Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
ASEE
Paper ID #45901

Creating a Community of Practice to Develop High School Biomedical Engineering Curricula

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Creating a Community of Practice to Develop High School Biomedical Engineering Curricula (Evaluation)

Introduction

It has been widely documented that there is a shortage of U.S. trained STEM professionals [3]. Summer research experience programs aim to build long-term collaborative partnerships with high school STEM teachers by involving them in research and introducing them to the most current developments in engineering and science with the goal of increasing student interest in STEM majors. However, it is also critical to support the translation of this experience to the teachers' own classrooms. The summer research experience described here and previously [4-14] offers teacher participants the opportunity to be immersed in both content and pedagogy as faculty from both the Colleges of Engineering and Education collaborate to enhance the skills of Chicago Public School science teachers. This program aims to help teachers more effectively communicate the nature of the scientific process in biomedical engineering to their students and enhance overall science literacy.

The Bioengineering Experience for Science Teachers ("BEST Program"), funded by an NIH grant to supports educational activities for biomedical research, has been a joint collaboration between the Colleges of Engineering and Education at the University of Illinois Chicago since 2016. The program goal is to enhance the skills of high school science teachers in biomedical engineering research through a summer immersion while providing guided instruction to create classroom curricula aligned with the Next Generation Science Standards (NGSS). The specific objectives of the program are to:

1. Enhance teachers' bioengineering content knowledge and pedagogical skills.
2. Enable teachers to translate laboratory research into practical, NGSS-aligned curricula.
3. Address educational equity by preparing teachers to better support diverse, urban student populations.

Adopted in Illinois in 2014 to be in effect by the 2016-17 school year, NGSS required complex curriculum planning on the part of districts. The framework relates science to students' everyday lives, ensures students learn about being careful consumers of scientific and technological information, and prepares them with the skills to enter careers in science, engineering, and technology. Most daunting is harmoniously integrating the three dimensions of science learning highlighted by NGSS: Core ideas, science and engineering practices, and cross-cutting concepts. While the core ideas are similar to previous standards, the emphasis on students' understanding of the approach and methods employed by engineers and scientists and the demand that engineering and technology be integrated into the structure of science education by "raising engineering design to the same level as scientific inquiry" [15] presented new challenges to science teachers.

The integration of these standards provides math, science, and engineering teachers the opportunity to develop students' knowledge and science skills. But it is important to note that these standards are not curriculum. While Illinois has adopted the standards, it is the districts and schools that were charged with creating curricular materials to help students master the NGSS. In a Center on Education Policy (CEP) report at the time [16], it was noted that in 80% of districts in the states adopting the new standards, new standards-aligned curricular materials needed to be developed. Further, 90% of districts stated that developing these materials has been a challenge. Because of the rapid introduction, adoption, and implementation of the NGSS, many districts and teachers have found themselves searching for quality curriculum that is rich in content and practice and aligned to the NGSS.

It has been suggested that exposure alone to research through traditional Research Experiences for Teachers (RET) may not easily influence teacher practice since their research experience differs widely from their classroom constraints [17-21]. Some examples are the differences in time and resources between the research lab and the schools, high-stakes testing requirements in high school, and "cookbook-style activities" in high school lab experiments that are scripted and teacher-centered [21]. Translation of these research experiences, then, requires additional programmatic features to connect these experiences to the classroom. The BEST program has been designed to provide a structured approach for translating the teachers' engineering experience to their classroom curriculum.

Interested teachers apply for admission to the program by submitting a statement of interest, a letter of recommendation, a resume, and an example of an existing unit curriculum. Selected teachers commit to a six-week, full-time summer program, spending Monday through Thursday of each week in their assigned bioengineering lab under the guidance of a faculty member. Each Friday, participants meet together with faculty members from the College of Education whom have expertise in secondary science education and curriculum design for curriculum workshops. These workshops are an opportunity for teacher participants to develop curriculum related to their summer research experience with guided instruction from faculty who have knowledge in Next Generation Science Standards and curriculum design.

Program Structure

Each year, the BEST program recruits between 6-10 high school science teachers through targeted emails to all district science teachers from the Chicago Public School Department of Science, notices sent to school principals, past participants, and other professional networks, as well as through the BEST website [22]. As part of the application, interested teachers indicate their preference for research laboratories that align with their interests and courses they teach. Teachers are selected on the strength of their application with consideration given to gender, ethnic/racial diversity, school type (neighborhood, magnet, charter, selective enrollment), geographic diversity, and student demographics in the school in which they teach. Through diversifying the portfolio of schools, the directors aim to expand the influence of the summer research experience program on the STEM instruction within this segregated, under-resourced, and largely minoritized school district. Schools are classified as either neighborhood (catering to students within a defined neighborhood boundary), magnet (offering a curriculum focused on specific programmatic themes to enhance educational opportunities for neighborhood students as well as increase choice for students citywide), charter (independently operated) or selective enrollment (open to students across the district as determined by standardized testing scores). BEST Teacher Fellows each receive an $8,000 stipend and a $1,000 allotment for classroom materials to implement their bioengineering curriculum upon completion of all deliverables following the program.

Prior to the start of the program, selected participants meet program directors (faculty from the Departments of Biomedical Engineering and Curriculum and Instruction) in a three-hour evening spring kickoff session. At this meeting, BEST Teacher Fellows have an introduction to the university, the program, one another, and the discipline of biomedical engineering. In addition, Teacher Fellows complete paperwork required for campus internet, building access, as well as complete safety and lab equipment training and a pre-program survey. Fellows are also provided publications describing recent work from the lab in which they will be working. Crucially, BEST Teacher Fellows are advised on the nature of research, acknowledging the “deep dive” they have committed to for professional development, understanding they are likely not familiar with the research science in their assigned lab.

Research Laboratory Opportunities

While not every research laboratory is available each year, the variety of experiences available through the BEST Program represent the breadth of the discipline. The research labs span a diverse range of topics from biomedical imaging and diagnostics to biomechanics, nanomedicine, and regenerative medicine. The Acoustics and Vibrations Laboratory explores mechanical wave motion for medical applications, while the BeaLab focuses on pregnancy and postpartum dynamics to address obstetric complications. The CoNECt Lab advances brain mapping for clinical conditions, and the DVJ Lab studies soft-tissue biomechanics in pulmonary hypertension. The Eddington Lab develops microfluidic solutions for biomedical applications, whereas the In-Situ Nanomedicine Laboratory creates smart biomaterials. Vascular dysfunction mechanisms are investigated in the Levitan Lab and the Microfabricated Tissue Models Laboratory engineers tissue systems for organ health. Imaging research is prominent in the Motion-encoding MRI Lab, Optical & Photoacoustic Imaging Laboratory and Papautsky Lab, all refining diagnostic imaging technologies. The Regenerative Medicine and Disability Laboratory focuses on motor neuron diseases and implant integration, while the Robotics Lab examines sensory-motor interactions and motor control through artificial systems. Collectively, these labs contribute to advancing biomedical engineering and provide opportunities for teachers to engage in diverse research settings.

BEST Teacher Fellows work in their assigned labs four days each week for the duration of the summer program. During this time, teachers are encouraged to observe and participate in research activities with lab members under the mentorship of the lab PI. The Friday curriculum workshops led by College of Education faculty emphasize principles of effective planning, instruction, and assessment to meet NGSS standards. As high school science teachers are expected to meet the challenges of integrating both CCSS (Common Core State Standards) and NGSS within their curriculum, they must ensure their students are engaged in analytical and strategic thinking about major world issues in science, technology, society and their environment. Participants are challenged to create a curriculum that promotes critical thinking about global issues, possible solutions, and improving designs. The curriculum plan must include elements of the research that the teacher conducted over the summer with an emphasis on how this research supports the goals of CCSS and NGSS. The specific objectives of the College of Education curriculum workshops are for participants to develop NGSS-aligned curriculum frameworks that integrate summer bioengineering projects into their classrooms, evaluate teaching materials for curricular relevance, design instruction tailored to diverse student needs and performance data, and create formative and summative assessments to monitor student progress and outcomes. Additionally, teachers will share their curriculum frameworks, instructional materials, and assessments with fellow teachers to promote collaboration and best practices.

The lesson plans, instructional materials, and assessments are intended to be implemented within their classrooms the following academic year. To facilitate classroom translation, participants were assessed on the development of their curriculum materials by College of Education faculty using rubrics aligned to the Chicago Public School Framework for Teaching. After program conclusion, teacher participants disseminate their curriculum frameworks, instructional materials, and student assessments to science teachers at their schools to increase the number of teachers and students who will benefit from the newly designed curriculum materials. In addition, the curriculum is available in the curriculum library on the BEST website [22].

Program Participants

Between 2016 to 2024, the BEST program has hosted 51 Teacher Fellows from the Chicago Public School District. The teachers represented 43 high schools across the district. Demographics of the teachers are shown in Table 1. Participants came from 24 unique neighborhood high schools, 9 selective enrollment high schools, 8 magnet high schools and 2 charter schools.

Research Approach

Participants completed pre- and post- program surveys. The pre-survey served as a baseline of Teacher Fellows' depth of content knowledge and pedagogical skills in bioengineering and educational practices. On the final day of the program, Teacher Fellows complete a survey that serves as a comparison to the pre-program survey, designed to examine growth in Teacher Fellows' content knowledge and pedagogical skills in bioengineering and educational practices.

Total Participants	n=51	%
Gender		
Female	27	53.9
Male	24	47.1
Race		
White	25	49.0
Black	14	27.5
Asian	10	19.6
Not reported	2	3.9
Ethnicity		
Hispanic	10	19.6
Non-Hispanic	41	80.4

Table 1. Gender, race, and ethnicity of BEST Teacher Fellows from 2016-2024

At the conclusion of each week of the program, Teacher Fellows also complete a survey to report their weekly experience in their research lab and educational workshop. These weekly surveys were designed to examine the aspects of the BEST program that give Teacher Fellows the opportunity to develop their depth of content knowledge and pedagogical skills. They further examine any barriers, obstacles, and supports that impeded or supported their ability to develop knowledge and skills. The weekly survey was designed with a combination of both closed-ended and open-ended responses. The closed responses allow for statistical analysis while the open-ended responses allow Teacher Fellows to respond to questions in their own words, encouraging a greater depth of response [23]. Participants are also contacted six months after BEST Program completion, with a request to complete a Post-program Implementation Survey. All surveys were developed using a university Qualtrics account for survey administration and analysis under IRB approval. In this paper, we report on the quantitative data collected only.

Impact of COVID-19

The BEST Program was not held in 2020 due to COVID-19. Due to ongoing campus restrictions for visitors in research labs in 2021, the program shifted to a 3-week virtual format that focused on the use of Arduino microcontrollers. Given the challenge of a virtual program for a cohort-based experience, the program was specifically offered to past participants as an opportunity to develop a new Arduino-based unit curriculum. Rather than a lab-based research experience, the 2021 BEST Program included technical workshops on Arduino and basic programming, virtual presentations and tours of bioengineering research labs, and small-group breakout sessions. Ten participants who completed all program expectations received a $3,000 stipend and $1,000 in classroom supplies. Survey results from 2021are not included in this analysis.

Results

Descriptive statistics (median, mode and mean) were used to summarize weekly feedback surveys and the post-program curriculum implementation surveys. Summary of Likert survey responses are shown in Tables 2 and 3. Differences in paired pre- and post- program Likert survey responses were determined by Wilcoxon signed rank test, shown in Table 4. Statistical analysis was performed, and significance was accepted at $p \leq 0.05$.

Please rate the extent to which you are familiar with the following:	Paired sample size (n)
Using backwards design in lesson planning	18
Using essential questions to promote critical thinking	19
Connecting curriculum to students' culture and interests	16
Appealing to students' intrinsic motivation	27
Creating rubrics for assessment	21
Using questioning techniques to check for students' understanding	20
Differentiating to meet all students' needs	25
Creating assessments aligned to learning objectives	19
Using assessments to inform instruction	20
Using Next Generation Science Standards to inform my planning and instruction	20

Please rate the extent to which you feel you have adequate knowledge in:	
Using backwards design in lesson planning	16
Using essential questions to promote critical thinking	19
Connecting curriculum to students' culture and interests	19
Appealing to students' intrinsic motivation	23
Creating rubrics for assessment	23
Using questioning techniques to check for students' understanding	20
Differentiating to meet all students' needs	24
Creating assessments aligned to learning objectives	23
Using assessments to inform instruction	23
Using Next Generation Science Standards to inform my planning and instruction	24

	Please rate the extent to which you believe it is important to incorporate the following:	
p=0.197 (not significant)	Using essential questions to promote critical thinking	12
C = 3 for n < 10 (not significant)	Connecting curriculum to students' culture and interests	8
p=0.165 (not significant)	Creating rubrics for assessment	15
p=0.263 (not significant)	Creating assessments aligned to learning objectives	10
p=0.055 (not significant)	Using assessments to inform instruction	13
p=0.222 (not significant)	Using Next Generation Science Standards to inform my planning and instruction	13
	Appealing to students' intrinsic motivation	11
	Using questioning techniques to check for students' understanding	9
	Using backwards design in lesson planning	14
	Differentiating to meet all students' needs	12

	Please rate the extent to which you believe it is important to incorporate the following:	
p=0.197 (not significant)	Using essential questions to promote critical thinking	12
C = 3 for n < 10 (p < .05) (not significant)	Connecting curriculum to students' culture and interests	8
p=0.165 (not significant)	Creating rubrics for assessment	15
p=0.263 (not significant)	Creating assessments aligned to learning objectives	10
p=0.055 (not significant)	Using assessments to inform instruction	13
p=0.222 (not significant)	Using Next Generation Science Standards to inform my planning and instruction	13
	Appealing to students' intrinsic motivation	11
	Using questioning techniques to check for students' understanding	9
	Differentiating to meet all students' needs	12
	Using backwards design in lesson planning	14

Table 2. Differences in pre- and post- program Likert survey responses was determined by Wilcoxon signed rank test. Significance accepted at $p \leq 0.05$

Please rate your overall experience. (Extremely satisfied 5 ; Somewhat satisfied 4; Neither satisfied nor dissatisfied 3; Somewhat dissatisfied 2; Extremely dissatisfied 1)			
	Median	**Mode**	**Mean**
BME Lab	5	5	4.4
Curriculum Workshop	5	5	4.64
Please rate the extent to which you agree or disagree with the following statements regarding your lab experience. (Strongly agree 5; Somewhat agree 4; Agree 3; Neither agree nor disagree 2; Somewhat disagree 1; Strongly disagree 0)			
I am comfortable voicing my concerns and questions in my bioengineering lab.	5	5	4.39
I feel engaged in a learning community	5	5	4.26
The instructional approach used was effective	4	5	4.07
My learning is adequately supported.	5	5	4.23
I will be able to transfer my learning in the lab to my classroom	5	5	4.17
I am comfortable voicing my concerns and questions in the curriculum workshop.	5	5	4.78
I feel engaged in a learning community	5	5	4.76
The instructional approach used was effective	5	5	4.64
My learning is adequately supported.	5	5	4.74
I will be able to transfer my learning to my planning and instructional practices	5	5	4.66
I have enough time to work on my individual curriculum.	5	5	4.53
Collaboration with the BEST teachers is helpful	5	5	4.71

Table 3. Weekly survey feedback from BEST Teacher Fellows from 2016-2024. n=229

Please rate the extent to which you agree or disagree with the following statements regarding your implementation of the BEST curriculum you created this summer. (Strongly agree 5; Somewhat agree 4; Agree 3; Neither agree nor disagree 2; Somewhat disagree 1; Strongly disagree 0)			
	Median	**Mode**	**Mean**
I had adequate resources to implement my curriculum	5	5	4.71
I had school-based support for implementation of my curriculum	5	5	4.57
I was able to implement all parts of my curriculum as planned	4	4	3.81
Students were engaged in the curricular activities I designed	5	5	4.61
Students have a better understanding of bioengineering after participating in my curriculum	5	5	4.54
My curriculum was an improvement in how concepts of bioengineering were previously taught	5	5	4.39
Implementation of my curriculum was successful overall	5	5	4.5
My ability to explain bioengineering concepts to students has improved	5	5	4.82
My ability to explain the nature of the scientific process has improved.	5	5	4.89
My curriculum planning has improved as a result of my participation in BEST.	5	5	4.79
I have shared my new bioengineering knowledge with my colleagues	5	5	4.61
I have shared components from the curriculum workshop with my colleagues	5	5	4.64
I have been able to transfer my learning in the bioengineering lab into my classroom.	5	5	4.82
Please rate the frequency with which you employ the following pedagogical concepts in your teaching practice. (Very frequently 5; Somewhat frequently 4; Frequently 3; Average 2; Not frequently 1; Never 0)			
Using backwards design in lesson planning	5	4	3.64
Using essential questions to promote critical thinking	5	4.5	4.18
Connecting curriculum to students' culture and interests	5	4	4.07
Appealing to students' intrinsic motivation	5	5	4.39
Creating rubrics for assessment	2	3	3.26
Using questioning techniques to check for students' understanding	5	5	4.64
Differentiating to meet all students, needs	5	5	4.61
Creating assessments aligned to learning objectives	5	4	4.18
Using assessments to inform instruction	5	4.5	4.29
Using Next Generation Science Standards to inform my planning and instruction	5	5	4.36

Table 4. BEST Teacher Fellow survey responses, 6 months post-program implementation. n=28

Discussion

In Table 2, results from Wilcoxon signed rank test for pre- and post- program Likert survey responses are shown. There was a statistically significant difference between responses before and after participation in the BEST program for 42 of the 50 survey questions. These questions focused on familiarity, possessing adequate knowledge, perceived importance, and frequency of use of instructional concepts and techniques in a teacher's practice. Quantitative survey data collected through Likert responses indicate that the BEST program had a positive impact in most aspects of increasing familiarity, knowledge, importance and use of instructional concepts and techniques in a teacher's practice. However, there was no significant difference in the following 8 survey questions:

Please rate the extent to which you believe it is important to incorporate the following:

- *Using backwards design in lesson planning*
- *Using essential questions to promote critical thinking*
- *Connecting curriculum to students' culture and interests*
- *Creating rubrics for assessment*
- *Creating assessments aligned to learning objectives*
- *Using assessments to inform instruction*
- *Using Next Generation Science Standards to inform my planning and instruction*
- *Using questioning techniques to check for students' understanding*

These items are core components in teacher education training, so we believe the lack of difference pre- and post-program responses is due to teachers already believing in the importance of these components before joining the BEST program.

Tables 3 and 4 illustrate the median, mode and mean of the Likert response data for each question of the survey. The three descriptive statistics are often used to represent non-paired, summary Likert data [24]. Table 3, which summarizes program data collected each week of the program, indicates that respondents rate their overall experience each week in both their assigned bioengineering lab and the curriculum workshop as extremely satisfied (mode, median), averaging 4.40 in the labs and 4.64 in the curriculum workshops, where 5 = extremely satisfied and 4 = somewhat satisfying (n=229).

Table 4 summarizes survey feedback 6 months after program end, after teachers have implemented their BEST curriculum. Overall respondents agreed that they were able to implement their curriculum, that students were engaged, that students have a better understanding of bioengineering concepts, and that they were able to share their curriculum with colleagues in their department (n=28). In addition, teachers felt the BEST experience enhanced their curriculum development and other pedagogical techniques.

Some challenges that participants reported was difficulty finding ways to adapt advanced bioengineering topics to a high school science curriculum. These challenges were a mix of the complexity of the research concepts, sophisticated lab equipment, level of class taught, necessity of computing languages such as Python and Matlab, and time constraints [7]. The community of practice that developed during the program was critical to assist teachers with creatively considering connections between biomedical engineering and their classroom. Sometimes the connection was a “social justice in science instruction” topic that teachers felt would spark their students’ interest. For example, one BEST Teacher Fellow participated in a lab that focused on identifying biomarkers of blood diseases. While the research was aimed at developing new methods to elucidate arterial biomechanics, the teacher decided to focus his unit curriculum on the biological science of sickle cell disease and support the science with the bioengineering techniques utilized in sickle cell disease research. While the unit focus was not on a bioengineering concept, the teacher chose to emphasize sickle cell disease because both he (an African American teacher) felt that his students, also predominantly African American, would likely have a personal connection to it. Further, some teachers expressed their participation in the BEST program as modeling a growth mindset, something they were eager to share with their students [6].

The initial research plan was scoped to extend into the science classrooms of participating BEST Teacher Fellows when the lessons were being taught. Program representatives planned to observe and assess the teachers and students when teaching the engineering curriculum. However, increased restrictions related to conducting research in the Chicago Public School District prevented follow-up observations of the bioengineering curriculum being implemented.

Finally, changes in content knowledge were assessed through free response and Likert survey questions. Teachers strongly agreed with the statements “I will be able to transfer my learning in the lab to my classroom” in Table 3, for example, and “Students have a better understanding of bioengineering after participating in my curriculum” in Table 4. Further analysis is intended to evaluate the newly developed curricula to more deeply understand the connection between self-reported increases in content knowledge and curriculum topics.

Conclusion

These findings share some of the benefits and challenges of the BEST Program. Teachers reported enhanced content knowledge which they successfully applied to their teaching practices. Weekly curriculum workshops further developed their pedagogical skills, fostering active learning, NGSS-aligned curriculum coherence, and strategies for integrating engineering practices into high school science instruction. Collaboration with peers and faculty, access to background research materials, and iterative feedback were identified as key enablers of professional growth. However, teachers in the program also faced challenges, such as adapting to research environments, mastering complex concepts, and the steep learning curve. Limited workshop time and difficulty translating advanced research into high school curricula also posed obstacles.

In response to ongoing teacher feedback collected annually, the BEST program has continuously evolved to enhance its structure and support, in an attempt to create an enriching experience for participants from year to year. Teachers have highlighted both the strengths and challenges of the program, allowing program directors to implement meaningful changes that better align with teachers' needs. These iterative updates aim to improve curriculum development and equip educators with the necessary resources and skills to maximize their learning in the program. Updates from year to year have included increased self-directed time, enhanced peer-to-peer support, regular feedback from program directors, expanded technical support, and the development of a resource library. By actively incorporating feedback, these enhancements demonstrate the program's commitment to continuous improvement and responsiveness to teacher needs. These updates are listed below.

- Increased Self-Directed Time: The final week of the program now includes additional self-directed time, allowing teachers to focus on completing and refining their curriculum materials at their own pace. This additional time gives participants the opportunity to process their learning more deeply and integrate insights gained throughout the program into their final curricula and presentation.

- Enhanced Peer-to-Peer Support: To cultivate a stronger professional learning community, additional opportunities for peer collaboration have been added into educational workshops each week. These structured interactions encourage teachers to exchange ideas, share best practices, and collectively troubleshoot challenges.

- Regular Feedback from Program Leaders: Weekly check-in sessions with program leaders provide a structure for teachers to receive real-time feedback on their curriculum development. Teachers have ongoing opportunities to share drafts of their curriculum, providing the opportunity to discuss progress, seek guidance, and address concerns, ensuring they are supported throughout the program.

- Expanded Technical Support: The program now offers enhanced computer and software training for participants working in labs requiring specialized software. These sessions help build educators' confidence and technical proficiency, allowing them to effectively participate in biomedical engineering lab research during their time in the program.

- Development of a Resource Library: A dedicated resource library has been created, offering a collection of materials on both biomedical engineering concepts and pedagogical strategies. This resource serves as an ongoing reference for participants, helping them integrate program content into their teaching practices long after the program concludes. The library has grown from year to year and is available to all current and past participants.

The BEST program offers a valuable summer research professional development opportunity for high school science teachers by providing hands-on experience in biomedical engineering and introducing educators to innovative teaching strategies. The collaboration across the Colleges of Engineering and Education provides a focus on both content and pedagogy, emphasizing curriculum development and ensuring that participants leave with well-structured, engaging lesson plans that align with real-world STEM applications. Through structured workshops, collaborative peer discussions, and mentorship, teachers gain practical knowledge and resources that can be directly applied in their classrooms. Another key component of the program is building a professional learning community to provide ongoing support.

This valuable experiential summer research opportunity provides teachers with the training, skillsets, and tools to create inquiry-based, NGSS-aligned engineering curriculum for the science classroom. It also promotes equity through targeted recruitment of educators from underserved schools. Teachers noted increased student engagement and interest in STEM fields, with some students expressing aspirations to pursue engineering careers, highlighting the program's broader impact on fostering a potential pipeline for future biomedical engineers. The BEST Program supports the University of Illinois Chicago commitment to improving STEM education, fostering teacher growth, and inspiring the next generation of STEM professionals.

Research reported in this publication was supported by National Institute of Biomedical Imaging and Bioengineering of the National Institutes of Health under award number R25EB021733.

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