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A introductory-level, student-taught biomedical neuroengineering course for 1st year undeclared engineering undergraduate students

Nyota Prakash Patel, University of Virginia
Deepika Sahoo, University of Virginia
Dr. Shannon Barker, University of Virginia

Dr. Shannon Barker is an Associate Professor and Undergraduate Program Director at UVA BME

Background and Motivation

Engineers are required to conceive, design, and maintain products, processes, and systems across many sectors to meet societal needs [1]. Projects often require training in fundamentals and across disciplines [2]. Engineering curriculums typically well-incorporate fundamental instruction through required introductory applied mathematics, physics, chemistry, computer science, and engineering design coursework. However, exposure to multiple disciplines is often overlooked in the process of developing engineering curriculums [3-5]. Given that major selection is typically done in students' first and second years [6-11], sufficient exposure to research, career/internship, alumni/professional experiences, and ethical/social insights is especially important early in college. This will enable students to better choose majors/careers that align with their interests and aptitudes [12-13]. Engineers stand to acquire many benefits from an interdisciplinary education, including a more comprehensive perspective on career options, stronger collaboration skills, and improved problem-solving abilities [2, 14].

Neuroengineering is an interdisciplinary field that applies engineering techniques to understand, repair, or enhance neural systems [15]. Brain-computer interfaces facilitate brain-device communication, helping restore lost sensory functions [16]. Neurostimulation devices activate specific nerves/brain areas, aiding patients with conditions like epilepsy or Parkinson's disease [17-18]. Neuroimaging allows for deep study of brain structure/function [19]. Given the potential of such neuroengineering technologies, it is critical for Biomedical Engineering (BME) curricula to incorporate its study.

In addition to introducing the neuroengineering subdiscipline, BME classrooms may also benefit from adopting a student-led learning approach. Student-led learning has grown more popular in higher education, with several peer-teaching models implemented outside of the classroom [20]. Models include student-led discussions, student learning groups, and the learning cell [21-23]. Peer-teaching models have demonstrated benefits for both the instructor and learners by increasing active participation, social interaction, and cooperation in the classroom [20].

This work describes learning outcomes of students enrolled in a 1-credit pass/fail student-taught introductory BME course, Innovations in Neuroscience, that aims to expose students to research and clinical technologies in neuroengineering, academic/career opportunities, and team-based neuroengineering device design. Our research questions are as follows:

1. Do introductory-level, student-taught courses contribute to an improved sense of academic confidence and understanding among students?
2. What changes, if any, occurred in broader engineering-based social/ethical/design understanding and academic competencies acquired among students?
3. Does introducing guest-lecturers into the curriculum improve students' major/career confidence?

Methods: Course Design and Structure

In the Fall 2023 semester, this course was offered to University of Virginia undergraduates for the first time, with the study conducted among solely the 20 students enrolled in that semester. This course introduces basic neuroscience and engineering-based technologies/methods used for brain study and treatment. The course learning objectives and topics are shown in Appendix Tables 1 and 2. Student and faculty instructor support arrangements are included in Appendix A.

Instructor-Led and Guest Lectures: Each instructor-led lecture presented a course topic and relevant physiological background, current state of research/design, clinical examples, social/ethical implications, and small-group and whole-class discussion. During discussion, participants were presented with a hypothetical case study or mock patient case to gauge their understanding of the material and prompt deeper thought. For hypothetical scenarios, students discussed ethical dilemmas, regulatory frameworks, and equity in healthcare, while mock patient cases required students to propose a diagnosis and treatment plan for a patient based on given symptoms. An example of a case study is shown in Appendix B [24]. Supplementing instructor-led lectures, the course welcomed 4 guest speakers who presented about their respective academic/career work (Appendix Table 3). These guest lectures facilitated student networking with professionals and exposure to diverse neuroengineering career paths.

Assignments and Final Project: To pass this course, students were expected to attend class, complete required assignments, and deliver a final presentation (see Appendix Table 4 for details). For this presentation, the class was divided into 4 groups of 5 students based on students' team-member preference as indicated by an online survey. The project goal was to introduce students to technical and non-technical factors associated with device design and use.

Methods: Assessment

This study occurred in the Fall 2023 semester at the University of Virginia and was performed with full Institutional Review Board (IRB) approval (protocol #3937). The study employed both qualitative and quantitative metrics. The qualitative metric used were assigned discussion questions. The quantitative metric was a pre/post survey conducted at the semester start and end. This survey included 18 Likert scale questions, 9 of which measured students' understanding of various neuroscience concepts, and 9 other questions to assess students' comfort level with engineering competencies and soft skills. 27 participants completed the pre-semester survey, while 12 participants completed the post-semester survey. After the add/drop deadline, a total of 20 students were enrolled in the Fall 2023 semester and student data is shown in Appendix C.

Data Analysis: A statistical test was conducted with Likert scale responses from the survey results. The Likert scale used in this study indicated a student's comfort level with a certain topic or competency, and each option was assigned a numerical value between 1-5, see Appendix Table 5 for more details. Based on student responses, the average for each Likert scale question was calculated, and two-tailed t-tests with 95% confidence interval value were conducted to determine whether results were statistically significant. For the qualitative data, student responses to the discussion questions were analyzed through inductive coding to extract insights.

Results

Class effects on students' comfort level with neuroengineering technologies and concepts: To address research question 1, we assessed for changes pre- and post-semester in students' comfort level with neuroengineering concepts. Likert scale response options and their assigned scores are shown in Appendix Table 5. For neuroengineering concepts, all categories demonstrated significant differences between pre- and post-semester survey responses (Appendix D).

Class effects on students' comfort level with general engineering, social and ethical issues, and academic and classroom skills: To address research question 2, we assessed for changes pre- and post-semester in students' comfort level with general engineering competencies and soft skills. Likert scale response options and their assigned scores are shown in Appendix Table 5. For engineering competencies and soft skills, statistically significant results were only seen for reading scientific literature between pre- and post-semester responses (Appendices E and F).

Guest lectures effect on student interest/understanding of engineering research/career opportunities: To address research question 3, we assessed open-ended responses to questions that attempted to discern the impact of the guest-lectures on participants' career and academic interests (Appendix G). When students were asked what they enjoyed the most about the guest lectures, an inductive coding analysis revealed that a large majority learned more about different career paths, acquired more career confidence, and better understood neuroengineering concepts (Appendix Table 6). Examples of student responses are shown in Appendix Table 7.

Discussion

Results suggest that this student-taught, introductory engineering course effectively teaches early engineering students topics in neuroengineering. Further, exposure to industry and research professionals through guest lectures positively impacts students' academic development. Future studies will ascertain if these outcomes extend to other engineering subdisciplines [25-26].

Limitations: This study operated during the Fall 2023 semester across a single cohort of students, offering a limited data pool. It employed self-report Likert scales to assess participants' understanding of neuroscience topics and their comfort level with engineering skills. Although the Likert scale provides useful information about a participant's confidence, the use of this subjective scale along with students' varying interpretations of the phrase "comfort level" can make it challenging to accurately assess their responses. Further, surveys did not inquire about students' major/career interests, making it challenging to draw full conclusions about how the course affected student choices. Additionally, inconsistent survey responses due to students who dropped the course before the add/drop deadline may have also affected the results accuracy.

Future Work: Survey approaches can be modified to improve assessment. Questions evaluating students' sense of academic-identity and community-belonging can be incorporated into future surveys to help determine the extent to which this course may affect student integration into academic environments. To better assess long-term effects on major/career interests and choices, a post-hoc survey can be administered among the participant cohort for retrospective analysis. To better interpret survey results, scenario-based assessment techniques can be used to determine how students would approach solving a hypothetical problem, and their responses would be assessed based on an analytic rubric [27]. Additionally, to reduce variability going forward, the pre-semester survey can be released after the add/drop deadline and surveys can be required for all students. In the classroom, to improve outcomes in academic/engineering competencies, we will assign 1-3 readings focused on ethical issues and product design prior to each class. In the future, to emphasize study of relevant policy frameworks, the course's final project will include a component focused on Food and Drug Administration regulation of medical technologies. Lastly, we will implement online discussion boards to help foster connections between students [28].

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APPENDIX

Table 1: The Learning Objectives for BME 1501: Innovations in Neuroscience

1. Learn and effectively communicate fundamental knowledge and concepts in neuroscience
2. Apply principles/concepts in biomedical engineering to neuroscience research and associated clinical fields
3. Learn about the professional opportunities and the research/development process as it relates to the fields of neuroscience and biomedical engineering
4. Understand the ethical and social implications of technological developments

Table 2: Course Topics for BME 1501: Innovations in Neuroscience

1. Brain Imaging Methods
2. Sensory Neuroprosthetics and Brain-Computer Interface Devices
3. Optogenetics for Brain Mapping and Controlling Neuronal Activity
4. Deep Brain Stimulation in Parkinson's Disease and Essential Tremors
5. Psychiatric medications
6. Electroencephalograms
7. Sleep-research technologies

Appendix A: Student and Faculty Instructor Fall 2023 Support Protocols

<u>Student Support</u>

Several forms of student support were made available throughout the semester, including real-time lectures and weekly office hours. The instructors' emails and phone numbers were also provided, to enable students to easily inquire about course content/assignments, opportunities in different fields of engineering and research, and enrollment in future classes. Students were consistently verbally encouraged to contact instructors with any questions or concerns.

<u>Instructor Support</u>

In order to acquire course approval, student-instructors were expected to have a designated faculty advisor. A faculty member and professor within the BMEbiomedical engineering department was asked and consented to serve as the course advisor. The student-instructors met throughout the Fall 2023 semester with the faculty advisor while teaching the course. Prior to the start of the semester, a meeting was held to discuss course/teaching plans, teaching strategies, possible revisions to course content, and advice for classroom management. As the semester progressed, meetings were held to discuss class progress/updates, scheduling, and any improvements that could be made. The student instructors and faculty advisor were in contact throughout the semester via in-person meetings and email correspondence. At the end of the semester, a meeting was held to discuss feedback received from the class, ways to improve the course and any other relevant information. While the student-instructors graded class assignments, the faculty advisor performed the final export of grades to the Student Information System (SIS).

Appendix B: An example of a case study with discussion questions that was presented to students during a lecture on deep brain stimulation [18].

7 years ago, President Jones disclosed to the nation that he was diagnosed with mild early Parkinson's Disease. During his second term, his tremors and symptoms progressively worsened. Medications started to become less effective. His doctors recommended deep brain stimulation (DBS) for treatment and informed him that this procedure can be performed without informing the media. His wife supports this treatment because she is worried about the stigma associated with Parkinson's Disease and the effect it can have on his legacy as a strong leader. The White House officials are adamantly opposed to DBS, citing security issues.

1. What are some security concerns that could arise if the President underwent DBS?
2. Should the President have to disclose whether he is getting a DBS? Why or why not?
3. Sometimes DBS can have side effects, such as depression or obsessive behavior (e.g., gambling). Does this change your view of whether the President should be allowed to get DBS treatment? Does it change your view of what the President should have to disclose to the public?
4. What if Jones was not the President but instead a pilot or a neurosurgeon or a truck driver. Should he undergo DBS? Can one's profession and the responsibilities and influences associated with the profession influence whether one can get DBS?

Table 3: An Overview of Guest Speakers and their Lecture Topics

Guest Speaker	Academic/Professional Role	Lecture Topics	Week Number
William Levy, Ph.D.	• Professor, University of Virginia School of Medicine Department of Neurological Surgery • Course Instructor for BME 3636: Neural Network Models of Cognition and Brain Computation	• Computational theories of brain function • Research in computational biology and neuroscience (specifically, computational simulations of the hippocampus and associated cortical regions) • Neural basis of cognition	Week 5
Rick Hamilton	• Chief Technology Officer at the Focused Ultrasound (FUS) Foundation	• Experience working at Fortune 50 organizations • Cloud computing, the Internet of Things (IoT), artificial intelligence, machine learning, blockchain, and intellectual property • Machine Learning and Data Science in FUS research	Week 8
Natasha Sheybani, Ph.D.	• Assistant Professor of Biomedical Engineering • Assistant Professor of Neurosurgery (by courtesy) • Assistant Professor of Radiology & Medical Imaging (by courtesy) • Research Director of the UVA Focused Ultrasound Cancer Immunotherapy Center	• Image-guided therapies (primarily FUS) for immuno-modulation and immunotherapy delivery in solid brain and peripheral cancers • Systems biology • Imaging informatics	Week 10
Katheryn Chun	• Fourth-year Student at University of Virginia School of Medicine	• Clinical Neurology and Neuroradiology • Clinical stroke case studies (including review of clinical background, analysis of radiograph images, determining clinical diagnosis, devising treatment plan) • Pre-Health and Medical School Experience	Week 11

Table 4: Assignment Distribution Breakdown for BME 1501: Innovations in Neuroscience

Assignment	Weight (%)	Details
Pre-Semester Survey	2.5%	• Students completed a survey at the start of the semester, which asked questions regarding their understanding of neuroscience concepts and their comfort level with engineering competencies and soft skills.
Post-Semester Survey	5.0 %	• At the end of the semester, students completed the same survey as from the start of the semester so that we can determine how their understanding and comfort level changed throughout the semester.
Discussion Questions	20%	• On a bi-weekly basis, each student completed an assignment that consisted of 3 to 4 short discussion questions. • These questions delved into the engineering and societal implications of different innovations within neuroscience. • Additionally, participants were asked to identify what aspects of the guest speakers' lectures they found the most engaging.
Attendance	22.5%	• Students were expected to attend lectures and participate in class; however, they did receive up to three excused absences.
Final Project	50%	• Students were required to give a PowerPoint presentation to the class. This presentation should not exceed 10 minutes and should cover the following components: o Limitations of previous technology (15 points) o Description of innovation (15 points) o Significance and implications of the technology (15 points) o Citations (5 points)

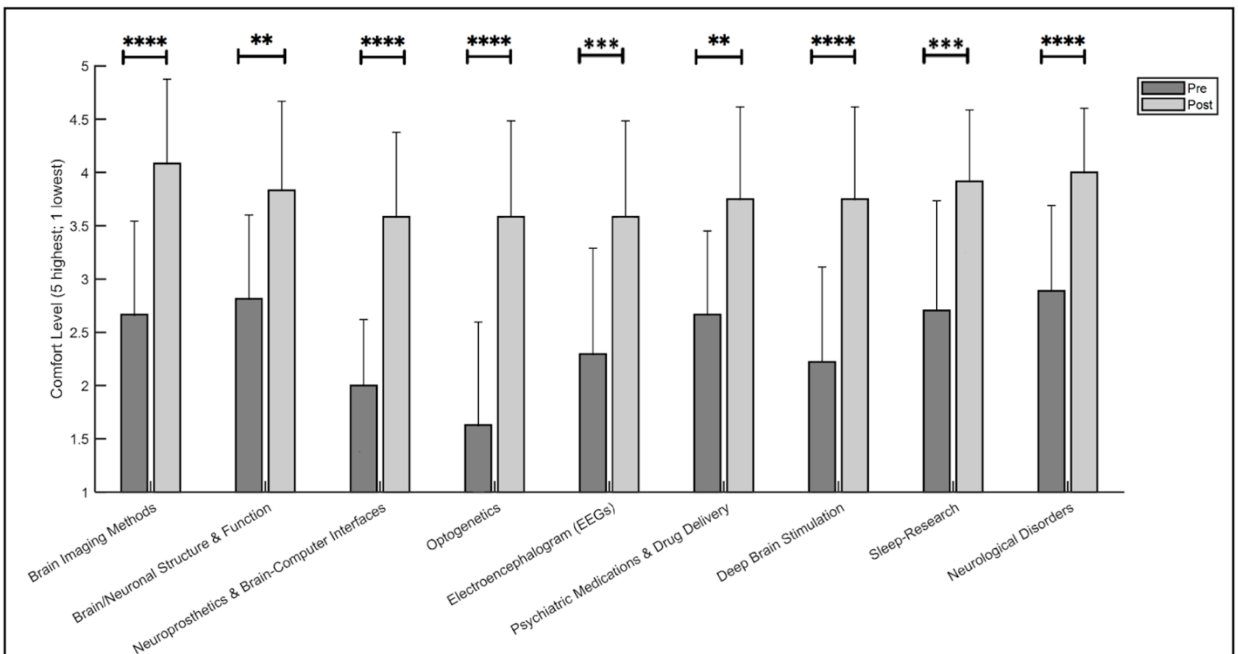
Appendix C: Study Participant/Student Cohort Data from the Fall 2023 semester of BME 1501: Innovations in Neuroscience

For the Fall semester of 2023, 27 participants completed the pre-semester survey, while 12 participants completed the post-semester survey. After the add/drop deadline, a total of 20 students were enrolled in the Fall 2023 semester. Of these 20 students, 8 (40%) were male and 12 (60%) were female. Further, 18 (90%) were first-year undergraduates, 1 (5%) was second-year undergraduate, 1 (5%) was third-year undergraduate, 0 (0%) were fourth-year undergraduates. All first-year students were undeclared in their undergraduate major, the second-year undergraduate student was a declared BME major, and the third-year undergraduate student was a declared psychology major. All first-year undergraduate students belonged to the University of Virginia's School of Engineering or College of Arts and Sciences.

Table 5: Likert Scale to Score Conversion Table

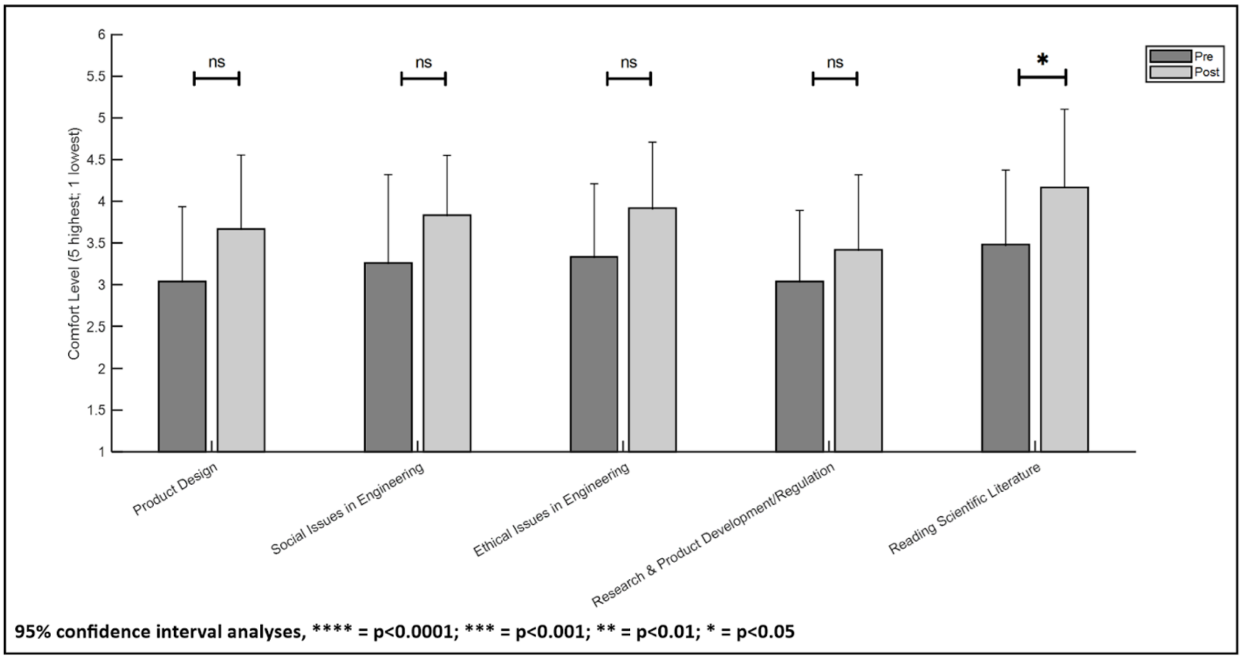
Appendix Table 1: Likert Scale to Score Conversion Table		
Assigned Score	**Neuroscience Concepts**	**Engineering Competencies**
5	Very Comfortable	Very Comfortable
4	Comfortable	Comfortable
3	Somewhat Comfortable	Somewhat Comfortable
2	Uncomfortable	Uncomfortable
1	Very Uncomfortable	Very Uncomfortable

Appendix D: Student Comfort Level with Neuroscience Concepts Pre- and Post-Semester

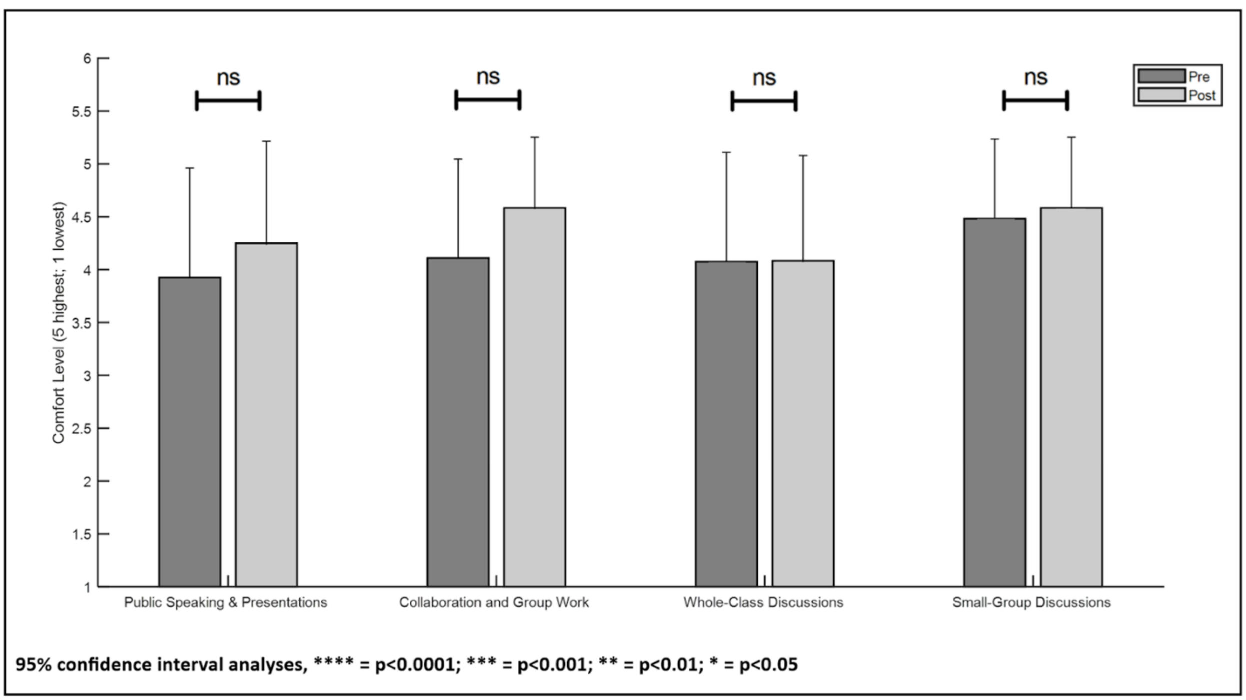


95% confidence interval analyses, **** = p<0.0001; *** = p<0.001; ** = p<0.01; * = p<0.05

Appendix E: Student Comfort Level with Engineering Competencies Pre- and Post-Semester



Appendix F: Student Comfort Level with Soft Skills Pre- and Post-Semester



Appendix G: Example questions asked to students for their discussion assignments

1. Are there any ethical or legal considerations regarding the use of deep brain stimulation in Parkinson's disease treatment? Justify your answer

2. What did you enjoy the most about the lectures given by Rick Hamilton and Katheryne Chun?
3. What are the mechanisms of action for different classes of psychiatric medications (e.g., anxiolytics, antidepressants, and antipsychotics, etc.)

Table 6: Inductive Coding Analysis of free response question focused on lectures given by guest speakers

What did you enjoy the most about the lectures given by the guest speakers?	Number of Responses
Better understanding of concepts within different fields such as medicine and neuroscience and its applications in the real world	9
Learned more about different career paths	8
Increased career confidence	7
Lectures were interesting and engaging	6
Broaden their knowledge in research and the opportunties within this field	3
Better understanding of data science/AI use in neuroengineering	3

Table 7: Example of student responses from discussion assignments

1. "The lectures that we listened to in class inspired me to consider becoming a pre-med BME more. If it's possible to turn pre-med and get into med school after switching to pre-med so late, then why should I be afraid of doing it early? If I have it as my goal from the beginning, then it is definitely possible for me to accomplish it."
2. "I thought Katheryne Chun's lecture was nice because it was very applicable to many different scopes of medicine as radiology is involved in many of them. I liked the real world application of her lecture and that she provided a lot of visual scan aids and a very broken down case study. I am not a BME student so it was sometimes difficult to understand some sections of the course or see the application for someone as a biology major but this one was nice."
3. "What I enjoyed most about the lectures given by Rick Hamilton and Katheryne Chun was that they were interesting to listen to. I liked how they were both enthusiastic about their field of work and related their topics to situations the audience could relate to. I especially appreciated that Katheryne Chun included case studies in her presentation, as they were very interesting and engaging."
4. "Hamilton's lecture inspired me to look more into the focused ultrasound institute at UVA and explore the possible research opportunities for undergrads."