unity in the procedures and techniques among the teaching team There were multiple moments where 2 TAs said slightly different things"
"A higher-level course offered for people that want to expand upon the things we learned"
"Maybe consider breaking the sessions up into two groups and have students go through the lecture slides the day before so that way students aren't standing around"
"Keep it the same The only area to improve upon is elaborating on 'how do you learn more from here'"
"For a 15-week course, I think it is fairly good More techniques and details could be added if there would be a longer workshop in the future"
"The lectures went a little long and having three people to a hood was very difficult, especially with the longer labs Sometimes the third person didn't start until 30 min before the workshop was over and they had to stay late It also was not fun to be finished with all the work and asked to stay so the last person could finish I would suggest using a bigger lab or limiting the class size"
"Some of the protocols could probably be broken up or something so that we aren't here for multiple hours without a break"

reliable, and reproducible results. Importantly, we believe the workshop will foster collaboration, knowledge sharing, networking, and professional development.

Although this workshop provided graduate students with the opportunity to learn the fundamentals of cell culture, the intensity of learning these skills in such a short period presented considerable challenges. To foster a low-stakes learning environment, the graduate student instructors employed self-reported surveys to assess the impact of the workshop. Although providing valuable insights into the students' perceptions, self-reported surveys may not reflect the actual skills gained. Incorporating objective assessments or external evaluations would further validate the impact of this workshop series, but it may deter student and TA enrollment due to the increased workload. To avoid conflict with class schedules, we elected to hold the sessions in the evening at the start of the Spring semester. While holding the sessions in the evening ensured the availability of the students, they generally did not enjoy having to stay late and were especially frustrated if a session ran over time. In addition, it can be difficult to maintain students' interest and willingness to learn for over 3 h, so an increased number of sessions with decreased session length may be advisable. Holding this initiative at the start of the Spring semester minimized conflict with course requirements that arise mid-semester and was more accessible to our first-year international student population who described the Fall semester as an overwhelming transition period. However, this timing does not engage first-year graduate students who need to learn cell culture upon arrival to perform research in their matched laboratory. Therefore, other institutions should carefully consider the timing of this workshop prior to implementation.

When providing anonymous feedback, students commonly requested either a semester-long course, with shorter sessions and more laboratory assays, or an additional workshop series that expands upon the fundamentals learned and addresses the question, "How do you learn more from here?" (Table 3). The availability of resources is also a limitation of this professional development series. To maintain a ratio of four students to one BSC, we are limited by the number of BSCs available. As such, the current capacity for this initiative is 32 students. To scale up this course, we would need both increased space and funds for more BSCs or we would need to offer the workshop multiple times a year. In addition, this workshop is currently run solely by graduate student instructors and TAs who volunteer their time. Near-peers have their own academic commitments and thus have a limited amount of time that they can dedicate to facilitating the learning of the workshop participants. Therefore, it may be necessary to provide compensation to expand upon the graduate student cell culture workshop.

Overall, we found that implementing a graduate student-focused hands-on workshop series not only increased the accessibility of complex skills like cell culture to all graduate students but also provided graduate students with the opportunity to build community and gain more experience disseminating their knowledge in a low-stakes environment. The education framework and materials provided (Supplementary Materials 1–4) make this initiative easily adaptable for other institutions seeking to enrich the teaching of BME-related skills to their graduate students.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s43683-023-00132-4.

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Author Contributions All authors contributed to the study conception and design. Material preparation and data collection were performed by MD, SL, MT, TY, and SF and data analysis was performed by SL.

The first draft of the manuscript was written by SL and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data Availability Course materials, including protocols and lectures, are available upon request.

Code Availability Not applicable.

Declarations

Conflict of interest The authors do not have conflicts of interest to declare.

Ethical Approval The University of Florida Institutional Review Board (IRB) determined that the study and student data are not subject to IRB approval.

Consent to Participate Not applicable.

Consent for Publication Not applicable.

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