NSF HBCU-UP TIP EVALUATION REPORT

September 2024

TENNESSEE STATE UNIVERSITY

Evaluation Findings: NSF HBCU-UP: Targeted Infusion Project (TIP): Development of a CRISPR-Cas9-Based Gene Editing Technology Curriculum at Tennessee State University

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Acknowledgements

The information provided within this report is summarized according to the author's understanding of data collected for evaluating the NSF HBCU-UP award (#2205542). The opinions, findings, conclusions, and/or recommendations expressed in this report are those of the author and do not necessarily reflect the view of the National Science Foundation.

RTRES CONSULTING

Robin T. Taylor, PhD.

https://www.rtresconsulting.com

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INTRODUCTION AND BACKGROUND

Dr. Sonali Roy, Research Professor at Tennessee State University, received a three-year grant (#2205542) by the NSF's HBCU-UP program for the Targeted Infusion Project: Development of a CRISPR Cas 9 based gene editing technology curriculum at Tennessee State University (TSU). The grant funds the development of a new undergraduate course in the College of Agriculture focused on training students on cutting-edge gene editing technologies, specifically the Clustered Regularly Interspaced Short Palindromic Repeats-Cas9 (CRISPR-Cas9) tool, and commenced on September 01, 2022, with an expected completion date of August 25, 2025.

The project is supported by:

- **Sonali Roy, PhD**, *Assistant Professor, Agricultural & Environmental Sciences at TSU*
  Roy serves as the PI and her role has included project management, development of CRISP-Cas 9 curriculum, taught AGSC 4630/5630; mentored 3 undergraduate student researchers
- **Ali Taheri, PhD**, *Associate Professor, Agricultural & Environmental Sciences at TSU*
  Taheri serves as a Co-PI. His role has inclued guest lecturing on CRISPR vector delivery to AGSC 4630/5630 and mentoring 1 undergraduate student researcher.
- **Suping Zhou, PhD**, *Research Professor, Agricultural & Environmental Sciences* at TSU
  Zhou serves as a Co-PI. Zhou shares lab space with Roy, encouraged her graduate students to take the AGSC 4630/5630 course, and was able to observe instruction at the start of the semester.
- **Divya Jain**, *Graduate Research Assistant at TSU*
  Jain served as the Graduate Assistant for the AGSC 4630/5630 courese (implementing the course practicum) and serving as a lab mentor for one undergraduate student researcher.
- **Mary Williams, PhD,** *Editor, Journal of Plant Cell; Developer of Teaching Tools in Plant Biology, American Society of Plant Biologists*
  Williams served as a consultant to support the PI's development of course content and appropriate assessmnets as well provided suggestions for teaching techniques and student engagement.
- **Vicki Caruana, PhD**, *Assessment Director, College of Education at St.Petersburg College*
  Caruana served as a consultant to support the PIs development of course content to learning objectives and connecting lessons to specific learning outcomes.
- **Rajni Parmar, PhD** *(Postdoctoral Researcher)***, Peter Prestwich** *(Research Associate)*
  Lab mentors supporting undergraduate students' research.

The grant focuses on three objectives (specific and measurable aims to achieve), with corresponding, more detailed outcomes. These include:

Objective 1. Developed and delivered a curriculum of theoretical content on CRISPR-Cas9 principles and uses in agricultural biotechnology and allied sciences, equivalent to 30 hours of lecture content to undergraduate students enrolled in Agricultural Sciences at TSU. Outcomes/outputs expected to support objective 1 include:

Outcome 1a[1] A new curriculum will be developed for undergraduate students in conjunction with the CRISPR Classroom (an education technology company delivering next generation-aligned content and courses) on the principles and CRISPR-Cas9 and adapted for plant biology.

Outcome 1b Slides covering at least 30 hours of lecture content and accompanying lecture notes will be developed and an outlet for publication (such as the Teaching tools published by the American Society of Plant Biology) will be found.

Outcome 1c All developed theoretical content will be delivered to 10 or more undergraduate students per year in a lecture-based, classroom course.

Outcome 1d PIs and/or undergraduate student on the project will present research at conferences such as ARD 1890 Research Symposiums

Objective 2. Provided hands-on, lab-based training to students including bioinformatics-based design and wet lab training to mediate a CRISPR-Cas9-facilitated gene edit. Outcomes/outputs expected to support objective 2 include:

Outcome 2a As part of the course, all enrolled students will independently be able to design a guide RNA using online tools, clone a guide RNA, transform the model plant, Arabidopsis thaliana, and identify gene-edited strains.

Outcome 2b Three undergraduate students per year (total nine) will perform hands-on research in the labs of Dr(s). Roy, Taheri, and Zhou on a CRISPR-related project.

Outcome 2c Two or more students will choose to pursue a graduate degree in Agriculture and allied sciences.

[1] Images are used throughout the report to illustrate concepts/convey information throughout. Attributions for images included within the report are provided in Appendix A.

Objective 3. Amplified the impact of the developed course by training 10-12 STEM Biology educators at HBCUs during a two-day workshop on site at TSU. Outcomes/outputs expected to support objective 3 include:

Outcome 3a

Recruit at least 10 (target 12) faculty at HBCU agriculture/biology instructors (professors, lecturers) to attend a 2-day on-site training workshop at TSU.

Outcome 3b

At least 10% of trainees will adapt the provided curriculum and exercises into their own lectures.

During the first year of the grant, Dr. Roy successfully obtained approval for a new course, AGSC 4630/5630: Gene Editing with CRISPR-Cas9 at TSU. This three-credits course aims to train both undergraduate and graduate students on cutting-edge gene editing technologies. The course curriculum combines theoretical knowledge of CRISPR-Cas9 with hands-on experience in designing and implementing gene edits. It also explores the potential of gene editing to address challenges in agriculture, linking scientific concepts to real-world applications.

Approval for the course involved a multi-step process during Fall 2022 and early 2023. Dr. Roy collaborated with the department to revise course material and submitted requests through TSU's Curriculog system. This online platform facilitates curriculum approval through a sequential workflow involving various academic levels. The undergraduate course received final approval on April 17, 2023, and the graduate course on May 02, 2023. The course was incorporated into TSU's course registration system in Fall 2023.

RTRES Consulting was contracted by TSU to externally evaluate the NSF HBCU-UP project. The evaluation of the project is guided by the following evaluation questions:

1. To what extent has the project's goals of 1) developing an agricultural biotechnology/allied sciences course based on theoretical content of the CRISPR-Cas9 gene-based editing techniques, 2) providing the course and training to students at TSU, and 3) sharing the course curricula with additional faculty across HBCUs for wider adoption. More specifically, to what extent has the project:

2. What challenges in project implementation emerged, and how were these challenges addressed?

3. How might components of the project be sustained beyond the grant period?

EVALUATION METHODOLOGY

Dr. Robin Taylor, Principal and Senior Evaluator of RTRES Consulting, is managing the evaluation of the project. The following data collection methods were used to inform the evaluation of the project during year 2: pre/post surveys for students enrolled in the gene editing course; interviews with project team members, course TA, and student researchers; review of program artifacts; ongoing meetings with the PI; and a site visit to TSU to observe the final course lecture and lab instruction as well as to conduct interviews and a focus group with students enrolled in the course.

Pre/Post Survey. Pre/Post survey administration for students enrolled in the AGSC 4630/5630 course.

Interviews. Conducted interviews with project team members (PIs and senior personnel), graduate assistant, and student researchers.

Program Documentation. Reviewed multiple sources of program documentation (e.g., curricula, syllabi)

PI Meetings. Continued to meet with Roy about project implementation and data collection.

Course Observation. Observed the final lecture and lab instruction on April 23, 2024.

Focus Group. A focus group was conducted with students in the AGSC 4630/5630 course on April 23, 2024.

Site visit. A site visit to TSU to 1) interview project personnel and student researchers, 2) observe the final day of teaching for the AGSC course, 3) conduct a focus group with students during the last hour of the course, and 4) tour campus facilities was completed on April 22nd and 23rd, 2024. Project personnel who were not at TSU or unavailable during the site visit as well as one student were interviewed after the visit using zoom.

The following data summary reports are attached within the appendices:

- Appendix B: TSU Student Pre-Survey Findings: AGSC 4630/5630
- Appendix C: TSU Student Post-Survey Findings: AGSC 4630/5630
- Appendix D: AGSC 4630/5630 Focus Group Summary Report
- Appendix E: Summary of Student Researcher Interviews

EVALUATION RESULTS

Findings to support the evaluation questions are grouped into two key areas: program accomplishments and challenges. Within the accomplishments section, findings are further categorized by their alignment to each project objective and subsequent outcomes.

Project Accomplishments

Objective 1. To develop a curriculum and deliver theoretical content on CRISPR-Cas9 principles and uses in agricultural biotechnology and allied sciences, equivalent to 30 hours of lecture content to undergraduate students enrolled in Agricultural Sciences at TSU.

The AGSC 4630/5630: Gene Editing with CRISPR-Cas9 was successfully offered in Spring 2024. This three-credits course is designed to equip students with knowledge and skills in cutting edge gene editing technologies, particularly CRISPR-Cas9. The course combines lecture and laboratory sessions to delve into the biological principles, ethical considerations, and diverse applications of CRISPR-Cas9 in agriculture and industry. Nine students (2 undergraduates and 7 graduates) completed the course.

AGSC 4630/5630: Gene Editing with CRISPR-Cas9 (3 credits)

This course will introduce students to these cutting-edge technologies with a focus on CRISPR-Cas9 based genome editing and prepare them for careers in biotechnology, including plant and animal biotechnology in a changing climate. Learn the theory behind the Noble-prize winning discovery and receive hands-on training in designing and implementing CRISPR-Cas9 mediated gene edits. This course covers the biology, ethics and applications of CRISPR-Cas9 in agriculture and industry and is designed for upper-level advanced undergraduate and graduate students enrolled at TSU for a degree in the Agricultural or Biological sciences.

The course will require students to have an understanding of basic molecular biology and/or biotechnology - AGSC 3109 Principles and methods to Biotech, AGSC 3710 Biotech and Society, BIOL 4110 Molecular Genetics, AGSC 5160 Animal Genetics and Breeding, AGSC 5190 Plant Breeding.

***Outcome 1a*:** A new curriculum will be developed for undergraduate students in conjunction with the CRISPR Classroom (an education technology company delivering next generation-aligned content and courses) on the principles and CRISPR-Cas9 and adapted for plant biology.

The 3-credits AGSC 4630/5630 Gene Editing with CRISPR-Cas 9 course was offered during Spring 2024 and consisted of theoretical instruction and a practical laboratory component. PI Roy utilized resources from the Innovative Genomics Institute (IGI) to enhance the curriculum. In addition to leveraging open educational resources (OER) such as IGI's CRISPRpedia, Addgene, and BLAST, PI Roy noted the valuable contributions of Dr. Mary Williams (Editor and Developer of Teaching Tools in Plant Biology, American Society of Plant Biologists) and Vicki Caruana (Assessment Director, St. Petersburg College) in developing learning objectives and well-written exam questions. Learning objectives include:

Apply the fundamental concepts of molecular biology in order to clone a DNA fragment (guide RNA).

Define the CRISPR-Cas9 system and its components focusing on its mechanisms including the roles of guide RNAs, Cas9 proteins, and target DNA recognition.

Appraise the complexity of CRISPR-Cas9 with other gene editing techniques such as TALENs and ZFNs.

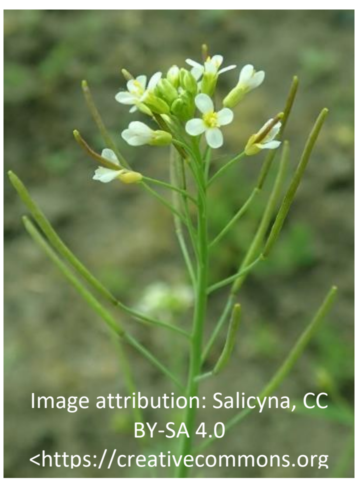
Evaluate CRISPR-cas9 delivery in plants and animals to differentiate between germline and somatic editing.

Assess various applications of CRISPR-Cas9 technology in fundamental plant research, and plant and animal biotechnology.

Judge the pro's and con's of the ethical guidelines set by governing bodies on CRISPR use in order to communicate the use of CRISPR in marketable businesses and public communication.

Communicate scientific findings related to CRISPR-Cas9 research.

Practical: **Demonstrate** practical application of mediating a gene edit.

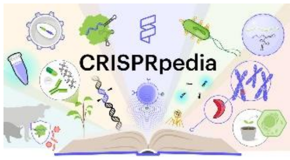


The practical component of the course focused on CRISPR gene editing techniques using *Arabidopsis Thaliana*. Students learned about databases and organisms, designed guided RNAs, and conducted in silico cloning. To enhance experiential learning, two constructs targeting the Phytoene Desaturase gene were used. Students designed and cloned guide RNAs for these constructs. Mutating this gene in *Arabidopsis* Thaliana resulted in observable phenotypic changes, such as stunting, and albino coloration, making it an ideal model for studying gene editing effects. The practical also included PCR for gRNA amplification, gel electrophoresis, and plant sterilization, cloning, bacterial transformation, plasmid extraction, and sequencing. Students analyzed phenotypic differences between wild-type and mutant plants, isolated DNA, sequenced target and off-target genes, and identified mutations. Finally, they performed Agrobacterium-mediated transformation using the floral dip method.

Guest lectures were also used to support the course – 1) CoPI, Taheri provided a guest lecture on CRISPR vector delivery, and 2) Dr. Kiona Elliot, a Plant Molecular Biologist at Bayer, a global life science company with a strong focus on healthcare and agriculture, delivered a lecture on CRISPR.

***Outcome 1b*:** Slides covering at least 30 hours of lecture content and accompanying lecture notes will be developed and an outlet for publication (such as the Teaching tools published by the American Society of Plant Biology) will be found.

A curriculum for the course has been developed and was successfully implemented during Spring 2024. The curriculum included teaching materials with a creative commons license, allowing for adaption and reuse, as well as slides developed by the PI. For the course, students were encouraged to use the following open-access textbooks: IGI's CRISPRpedia and Addgene's CRISPR 101 e-book. The course also provided opportunities for students to use web-based tools such as Benchling, CRISPR-P, and BLAST. Short descriptions for these resources follow.



CRISPRpedia is a free, online textbook on CRISPR-Cas9 offered through the Innovative Genomics Institute. The text covers the role of CRISPR in bacterial immunity, tool for genome editing, and the many applications of CRISPR in basic research, medicine and agriculture.

https://innovativegenomics.org/crisprpedia/

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addgene

Addgene: A better way to share plasmids. CRIPSR 101 is an eBook created and compiled by addgene (a nonprofit plasmid repository that serves as a global hub for sharing biological materials). The eBook provides an introduction to CRISPR gene editing technology, including basics of CRISPR, its applications, and practical considerations for researchers.

https://www.addgene.org/educational-resources/ebooks/

Benchling

Benchling is a cloud-based software platform designed to streamline and accelerate molecular biology research. It provides tools for managing DNA sequences, designing experiments, analyzing data, and collaborating with other scientists.

https://benchling.com

CRISPR-P 2.0

CRISPR-P 2.0 is a web-based tool specifically designed for plant genome editing using CRISPR-Cas 9. The tool can be used to investigate gene function, develop new crop varieties, and engineer plants with desirable traits.

http://crispr.hzau.edu.cn/CRISPR2/

Basic Local Alignment Search Tool (BLAST), is a foundational bioinformatics tool used to compare biological sequences (DNA or protein) and identify similar sequences within a database. BLAST can be used for various purposes, including sequence comparison, homology searches, database searching, and gene annotation.

https://blast.ncbi.nlm.nih.gov/Blast.cgi

The PI plans to share teaching materials developed through the course, but intends to adapt them based on lessons learned from teaching the course this past spring.

Outcome 1c**:** All developed theoretical content will be delivered to 10 or more undergraduate students per year in a lecture-based, classroom course.

A total of nine students completed the AGSC 4630/5630 course during the Spring 2024 semester – see Figure 1. Of these nine students, two students were undergraduate students majoring in Agricultural Science with a concentration in Biotechnology. The remaining seven enrollees were graduate students (Master's and doctoral) pursuing degrees in Agricultural Science, Biological Science, and Biotechnology. There was a diverse representation of students across gender and race. Among the eight students reporting their gender, five identified as women, two as men, and one as non-binary. Out of the seven students who shared their race, three were Asian, two Black, and two White.

The instructor emphasized integrative learning (combining theoretical instruction with practical laboratory activities), fundamental molecular biology concepts, applications of CRISPR-Cas9 in biotechnology, and practical skills. A variety of active learning strategies to engage students and facilitate understanding were employed. Interactive techniques like icebreakers, group discussions, and in-class quizzes created a dynamic and interactive learning environment. During the focus group, students said:

> *This course taught me to open-up.*

> *Very positive vibes, very engaging, conversation (+)*

> *Overall, learning environment was good. I have learned how to employ CRISPR tech in plants. Especially Q&A sessions made me to be more attentive in class*

> *I think a lot was taught and concepts were made clear. Combination is a good pathway for better learning.*

Figure 1. Image of students enrolled in AGSC 4630/5630 during Spring 2024 taking notes during the final lecture of the course. The AGSC 4630/5630 classroom (pictured below) provided laboratory tables for students to sit. The classroom also included a whiteboard for instruction which was located on the opposite wall, parallel to the windows. The instructor used the whiteboard to review lecture notes and engage students throughout the class lecture.

The instructor fostered a student-centered learning approach, encouraging students to ask questions, participate in discussions, and take ownership of their learning. OER (including textbooks and online tools) were leveraged, making the course more accessible and affordable for students. By connecting course material to real-world examples, such as CRISPR-Cas 9 applications in agriculture, the instructor helps students understand the practical significance of the subject matter.

The instructor incorporated a balanced assessment approach, combining formative and summative assessments. Formative assessments, such as in-class activities, quizzes, and practical assignments, provided ongoing feedback to students and helped the instructor identify areas where additional support may be needed. Summative assessments, such as exams, evaluated students' overall learning and mastery of the subject matter.

In addition to positive feedback provided by students in the focus group, students feedback to a postsurvey were overwhelmingly positive. Survey findings with supporting comments are provided.

- **All students indicated the course increased their interest in the field of genetic engineering.** Comments included:

    > *This class opened my eyes to the possibilities that gene editing research holds.*

    > *Some of the fear of anything gene editing sounding too difficult has been resolved with this course, showing me that when I apply hands on techniques, I am just as capable as my colleagues.*

- **All students indicated they could explain gene editing concepts to their family and friends.** Comments included:

    > *After taking this class, I feel like I do have more information on gene editing and CRISPR. In addition, I feel as thought I can explain these terms in an effective manner to both scientists and non-scientists.*

    > *I believe that the information I have learned in this course has prepared me to be more knowledgeable in future discussions about gene editing. I also feel like I will be able to relate this topic back to media (movies, shows, books), so that it can be more relatable.*

    > *Yes, I believe I have enough information on gene editing to explain the concepts to my family and friends by describing it as a precise technology used to modify genes in organisms, including plants, for specific purposes like improving traits or addressing diseases. I can also discuss its applications, benefits, and potential ethical considerations in accessible terms.*

- **All students indicated they would recommend the course to another student.** Comments included:

    > *It is a very good, very well-designed course. Dr. Roy is a very good educator*

    > *I have really enjoyed this course and have gained knowledge and confidence with the methods practiced over the semester.*

Students were also asked on surveys to indicate their comfort across multiple steps of conducting a CRSIPR-Cas 9 experiment. At post students are asked to reflect on their comfort level at pre and now and indicate their comfort again for pre and now at post. These results are summarized in Figure 2 and reveal students increased comfort across key aspects of conducting a typical CRISPR-Cas9 experiment.

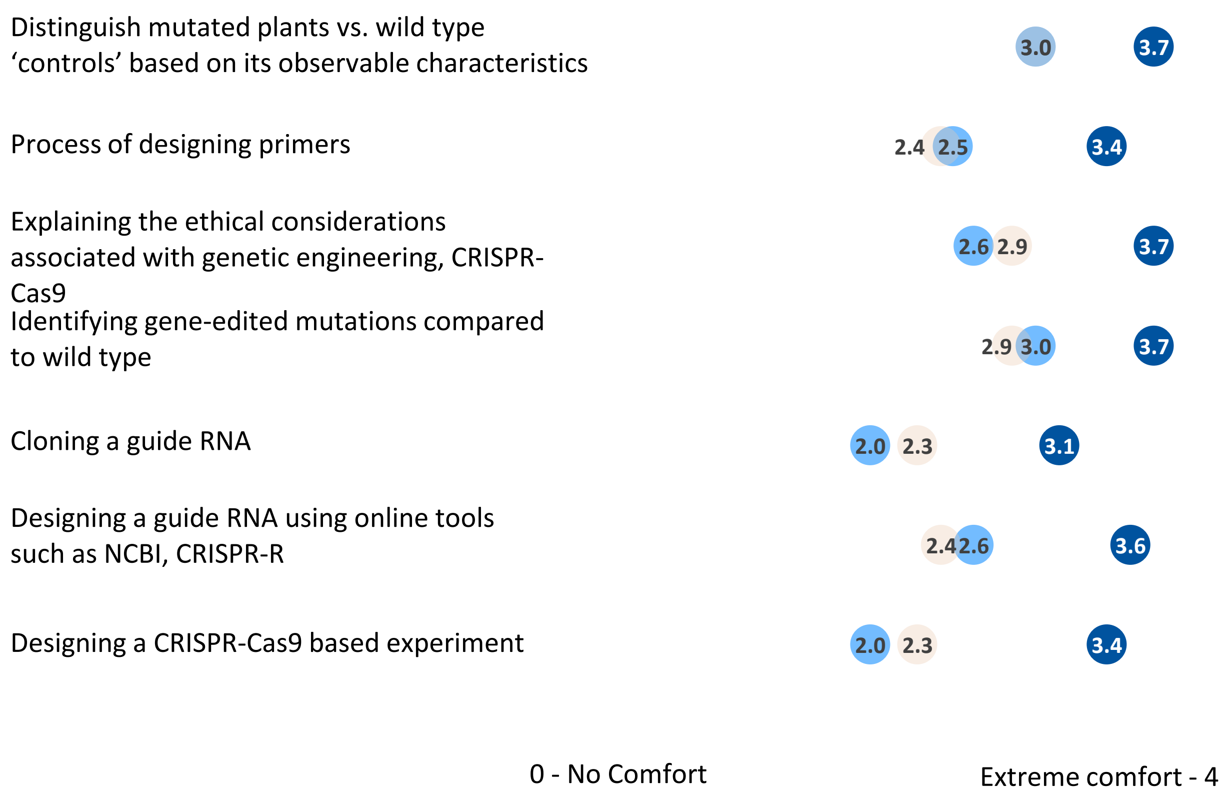

Figure 2. Using a scale of 0 (Not important) to 4 (Extremely Important), average student rating for level of comfort across learning areas at pre (●) and post (●). Light orange (●) represents retrospective ratings where students reflected on their initial comfort level after completing the course.

Outcome 1d**:** PIs and/or undergraduate student on the project will present research at conferences such as ARD 1890 Research Symposiums.

The list of presentations and publications for undergraduate students, graduate students, and PIs engaged with aspects of the NSF CRISPR-Cas9 genome editing was curated from Dr. Sonali Roy's web page, https://www.legumegenetics.org/. This includes 1 podcast episode, 2 journal publications, 3 keynote or plenary engagements, 4 conference presentations, and 9 poster presentations. An asterisk is used to indicate presentations and publications which were shared or noted on during interviews.

Publications

Roy, S., Kang, Y., Zhang, S., Torres-Jerez, I., Jain, D., Sanchez, B., ... & Udvardi, M. (2024, June). A Multitrait Genome-Wide Association Study Reveals a Requirement for the Strigolactone Receptor DWARF14 in Optimal GOLVEN10 Signaling. *bioRxiv*, DOI: 10.1101/2024.06.24.599968

Roy, S., Torres-Jerez, I., Zhang, S., Liu, W., Schiessl, K., Jain, D., Lee, H.K., Boschiero, C., Krom, N., Zhao, P., Oldroyd, G. E. D.; Murray, J., Scheible, W., Udvardi, M. K. (2024) The peptide GOLVEN10 Alters Root Development and Noduletaxis in *Medicago truncatula The Plant Journal*, *118*(3), pp. 607-625. DOI: /10.1111/tpj.16626

Keynotes, Plenaries or Invited Lectures

Roy, S. (2024, June 22). The Art and Science of Harnessing Legume Diversity. [Plenary: President's Symposium: Why do we study plants – celebrating the broad reach of plant science]. ASPB Plant Biology 2024, Honolulu, HI, United States.

Roy, S. (2023, August 08). *From Genes to Communities: Uncovering the Impact of GOLVEN10 on Root Nodule Symbiosis through GWAS.* [Symposium Speaker]. ASPB Plant Biology 2023, Savannah, GA, United States.

Roy, S. (2023, August 04). *Virtual Workshop: Networking into an industrial, federal, or academic job*. [Invited Workshop Panelist]. ASPB Plant Biology 2023, Savannah, GA, United States.

Conference Presentations

Jain, D. (2024, June 25). *Uncovering MtCAPE16 as a novel regulator of lateral root development and RNS in Medicago truncatula.* [Conference session]. ASPB Plant Biology 2024, Honolulu, HI, United States.*

Dharam, S. (2024, June 04). *Identification of Peptide Responsive Histone Modification genes during Root Nodule Symbiosis in Medicago truncatula.* [Lightning Talk]. 26th North American Symbiotic Nitrogen Fixation Conference (NASNFC), Burlington, VT, United States.

Dharam, S., & Roy, S. (2024, June 04). *Identification of Peptide Responsive Histone Modification genes during Root Nodule Symbiosis in Medicago truncatula*. [Lightning Talk]. 26th North American Symbiotic Nitrogen Fixation Conference (NASNFC), Burlington, VT, United States.

Jain, D., Hughes, K., & Roy, S. (2023, July 18). Investigating small signaling peptides involved in nitrogen acquisition and nodulation. [Concurrent session: Showcasing Undergraduate Research and Mentorship]. 2023 IS-MPMI (International Society for Molecular Plant Microbe Interactions) Congress, Providence, RI, United States.*

Poster Presentations

Jain, D. (2024, June 22). *MtCAPE16 Modulates Methylation Signatures under Nitrogen Deficiency in Medicago truncatula.* [Poster]. ASPB Plant Biology 2024, Honolulu, HI, United States.*

Jain, D. (2024, June 22). *Uncovering MtCAPE16 as a novel regulator of lateral root development and RNS in Medicago truncatula.* [Poster]. ASPB Plant Biology 2024, Honolulu, HI, United States.*

Roy, S. (2024, June 22). *Development of a CRISPR-Cas9-based gene editing technology curriculum in Plant Science.* [Poster]. ASPB Plant Biology 2024, Honolulu, HI, United States.*

Jain, D., Hughes, K., Balakrishnan, S., Chazin, W., & Roy, S. (2023, July 17). *CAPE Peptides are involved in Nitrogen Acquisition and Nodulation in Medicago truncatula.* [Poster]. 2023 IS-MPMI (International Society for Molecular Plant Microbe Interactions) Congress, Providence, RI, United States.

Hughes, K., Jain, D., & Roy, S. (2023, July 19). *Investigating CAPE16 Function in Plant Nitrogen Acquisition*. [Poster]. 2023 IS-MPMI (International Society for Molecular Plant Microbe Interactions) Congress, Providence, RI, United States. *

Jain, D. (2024, April 7-9). Title of Poster. [Poster]. 21st Biennial ARD Research Symposium, Nashville, TN, United States. *

Dean-Motley, S., D. (2024, April 7-9). Title of Poster. [Poster]. 21st Biennial ARD Research Symposium, Nashville, TN, United States. *

Harding-Jones, A. (2024, April 7-9). Title of Poster. [Poster]. 21st Biennial ARD Research Symposium, Nashville, TN, United States. *

Parmar, R. (2024 January, 15). *MediCARGO: Decoding peptide perception during Medicago-Sinorhizobium symbiosis using CRISPR-cas9 as a reverse genetics tool*. [Poster] Plant & Animal Genome Conference 2024 (PAG XXXI), San Diego, CA, United States.

Podcasts

Ashraf. A, & Roy, S. (Hosts). (2024, May 25). The Peptide GOLVEN 10 alters root development and noduletaxis in Medicago truncatula. (S3E2) [Audio podcast episode]. In *No time to read*.

Objective 2. To provide hands-on, lab-based training to students including bioinformatics-based design and wet lab training to mediate a CRISPR-Cas9-facilitated gene edit.

A total of 12 students (5 undergraduates and 7 graduates) at TSU have engaged in hands-on lab-based training through either undergraduate student research experiences and/or completing the AGSC 4630/5630 course.

***Outcome 2a*:** As part of the course, all enrolled students will independently be able to design a guide RNA using online tools, clone a guide RNA, transform the model plant, Arabidopsis thaliana, and identify gene-edited strains.

The course structure for AGSC 4630/5630 included a balanced combination of lecture, classroom activities and practical sessions. Lectures provided theoretical foundations, while classroom activities and the practical offered hands-on experience

The practical component focused on CRISPR gene editing techniques using *Arabidopsis Thaliana*. Students delved into databases and organisms, designed guide RNAs, and conducted in silico cloning. Students designed and cloned guide RNAs for two constructs targeting the Phytoene Desaturase (PDS) gene. Mutating the gene in *Arabidopsis Thaliana* resulted in observable phenotypic changes, such as stunting and albino coloration.

The practical also included a comprehensive range of laboratory techniques, including PCR for gRNA amplification, gel electrophoresis, plant sterilization, cloning, bacterial transformation, plasmid extraction, and sequencing. Students analyzed phenotypic differences between wild-type and mutant plants, isolated DNA, sequenced target and off-target genes, and identified mutations. Finally, they performed Agrobacterium-mediated transformation using the floral dip method

Key learning outcomes included:

- Students gained hands-on experience with CRISPR techniques to modify the PDS gene.
- Students observed and analyzed phenotypic changes resulting from gene editing.
- Students learned or reinforced a variety of laboratory techniques, including PCR, gel electrophoresis, cloning, and sequencing.
- Students analyzed DNA sequences to identify mutations and understand gene editing effects.

Students were also required to utilize electronic lab notebooks as they offer numerous benefits, including automated timestamps, IP conflict resolution, organized data, and integrated data analysis tools. The class used Benchling, an open-source platform, for electronic notebooks. Students received training on proper lab notebook practices and regular feedback from the instructor.

The TA planned each practical experiment, conducting them prior to each course to ensure all students could progress smoothly through subsequent steps, regardless of any challenges or failures encountered. This proactive approach ensured that students remained on track and could access completed steps if necessary.

Outcome 2b: Three undergraduate students per year (total nine) will perform hands-on research in the labs of Dr(s). Roy, Taheri, and Zhou on a CRISPR-related project.

A total of four undergraduate student researchers performed hands-on research related to CRISPR. Research laboratories for Drs. Sonali Roy, Suping Zhou, and Ali Taheri (research professors at Tennessee State University's Department of Agricultural and Environmental Sciences and PIs for the HBCU-UP award) are located on TSU's main campus within the Agricultural Biotechnology Building. A brief description of each faculty member's lab follows.

Figure 3. Images of Drs. Roy and Zhou's shared lab space

The Roy Lab. Dr. Roy's lab investigates fundamental plant biology related to nitrogen acquisition, with the ultimate goal of reducing reliance on synthetic nitrogen fertilizers in agriculture. Research currently focuses on three key areas: root nodule symbiosis; peptide hormones, and plant memory. Three undergraduate student researchers were supported in Roy's lab during the 2023-24 academic year, and one graduate student researcher benefited from completing AGSC 5630.

Dr Zhou's Laboratory. Dr Zhou's lab provides basic and applied research opportunities related to plant stress tolerance and agriculture. Ongoing projects within the lab range from uncovering core mechanisms of plant stress responses, developing practical solutions for agriculture, to exploring the potential of microbes to enhance plant health and biofuel production. Two graduate student researchers from Zhou's lab benefited from completing AGSC 5630.

Taheri Lab. Dr. Taheri's lab focuses on the development of next-generation crops with enhanced performance and yield potential through multiple approaches: cutting-edge genomics, traditional plant science techniques, and bioinformatics.

One undergraduate student researcher was supported in Taheri's lab during the 2023-24 academic year

Undergraduate student researchers were recruited through the TSU Dean Scholars program, a competitive scholarship that provides financial aid and research opportunities for high-achieving students interested in agriculture, food and related sciences. During the 2023-24 academic year, three undergraduate students participated in hands-on research within Dr. Roy's lab and one undergraduate student participated in hands-on research within Dr. Taheri's lab. A description of each students' undergraduate research project is provided. [*To address the evaluator's lack of expertise in the field, summaries were generated using GEMINI AI to analyze abstracts provided by faculty researchers and information supported by student interviews.*]

Kyla Hughes. Major: Agricultural Sciences w/ Biotechnology concentration (Sophomore)

Mentored by Divya Jain (Graduate student) and Dr. Sonali Roy (Research Professor)

Research Project. Study to explore the role of MtCAPE16 Peptide in Root Development and Its Potential for Plant Growth Improvement. This study investigates the function of MtCAPE16, a small signaling peptide in the legume Medicago truncatula. The research builds on previous work for applying the MtCAPE16 peptide increases lateral root growth in Arabidopsis, where the MtCAPE16 was shown to have contrasting effects on root development in Arabidopsis and M. truncatula.

During the past academic year, Kyla worked directly with graduate student, Divya Jain, to identify mutations in MtCAPE16 and two related genes, MtCAPE17 and MtCAPE19, using CRISPR-Cas9 mutagenesis in M. truncatula. Her research has involved the following:

- **Polymerase Chain Reaction (PCR) amplification** of target regions of all three genes from 8-10 independent transgenic lines.
- **Sanger sequencing** to determine the exact nucleotide sequences.
- Utilization of the **National Center for Biotechnology Information (NCBI) database** to obtain the wild-type (unedited) gene sequences; identify and mark the open reading frames (coding regions of the genes) in both wild-type and mutant sequences.
- **Identification, classification and recording** of differences such as insertions (extra nucleotides) or deletions (missing nucleotides).

In January, 2024, Kyla was invited to attend the MIT Quantitative Workshop in Cambridge, MA. This seven-days intensive workshop is designed to introduce undergraduate students to quantitative tools and programming languages used to analyze experimental data in biology and neuroscience.

Shania Dean-Motley. Major: Political Science and Agriculture Science w/ Biotechnology concentration (Sophomore)

Mentored by Dr. Rajni Parmar (Postdoctoral Fellow) and Dr. Sonali Roy (Research Professor)

Research Project. Study utilizing CRISPR-Cas9 reverse genetics approach to investigate the function of the MtBAK1 gene in Medicago truncatula**,** specifically its role in root nodule symbiosis. The research will target all six orthologs (closely related gene copies) of MtBAK1 to gain a comprehensive understanding of its function. A broad overview of the research includes:

- **Design three specific guide RNAs** that target each of the six MtBAK1 orthologs.
- **Clone each guide RNA into a vector** backbone called pDIRECT23C using the Golden Gate cloning technique.
- Verify sequences of cloned guide RNAs using **Sanger sequencing.**

Aminah Harding Jones Major: Agricultural Sciences w/ Biotechnology concentration (Freshman)

Mentored by Dr. Rajni Parmar (Postdoctoral Fellow) and Dr. Sonali Roy (Research Professor)

Research Project. Study to uncover the role of BAK1 co-receptor proteins in the legume-rhizobia symbiosis using CRISPR-Cas9 gene editing in a TNt1 mutant collection. A short overview of the research includes:

- Use **CRISPR-Cas9 gene editing** to target all six MtBAK1 gene orthologs in Medicago truncatula (legume plant) to assess their individual roles in legume-rhizobia symbiosis through functional disruption.
- Introduce random mutations throughout the M. truncatula genome using a technique called Tnt1 mutagenesis.
- Identify mutants with disrupted peptide receptor genes, including potential MtBAK1 co-receptors.
- Examine mutants for defects in forming symbiotic relationships with rhizobia bacteria to identify which receptors are crucial for symbiosis.

Janae Terrell. Major: Agricultural Sciences w/ Biotechnology concentration (Junior)

Mentored by Peter Prestwich (Research Associate) and Dr. Ali Taheri (Associate Professor)

Research Project. Study on soybean-specific CRISPR Vectors: A leap in gene editing precision. A short overview of the research includes:

- Create new CRISPR vectors incorporating soybean-specific promoters and the chosen reporter gene.
- Desing guide RNAs targeting specific genes of interest in soybeans.
- Assemble the CRISPR vectors using appropriate cloning techniques.
- Introduce the constructed vectors into Agrobacterium tumefaciens, a soil bacterium used for plant transformation.
- Infect soybean explants with the Agrobacterium-containing vectors.
- Culture the explants to include the formation of hairy roots.
- Regenerate transgenic soybean plants from the hairy roots.
- Verify presence of desired gene edits in the transgenic plants using molecular biology techniques.
- Assess effects of gene edits in the transgenic plants using molecular biology techniques.
- Evaluate functionality of the reporter gene and its ability to distinguish transgenic plants from non-transgenic ones.
- Refinement of results to optimize vectors.

***Outcome 2c*:** Two or more students will choose to pursue a graduate degree in Agriculture and allied sciences.

Additional time is needed before understanding if completion of the AGSC 4630/5630 course or undergraduate student research experiences will result in students choosing to pursue a graduate degree in Agriculture and allied sciences. However, initial feedback from one undergraduate student researcher suggests that her aspiration of pursuing medicine has shifted towards research, particularly in the field of agriculture and biotechnology.

Students enrolled in the AGSC 4630/5630 course were asked if taking the course influenced their academic major or career interests. Almost all students indicated that the course was influential. The one exception stated that they were already confident in their career path. Open-ended feedback from students included:

- “ *It gave me more confidence in my understanding of gene editing and techniques.*
- “ *The class definitely opened my eyes to different career paths/options that are available, specifically aligning using CRISPR.*
- “ *Yes, taking the AGSC 4630/5630 course significantly influenced my academic major and career interests. This course introduced me to CRISPR-Cas9 technology, which has become a cornerstone of my PhD research project. The knowledge and skills gained from this course have been instrumental in shaping my research direction and enhancing my expertise in utilizing CRISPR-Cas9 for genetic manipulation. The course provided a solid foundation in understanding the principles and applications of this cutting-edge technology, enabling me to implement advanced genetic engineering techniques effectively in my research. As a result, my interest and proficiency in this area have deepened, aligning my academic pursuits and career aspirations with the forefront of molecular biology and biotechnology.*

Objective 3. To amplify the impact of the developed course by training 10-12 STEM Biology educators at HBCUs during a two-day workshop on site at TSU.

Activities related to Objective 3 are intended to be implemented during year 3 of the grant; thus, no progress has been made, nor is it expected at this time.

Outcome 3a**:** Recruit at least 10 (target 12) faculty at HBCU agriculture/biology instructors (professors, lecturers) to attend a 2-day on-site training workshop at TSU.

While full implementation of Objective 3 is planned for year 3, strong initial interest has been provided by five HBCU institutions including Fayetteville State University, Grambling State University, Jackson State University, Fort Valley State University, and Winston Salem State University. During year 3, recruitment will prioritize faculty and instructors from these five universities. Additionally, the workshop will be advertised to a broader network of HBCUs to expand participation. To ensure a strong cohort, potential participants will complete an application which will be used to select participants based on NSF supported selection criteria.

Outcome 3b**:** At least 10% of trainees will adapt the provided curriculum and exercises into their own lectures.

No progress has been made for Outcome 3b at this time, nor is progress expected until the third year of the grant award.

Challenges

Another aspect of the evaluation is to consider challenges encountered during the project's implementation and how they were addressed. For this project, the implementation timeline was extended due to factors related to planning and development of the new curriculum, institutional course approval, and student recruitment. However, as with many new programs, these challenges are expected. Successful programs require careful planning, recourse allocation, and development. Funding agencies should support this deliberate process when funding new, innovative projects.

While the proposal aimed to build a curriculum for undergraduate students, the initial enrollment was skewed towards graduate students. This is likely common for courses that delve into advanced topics or concepts that align with graduate students' academic pursuits. Graduate students highly valued the course material and skills developed. This demonstrates the importance of including both undergraduate and graduate students. Peer recommendations may influence undergraduate students to enroll in future course offerings.

Scientific inquiry often leads to failed experiments, providing valuable learning opportunities. However, this process requires time resources, which can be challenging in a time-controlled setting. To address this, the TA proactively ensured students who struggled with a practicum component could keep up. Jain conducted the experiments beforehand and provided successful specimens for students to use if their experiments failed, allowing them to stay on track.

Finally, time availability is a challenge when conducting research in labs with controlled access. When personnel cannot access the lab, experiments may fail, leading to increased time and resource commitments; thus, requires careful planning to ensure progress continues during campus closures. Faculty and lab researches typically commit to their work, even during breaks away from campus.

SUMMARY

The HBCU-UP Targeted Infusion project at Tennessee State University has successfully achieved significant milestones in its second year. The new undergraduate course, AGSC 4630/5630: Gene Editing with CRISPR-Cas9, was developed and offered in Spring 2024. The course curriculum combines theoretical knowledge with practical laboratory experiences, equipping students with the skills and knowledge to utilize CRISPR-Cas9 technology in agricultural biotechnology.

The course attracted a diverse group of students, both undergraduate and graduate, demonstrating its appeal across academic levels. Student feedback has been overwhelmingly positive, highlighting the course's effectiveness in enhancing understanding and interest in gene editing. They project also supported hands-on research experiences for undergraduate students, fostering their interest in research careers.

While implementation of Objective 3, focused on training HBCU STEM Biology Educators, is planned for year 3, initial outreach efforts in the proposal stage have generated interest from five HBCU institutions. Continued efforts will likely expand participation to broaden the project's impact.

The evaluation also identified challenges related to initial enrollment skewing towards graduate students and time constraints impacting research projects. These are common challenges encountered during program development, and the project team has implemented strategies to mitigate them.

Overall, the project is on track to achieve its goals of developing and disseminating knowledge on CRISPR-Cas9 technology while fostering future generations of scientists, particularly at HBCUs. The project's success underscores the importance of well-planned, innovative approaches to science education and research.

APPENDICES

Appendix A. Icon and Image Attributions

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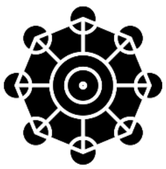	Learning by Flatart from Noun Project (CCBY3.0)		education by roughen.line from Noun Project (CCBY3.0)
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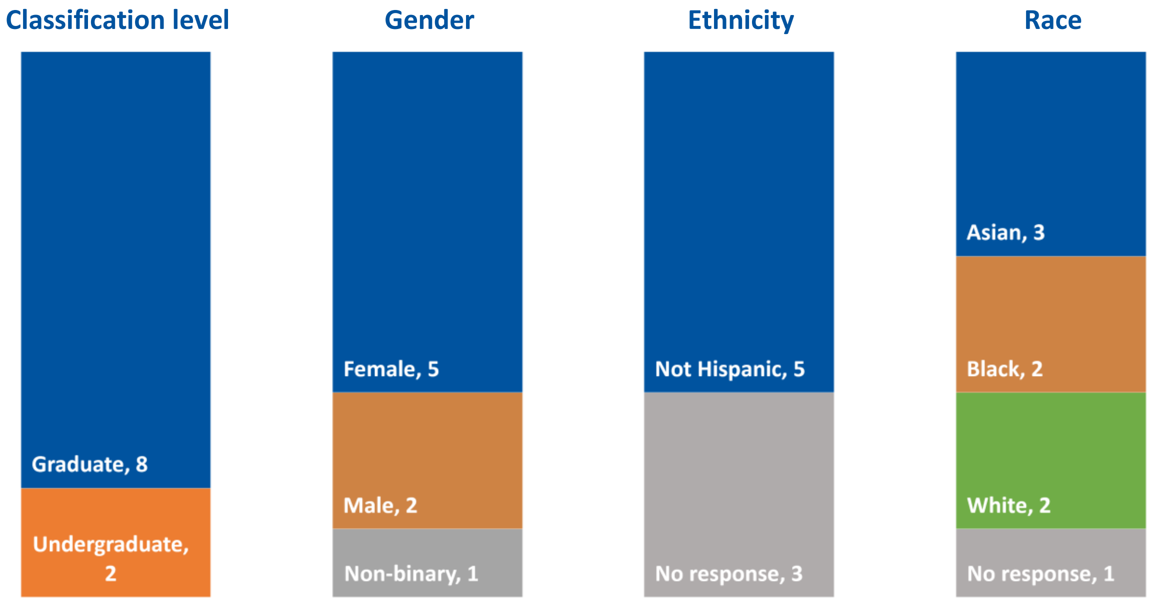
Appendix B. TSU Student Pre-Survey Findings: AGSC 4630/5630

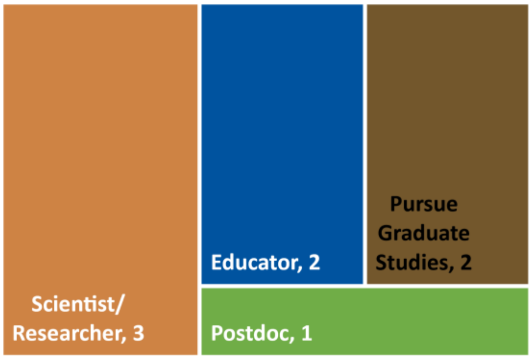
A pre-survey was administered to all students enrolled in AGRI 4630/5630: Introduction to Gene Editing with CRISPR/Cas9 at the start of the Spring 2024 semester. A total of 8 of the 9 students enrolled within the course completed the survey – response rate of 89.9%. An additional survey was completed by the TA but these responses are not included in this report.

Students' self-reported characteristics



Students' Academic Majors

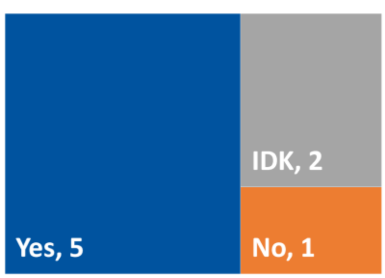
Students' Career Interests



Students' definition for a "Scientist"

- A person whom attempts to study and define the world around them using any method of hypothesis, questions, and testing.
- A scientist is a person who utilizes his/her knowledge, skills and extend them to conduct experiments and keeps on learning from their doings.
- In my mind a scientist is the one find something new in his/her filed. It can include the one find a new principle or the one use such principle to reveal new things we don't know or a new way to confirm it.
- Someone whose career is to do research by testing hypotheses and sharing those findings.
- as a knowledge and information manual
- People who research and discover new things that directly benefit human being
- I think a scientist is someone who conducts research. However, this research is not always what we think. Research does not always have to be conducted in a lab.
- A scientist is someone who uses science and logic to solve problems and answer questions.

Students' Identification as a Scientist



Response: I am not sure (IDK)

- I am current master's student; I am learning skills, how to do research. How to think like a researcher.
- I am new to PhD in United States so I feel new to everything

Response: No

- I haven't command[ed] a strong knowledge background in my field. I need to learn more.

Response: Yes

- I am attempting to increase understanding of ecology, sustainable agriculture, and education through learning, communication, and testing hypothesis
- Before going back to grad school I was a technician who regularly took part in conducting experiments and writing reports.
- I am currently doing research on tomato germinating pollen that are exposed to three different temperatures to identify heat-induced proteomes, which identify the proteins that may help to understand how plants respond to environmental stress for the development of heat-tolerant tomato varieties and agricultural practices.
- Since my freshman year, I have worked in a lab where I have set up and conducted experiments. I also have had the opportunity to present some of my research.
- I have completed work in a scientific lab where I worked to solve a problem and answer questions.

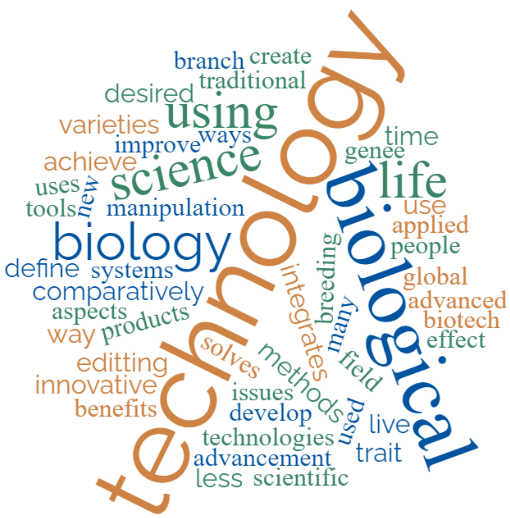
Prior experience or coursework related to bioinformatics, cloning or transformation techniques

- I learned gene editing from professors.
- Bioinformatics
- Bioinformatics

Hands-on experience with genetic engineering techniques prior to enrolling in this course

- Some PCR with predifined primers to find the Y chromosome in waterhemp
- Using Crispr/cas9 to modify target gene.

Students' definition for "Biotechnology"



- Using gene editing and manipulation to achieve a desired trait or effect
- Biotechnology is branch of science with integrates traditional breeding methods with advanced technologies to develop new varieties in comparatively less time.
- Technology used on biology.
- Biotechnology is a way to improve many aspects of life through innovative biological technology.
- ways to live life
- Technology that uses biological systems to create products that benefits people
- I would define biotechnology as an applied science field which solves global issues by using biological tools.
- Biotech is the use of biology and technology for scientific advancement.

Concerns about ability to perform well within the course

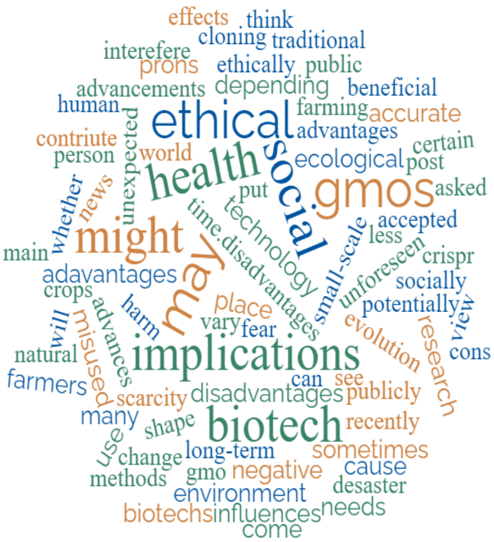
Response: Yes

- I have avoided genetics thus far in my academic career. I know I can do well, but I have some catching up to do
- For me, I'm an international student and my language still not good enough to express my thoughts.
- Yes, as it is my first time learning CRISPR, I have some concerns, but I'm eager to learn and understand it.

Response: No

- I am a nervous individual who does worry about performing well, but the course so far has been explained very well.
- So far, this course has been well explained and I have not struggled.

Students' beliefs about the main social and ethical implications of biotech research



- Potentially, it would contribute to a post scarcity world, but I do fear for unexpected ecological disaster.
- It has both advantages and disadvantages. Advantages : Its more accurate, less time. Disadvantages: GMO are not publicly accepted, sometimes may be misused
- The main social and ethical influences may cause by biotech can be whether such technology will change the shape of the natural evolution and human health.
- Social and ethical implications vary depending on the person who is asked. Many have a negative view on certain biotechs such as GMOs.
- it has both prons and cons
- Socially, the use of GM crops might interefere with traditional farming methods and harm small-scale farmers. Ethically, there might be unforeseen effects on the environment and public health
- More recently, news has come out about GMOs and CRISPR. I think both biotech advances are beneficial, but more research needs to be put in place to see the long-term implications of these advancements.
- Cloning

Students' belief that plant biotechnology has the potential to positively impact agriculture and food production

Response: Yes

- We need methods to speed up traditional hybridization to meet food needs. Gene editing does this
- There are many food crisis issues around the globe that can be fixed with science. For example, food biofortification and increasing crop yields.
- Depending on how climate change impacts food crops, utilizing biotechnology may be essential to produce enough food, whether that be from increased yield or from plants being manipulated into being able to survive conditions that it may not have been able to previously.

Response: No

- It has the potential to increase crop quality and yield, making farmers more profitable.

Students' belief scientists or countries 'owning' the rights for commercial use of these plants

Response: No

- There are many ethical issues with 'owning' food crops, such as cross pollination from gene edited crops to small farmers. I don't believe anyone should have a right to a specific food, especially if it ends up being essential for the production of that food with climate change.
- Globally, people should be able to get the benefits so that they can be used around the world in order to meet the demand of growing population.

Response: Yes

- Only as a patent. After a set number of years, they become public access
- Developing science and research takes committed time and effort, I think the people developing this research deserve credit and rights.

Students' belief that gene edited plants are considered to be genetically modified organisms (living things)

Response: Yes

- If you edit the organism, it is modified.
- Yes, since gene edited plants indicates modification.
- I would consider them as such. Even basic plant cross-breeding is GMO: breeding plants for specific traits. However, the stigma surrounding GMOs in recent years has created a negative discussion around gene-edited plants. I think they can be beneficial when used correctly and safely.

Response: No

- In gene edited plants we are not integrating the foreign DNA, but just creating mutation within the genome
- GMO's are created by adding foreign DNA while Gene editing precisely alters a genome without adding DNA.

Students' beliefs that gene edited plants are a threat to the environment

Response: Yes

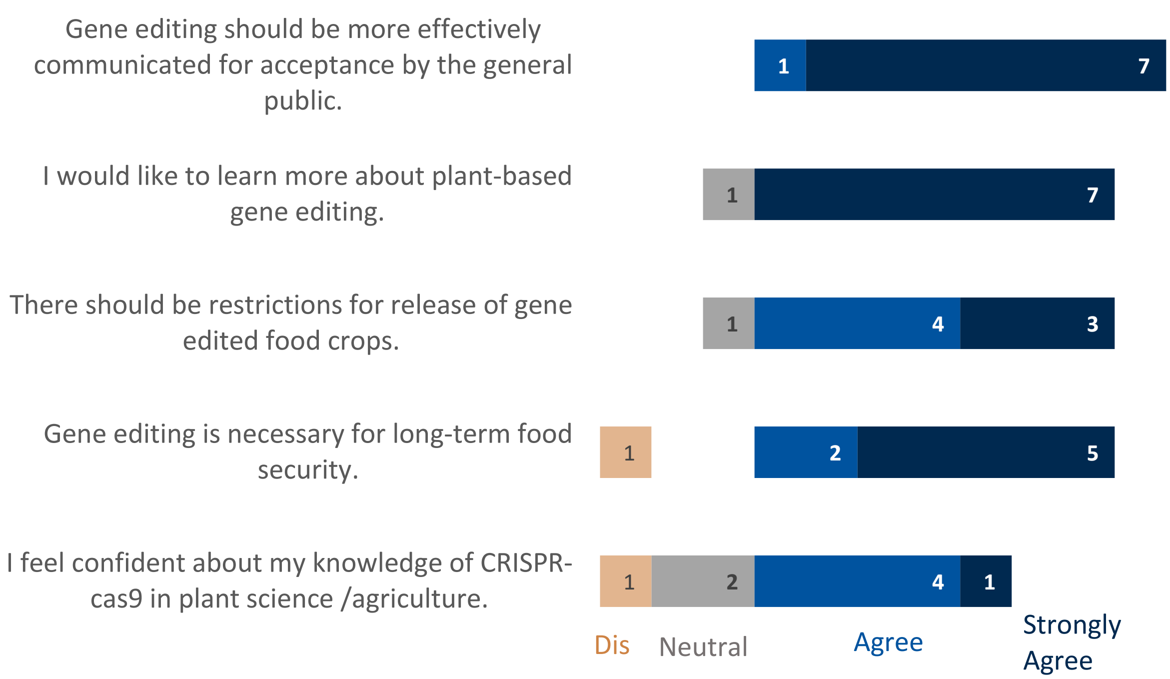
- SOME are. Careless testing and editing can lead to disaster, ut if it is careful monitored and tested, then it the threat is minimal and acceptable
- in some ways
- There might be some unforeseen consequences.
- I think studying the long-term effects of gene-edited plants can determine this. Gene-edited plants may eventually take over wild-type breeds, so in terms of plant diversity, I think they could be a threat.

Response: No

- Not always they are threat to environment. It depends on the way we use.
- I would assume gene edited plants are typically contained to the specific reason they were produced. However, I lack research on this question.

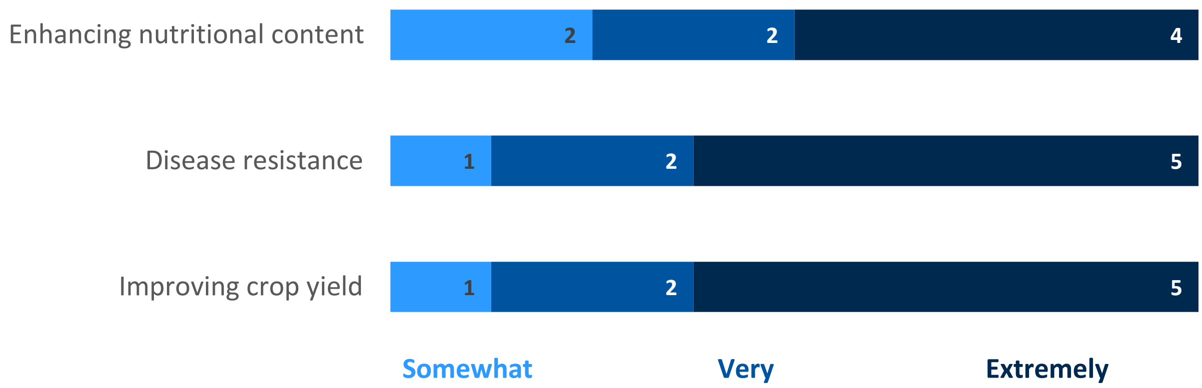
Students agreement towards statements on gene-editing

(Response scale of Strongly Disagree, Disagree (Dis), Neutral, Agree, or Strongly Agree)



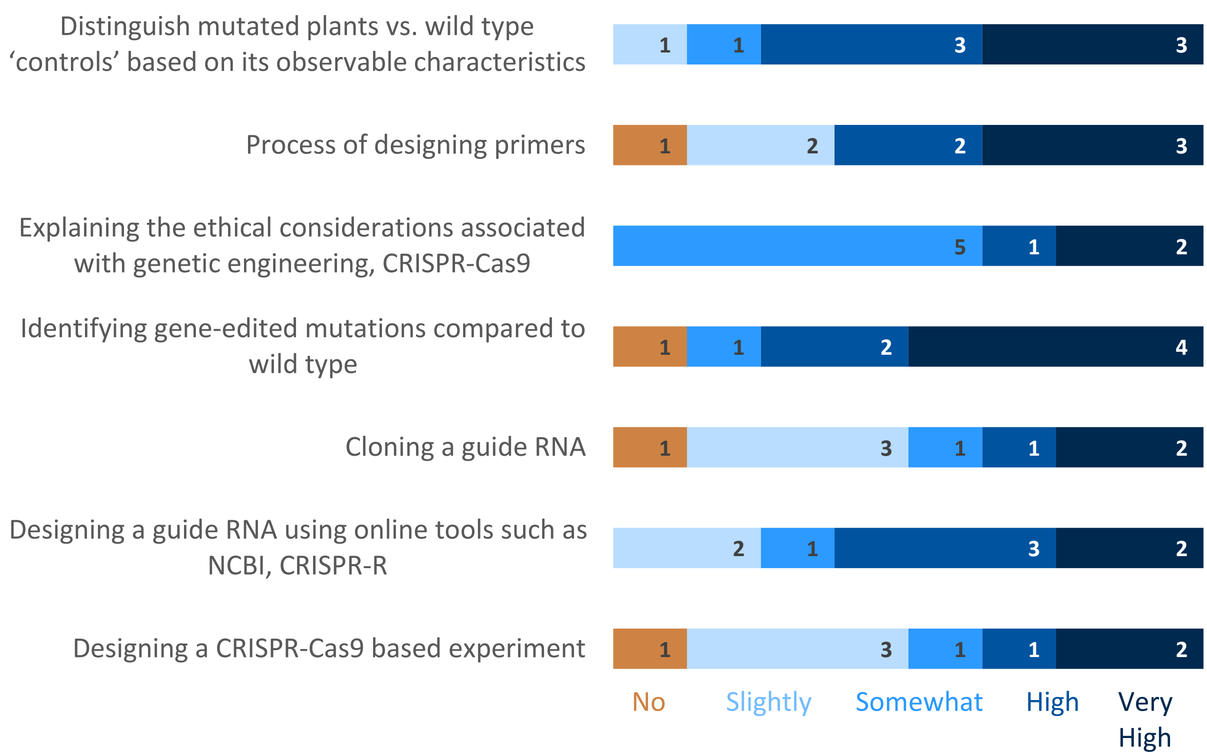
Students' assignment of importance for gene editing in addressing the following challenges in agriculture.

(Response scale of Not important, Slightly, Somewhat, Very, or Extremely Important)



Students' level of comfort for each of the following learning areas.

(Response scale of No comfort, Slight, Somewhat, High, or Very High Comfort)



100% **of students (8 out of 8) indicated that attending TSU has influenced or shaped their career aspirations.**

- Makes me want to teach undergrad more
- Yes, working with colleagues and multidisciplinary people has helping me to extend my knowledge and also helping in networking and knowing new research insights.
- I think I learned a lot about my major. I would like to say studying here make me confirmed my mind to do research in this field. Thanks Tennessee State University.
- Attending TSU was how I was able to be a lab tech for many years before coming back to school at TSU again.
- it helped me to expand my horizons
- Definitely, With the mentorship of my professor, Dr. Suping, I am able to know and do molecular level research. From taking course to some real-life experiences, being a student at TSU has been engaging journey.
- Most definitely. Attending TSU, specifically being under the College of Agriculture, has provided me with various research and academic opportunities. Because of this, my future research aspirations have been broadened.

Appendix C. TSU Student Post-Survey Findings: AGSC 4630/5630

A total of nine students were enrolled in the AGSC 4630/5630: Introduction to Gene Editing with CRISPR-Cas9 course during Spring 2024. Of these nine students seven were graduate students and two were undergraduate students. The breakdown for student reported identification for gender, ethnicity and race includes:

- Sex/Gender: Female (5), Male (2), Non-binary (1), and Not reported (1)
- Ethnicity: Not Hispanic (5) and Not reported (4)
- Race: Asian (3), Black (2), White (2), and Not reported (2)
- Academic Majors: Biotechnology (5), Agricultural Science (2), Not reported (2)
- Career Interests. Scientist/Researcher (3), Educator (2), Postdoc (1), Graduate studies (2), and Not reported (1).

Pre and post surveys were administered to all students enrolled in the course. A total of eight students completed the pre-survey and seven completed the post. This resulted in a total of 6 (67%) matched surveys across time periods as two students who completed the pre-survey did not complete a post, and 1 student who completed a post-survey did not complete a pre. For the purposes of this report, all students data are included in analyses, although where appropriate references will be made to compare how the data compares to actual matched data.

Dumbbell plots (e.g., barbell charts) illustrate average agreement across ratings at pre- and post. For these plots, averages at pre are color coded with a lighter shade of blue (●) and averages at post are shaded with a darker blue (●).

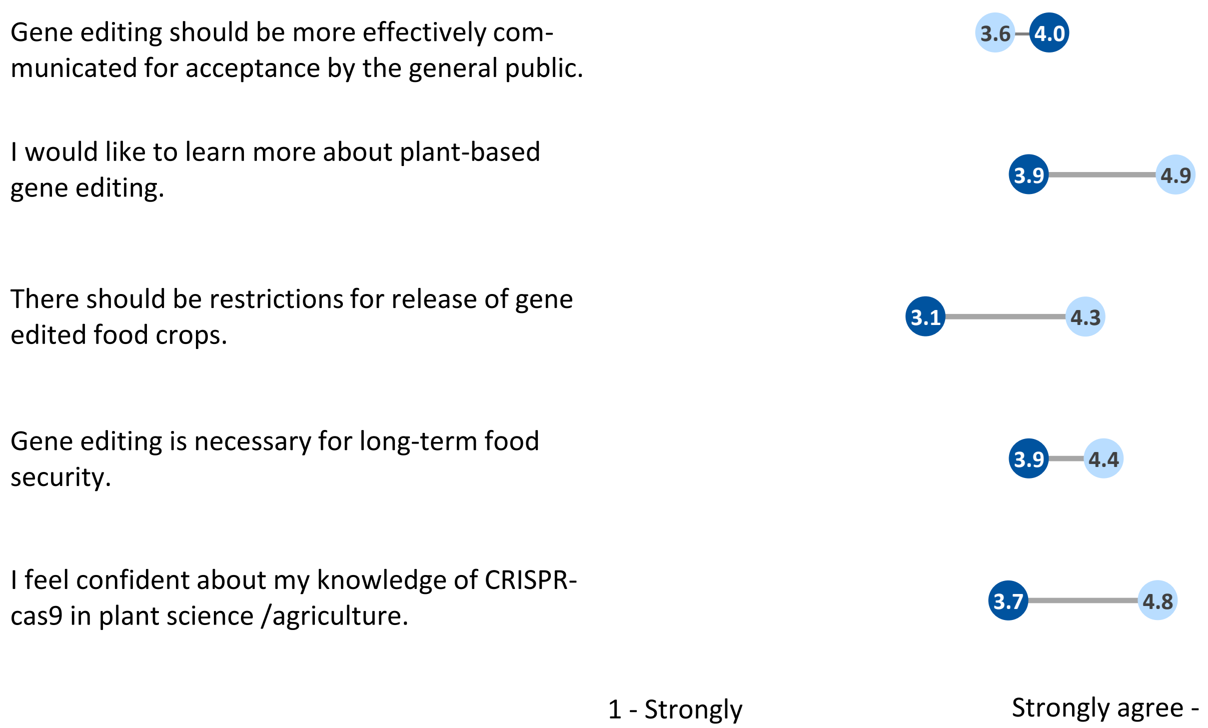


Figure 1. Using a scale of 1 (Strongly disagree) and 5 (Strongly agree), average student agreement towards statements on gene-editing at pre (●) and post (●).

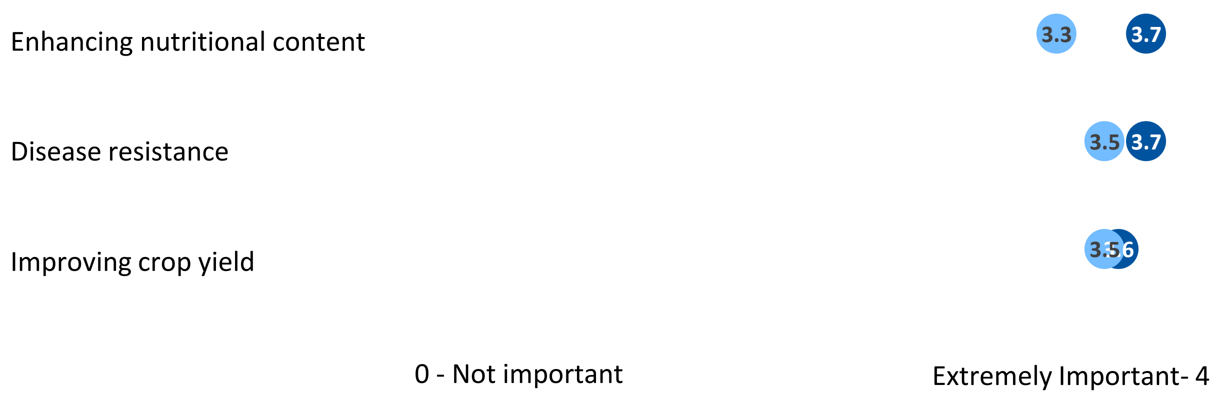


Figure 2. Using a scale of 0 (Not important) to 4 (Extremely Important), average student rating of importance for gene editing in addressing the following challenges in agriculture at pre (●) and post (●).

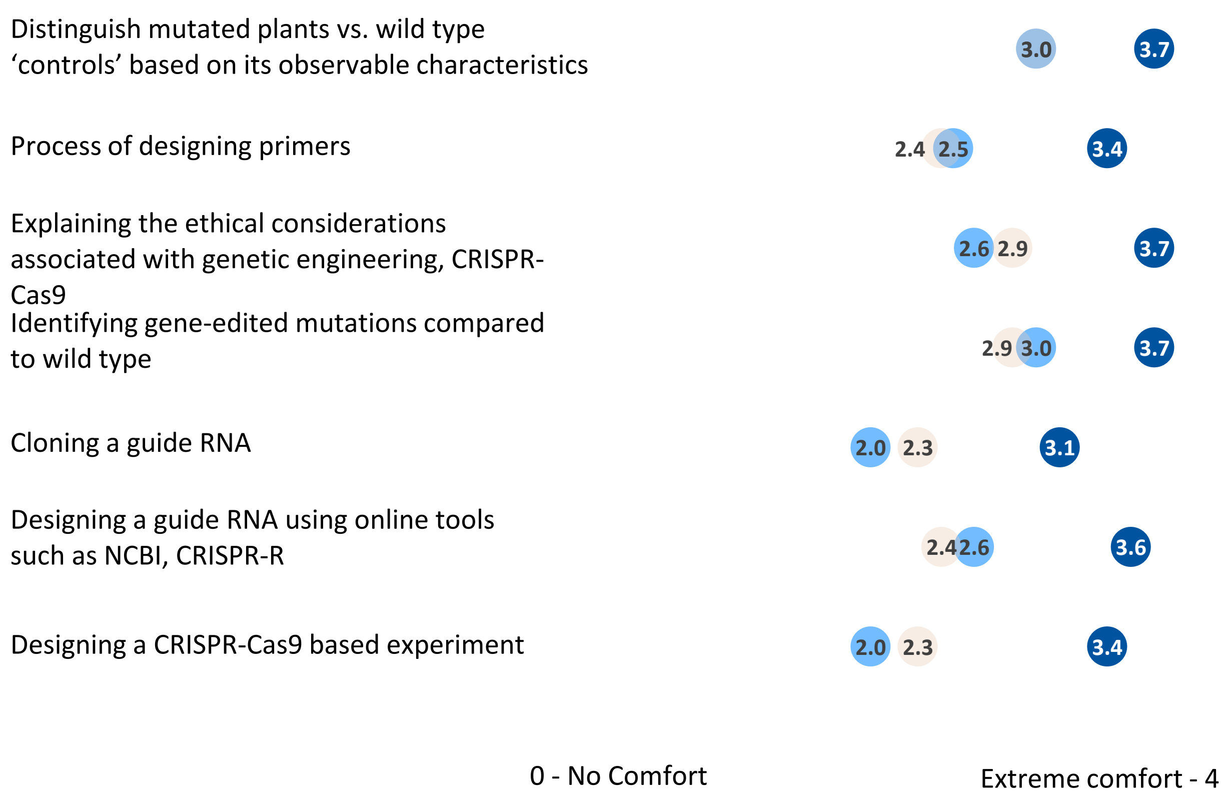


Figure 3. Using a scale of 0 (Not important) to 4 (Extremely Important), average student rating for level of comfort across learning areas at pre (●) and post (●). Light orange (●) represents retrospective ratings where students reflected on their initial comfort level after completing the course.

6 out of 7

students indicated that they consider themself a scientist.

- I am attempting to answer questions by forming a hypothesis, experimentation, and analyzing the data
- I think even beyond research in the lab, I live everyday as a scientist. Asking questions/hypotheses and figuring out those questions is a day-to-day thing.
- I have assisted with many research projects and am also working on my own.

The one student indicating no, provided an explanation in the pre-survey for wanting to further develop their knowledge within the field.

Word clouds are visualizations of text data used to show frequency of word used in the text by increasing the font size of words that were most prominently used throughout the text. Students in the course were asked to define ‘scientist’ at pre- and post-survey. Figure 4 shows the word clouds created based on the definitions students provided at pre- and at post.

The word cloud generated by students responses on the pre-survey is shown top left. Themes identified across students’ responses on the pre-survey using Gemini AI included: curiosity, exploration, experimentation, testing, knowledge and learning, problem solving, and benefitting humanity.

The word cloud generated by students responses on the post-survey is shown bottom left. Themes identified across students’ responses on the post-survey using Gemini AI included: inquiry, problem solving, hypothesis-driven approach, experimentation, observation, evidence-based reasoning, and contribution to knowledge.

Figure 4. Word clouds for defining a ‘scientist’ at pre- and post-survey.

Students enrolled in the course were asked to indicate their beliefs using 'yes/no' responses on the potential and implications of gene editing in agriculture. For each question, students were encouraged to explain their answers. Results from their beliefs from the start of the course and at the end of the course are summarized using mosaic plots – graphical visualizations of a contingency table that are useful for showing relationships between two or more categorical variables. Key features of Mosaic plots include:

- The total area of the plot is proportional to the total number of observations.
- The width of each column is proportional to the number of observations in each level of the variable plotted on the horizontal axis.
- The vertical length of the bars within each column is proportional to the number of observations in the second variable within each level of the first variable.
- Color can be used to highlight the relationships between variables.

In addition, open-ended explanations were coded to gain deeper insights into students' thinking. The focus of this analysis was to understand the thought processes behind students' justifications and track how their beliefs changed throughout the course. To expedite the qualitative coding process, I leveraged Gemini AI, a large language model developed by Google, to streamline the initial thematic coding in students' open-ended survey responses. The AI tool was utilized to generate a preliminary set of codes that capture main themes emerging from the data. These preliminary codes were then used to support a secondary review of the responses to determine the appropriateness of the codes generated and the supporting evidence to support each code.

Pre/Post agreement: Do you believe plant biotechnology (i.e., the genetic manipulation of plants for human benefit) including gene editing, has the potential to positively impact agriculture and food production?

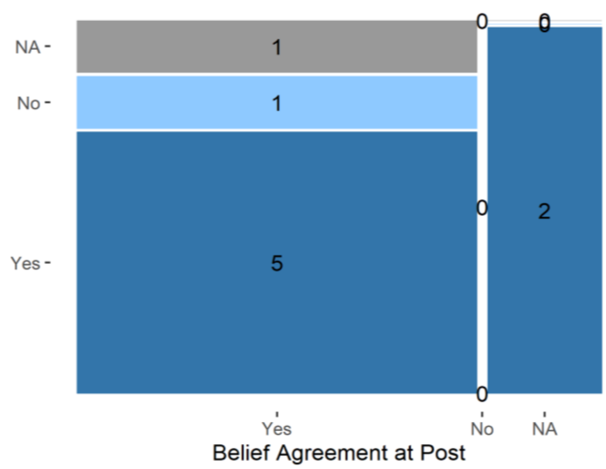


Figure 5. The Mosaic plot visualizes the distribution of 'yes' and 'no' responses to the question, "Do you believe plant biotechnology has the potential to positively impact agriculture and food production?". The x-axis is used to denote post-survey responses with pre-survey responses color coded as dark blue (■) for *yes*, light blue for *no* (■), and missing (*NA*) color coded grey (■).

All seven students who completed the post-survey indicated *yes*. For these students, five out of the seven had also indicated *yes* at pre, one changed their response from *no* to *yes*, and one student did not complete the pre-survey. Additionally, two students who completed a pre-survey did not complete a post-survey, but had indicated *yes* at pre.

Open-ended explanations provided before and after the course. Color coding is used connect explanations to yes/no response, where *yes* is dark blue (■) and *no* is light blue (■). Explanations at pre included increased efficiency and productivity, addressing global food security challenges, and adaptation to changing environment. Explanations at post were similar, but with language that suggested efficiency and precision, climate change resilience, and comprehensive benefits.

Before	After
▪ We need methods to speed up traditional hybridization to meet food needs. Gene editing does this ▪ There are many food crisis issues around the globe that can be fixed with science. For example, food biofortification and increasing crop yields. ▪ Depending on how climate change impacts food crops, utilizing biotechnology may be essential to produce enough food, whether that be from increased yield or from plants being manipulated into being able to survive conditions that it may not have been able to previously. ▪ It has the potential to increase crop quality and yield, making farmers more profitable.	▪ I mean, it is self-explanatory. Biotechnology allows for faster, more exact, and more quicker methods of developing desirable traits in plants ▪ I definitely think so. We live in an age where our climate is changing constantly. Agriculture is something that is impacted by climate change, so plant biotechnology is a definite solution. ▪ Through biotechnology, we can more rapidly develop plants that are tolerant to changing conditions due to climate change, heat/cold stress, drought/flood conditions, etc. If we have plants that have a greater output on smaller sections of land, we can continue to produce enough (food, resources) for everyone. ▪ Yes, plant biotechnology, including gene editing, has the potential to positively impact agriculture and food production by enabling the development of crops with enhanced traits such as increased yield, improved resistance to pests and diseases, and greater tolerance to environmental stresses. These advancements can contribute to sustainable farming practices, food security, and adaptation to changing climatic conditions.

Pre/Post agreement: Do you think scientists or countries developing gene edited crops should 'own' the rights for commercial use of these plants?

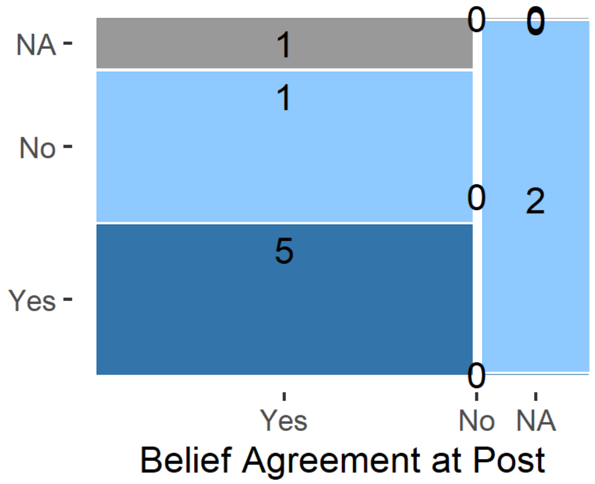


Figure 6. The Mosaic plot visualizes the distribution of 'yes' and 'no' responses to the question, "Do you think scientists or countries developing gene edited crops should 'own' the rights for commercial use of these plants?". The x-axis is used to denote post-survey responses with pre-survey responses color coded as dark blue (■) for *yes*, light blue for *no* (■), and missing (*NA*) color coded grey (■).

All seven students who completed the post-survey indicated *yes*. For these students, five out of the seven had also indicated *yes* at pre, one changed their response from *no* to *yes*, and one student did not complete the pre-survey. Additionally, two students who completed a pre-survey did not complete a post-survey but had indicated *no* at pre.

Open-ended explanations provided before and after the course. Color coding is used connect explanations to yes/no response, where *yes* is dark blue (■) and *no* is light blue (■). Explanations at pre considered recognition and reward for innovation and conditional ownership with public access. Explanations at post tended to focus on incentive for research and innovation, reward for intellectual property, and conditional ownership with considerations.

Before	After
▪ There are many ethical issues with 'owning' food crops, such as cross pollination from gene edited crops to small farmers. I don't believe anyone should have a right to a specific food, especially if it ends up being essential for the production of that food with climate change. ▪ Globally, people should be able to get the benefits so that they can be used around the world in order to meet the demand of growing population. ▪ Only as a patent. After a set number of years, they become public access ▪ Developing science and research takes committed time and effort, I think the people developing this research deserve credit and rights.	▪ As far as specifically commercial use when making an initial sale, I do not feel specifically strongly one way or the other. I believe that any research input monetarily will probably be desired to get as an output in the form of a product. However, I believe that we must be careful with this, so we avoid big companies suing small farmers, or any similar situation. ▪ If they are using a company or university equipment, they don't have 100% of the rights. But they should have a significant say in how it is dispersed and the associated profits. ▪ Science takes time, money, and other resources so having the rights to your research is important. ▪ Yes, scientists or countries developing gene-edited crops should have the opportunity to own the rights for commercial use of these plants, as it can incentivize research and innovation. However, ethical considerations should ensure fair access, equitable distribution, and benefit sharing, especially for crops developed using public resources or traditional knowledge.

Pre/Post agreement: Do you consider gene edited plants to be genetically modified organisms (living things)?

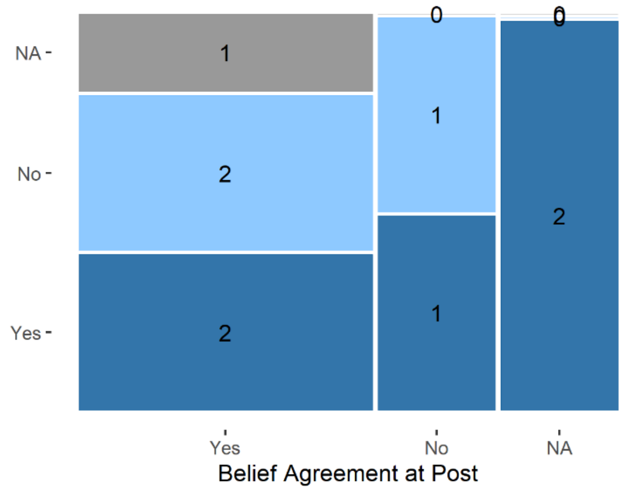


Figure 7. The Mosaic plot visualizes the distribution of 'yes' and 'no' responses to the question, "Do you consider gene edited plants to be genetically modified organisms (living things)?". The x-axis is used to denote post-survey responses with pre-survey responses color coded as dark blue (■) for *yes*, light blue for *no* (■), and missing (*NA*) color coded grey (■).

Five out of seven students who completed the post-survey indicated *yes*. For these students, two out of the five had also indicated *yes* at pre, one changed their response from *no* to *yes*, and one student did not complete the pre-survey. For the two *no* responses at post, one had also indicated *no* at pre, and one changed their response from *yes* at pre to *no*. Additionally, two students who completed a pre-survey did not complete a post-survey, but had indicated *yes* at pre.

Open-ended explanations provided before and after the course. Color coding is used connect explanations to yes/no response, where *yes* is dark blue (■) and *no* is light blue (■). The explanations from students who consider gene-edited plants to be GMOs (Genetically Modified Organisms) at pre- are centered on the focus of the definition or broader definitions of GMOs. Explanations at post include aspects focused on genetic change, nuance with foreign DNA, and scientific accuracy with regulatory context.
The explanations from students who disagree with classifying gene-edited plants as GMOs (Genetically Modified Organisms) focus on distinction from foreign DNA integration.

Before	After
▪ In gene edited plants we are not integrating the foreign DNA, but just creating mutation within the genome ▪ GMO's are created by adding foreign DNA while Gene editing precisely alters a genome without adding DNA. ▪ Yes, since gene edited plants indicates modification. ▪ If you edit the organism, it is modified. ▪ I would consider them as such. Even basic plant cross-breeding is GMO: breeding plants for specific traits. However, the stigma surrounding GMOs in recent years has created a negative discussion around gene-edited plants. I think they can be beneficial when used correctly and safely.	▪ Depends on the incorporation of foreign DNA. ▪ Yes. Anytime a change is made to a genome, it is, by definition, edited. ▪ Yes, there is a genetic change so I would classify these plants as GMOs. ▪ Yes, gene-edited plants are considered genetically modified organisms (GMOs) because they have been altered at the genetic level, albeit using precise techniques like CRISPR-Cas9. However, the regulatory classification of gene-edited plants varies by region and depends on specific definitions and policies regarding GMOs.

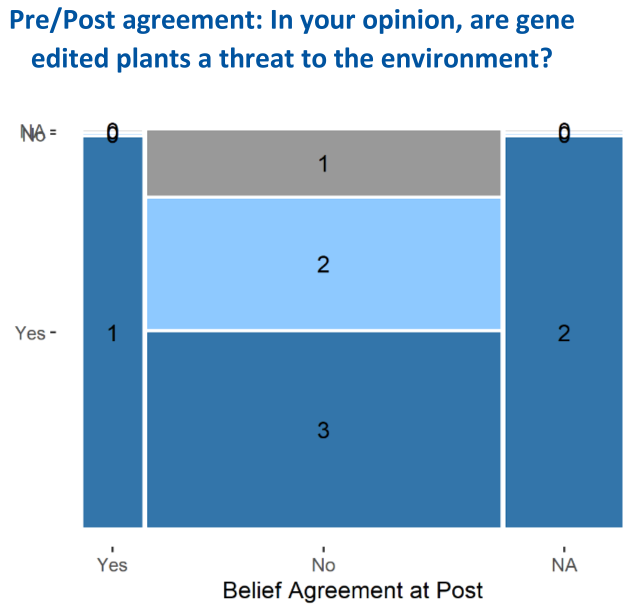


Figure 8. The Mosaic plot visualizes the distribution of 'yes' and 'no' responses to the question, "In your opinion, are gene edited plants a threat to the environment?". The x-axis is used to denote post-survey responses with pre-survey responses color coded as dark blue (■) for *yes*, light blue for *no* (■), and missing (*NA*) color coded grey (■).

Only one out of seven students who completed the post-survey indicated *yes* – constant belief at pre- and at post. Five out of the seven indicated *no*, with three of these students having indicated *yes* at pre. Additionally, two students who completed a pre-survey did not complete a post-survey, but had indicated *yes* at pre.

Open-ended explanations provided before and after the course. Color coding is used connect explanations to yes/no response, where yes is dark blue (■) and no is light blue (■). Thematic coding across explanations for why gene-edited plants may not be a threat to the environment at pre included risk depends on use, potential for environmental benefit, or uncertainty and need for research. Post coding includes low risk of gene transfer as well as management and coexistence. The explanations from students who believe gene-edited plants pose a threat to the environment can be categorized based on the nature of the perceived risks such as unintended consequences, loss of biodiversity, and conditional threats.

Before	After
▪ Not always they are threat to environment. It depends on the way we use. ▪ I would assume gene edited plants are typically contained to the specific reason they were produced. However, I lack research on this question. ▪ I think studying the long-term effects of gene-edited plants can determine this. Gene-edited plants may eventually take over wild-type breeds, so in terms of plant diversity, I think they could be a threat. ▪ There might be some unforeseen consequences. ▪ SOME are. Careless testing and editing can lead to disaster, but if it is careful monitored and tested, then it the threat is minimal and acceptable ▪ In some ways	▪ I believe that any potential for a plant to transfer foreign genes to wild relatives is probably relatively low. Additionally, most of these plants are in cropping systems with few outputs otherwise. However, being careful not to have wild relatives that can breed with gene edited plants nearby may be beneficial. ▪ I think as long as scientists and environmentalists are conscious about native, non-gene edited plants then there is no threat. ▪ In my opinion, gene-edited plants themselves are not inherently a threat to the environment, as the technology can be used to develop crops with beneficial traits like disease resistance and reduced pesticide use. However, the environmental impact depends on how these plants are deployed, managed, and monitored to ensure they do not pose risks such as unintended effects on ecosystems or biodiversity. ▪ They can be if they are not regulated and transparent. I do not think they are currently, but it is a real possibility.

7 out of 7
students indicated the course increased their interest in the field of genetic engineering.

- I am less afraid of the difficulties.
- This class opened my eyes to the possibilities that gene editing research holds.
- Some of the fear of anything gene editing sounding too difficult has been resolved with this course, showing me that when I apply hands on techniques, I am just as capable as my colleagues.

6 out of 7
students indicated that completing the AGSC 4630/5630 course **influenced their major or career interests.**

Yes:

“It gave me more confidence in my understanding of gene editing and techniques

“The class definitely opened my eyes to different career paths/options that are available, specifically aligning using CRISPR.

“Yes, taking the AGSC 4630/5630 course significantly influenced my academic major and career interests. This course introduced me to CRISPR-Cas9 technology, which has become a cornerstone of my PhD research project. The knowledge and skills gained from this course have been instrumental in shaping my research direction and enhancing my expertise in utilizing CRISPR-Cas9 for genetic manipulation. The course provided a solid foundation in understanding the principles and applications of this cutting-edge technology, enabling me to implement advanced genetic engineering techniques effectively in my research. As a result, my interest and proficiency in this area have deepened, aligning my academic pursuits and career aspirations with the forefront of molecular biology and biotechnology.

No:

- I was already fairly sure of my career interest before this class.

7 out of 7
students indicated they could explain gene editing concepts to their family and friends.

“I know I can explain these concepts well

“After taking this class, I feel like I do have more information on gene editing and CRISPR. In addition, I feel as thought I can explain these terms in an effective manner to both scientists and non-scientists.

“I believe that the information I have learned in this course has prepared me to be more knowledgeable in future discussions about gene editing. I also feel like I will be able to relate this topic back to media (movies, shows, books), so that it can be more relatable.

“Yes, I believe I have enough information on gene editing to explain the concepts to my family and friends by describing it as a precise technology used to modify genes in organisms, including plants, for specific purposes like improving traits or addressing diseases. I can also discuss its applications, benefits, and potential ethical considerations in accessible terms.

7 out of 7

students indicated they would recommend this course to another student.

- It is a very good, very well-designed course. Dr. Roy is a very good educator
- This technology can not only be used in plants sciences, but animals, even human beings also.
- This course was engaging and valuable information.
- I have really enjoyed this course and have gained knowledge and confidence with the methods practiced over the semester.
- 100%

Appendix D. AGSC 4630/5630 Focus Group Summary Report

A focus group to gain a deeper insight into students' learning preferences and experiences across different teaching methods was conducted with all nine students enrolled in the AGSC 4630/5630 course on Tuesday, April 23, 2024, during the last hour of their class. [One student had to leave the class early but was interviewed at a later time to provide their input to the questions asked during the focus group. Their feedback was included with the feedback provided from all students.]. The focus group was held within the course classroom – pictured below. Students remained at their seats, and I facilitated discussion from the front of the classroom (opposite windows). The protocol used to introduce the purpose of the focus group with students and the discussion questions are attached.

During the session, I facilitated discussion among participants and took notes of their responses. Students also provided permission to record the discussion. With their permission, the discussion was recorded using a Sony ICD-PX370 Mono Digital Recorder with built-in USB to capture a complete audio record. This recording was uploaded to Otter.ai, a speech-to-text platform, to create a transcript. Due to suboptimal recorder placement, audio quality varied, resulting in gaps within the transcription. Students also received a hard copy of the discussion questions and were encouraged to write down their responses if they preferred. The meeting notes, transcription, and written responses were used summarize key findings that emerged from the focus group.

The focus group was conducted in the AGSC 4630/5630 classroom (pictured below). The setting allowed for all students to participate; however, not all voices were clearly captured on the audio recording

The initial focus group question aimed to identify recruitment methods that informed students about the AGSC 4630/5630 course. Students most frequently cited that they learned about the course through email communication and information shared by faculty at TSU. One student reported learning about the course while selecting their schedule through the school's Banner system.

Overall, the focus group revealed:

- Students valued the instructional approaches utilized by Dr. Roy to teach the AGSC 4630/5630 course, including instructor-led discussions, opportunities for asking questions, and timely assessments to reinforce learning.
- Hands-on experiences were highly valued as effective tools for knowledge acquisition and development.
- Students appreciated clarity of course assessments and recognized the course's potential to enhance communication, teamwork, and critical thinking skills.

Additional findings from the focus group are summarized by question topics. These topics include a) AGSC 4630/5630 course experience, b) engagement and interaction, c) learning preferences, and d) development of workforce readiness skills. Student feedback is supported by direct quotes from transcripts and written responses where available.

AGSC 4630/5630 Course Experience.

- **Positive Experience**. Students expressed high satisfaction with the course and credited the instructor for creating a positive learning environment that encouraged active participation from all students. . Valued aspects of the course included multiple instructional approaches, openness to ask questions, hands-on learning of the practicum, and real-time evaluation quizzes to inform instruction.

  " *I took this course even though I had already completed my courses. I am glad I did.*

  " *She created a safe space to ask questions.*

  " *It felt like even if you made mistakes...you're not shamed.*

- **Student Interest/Motivation**. Students enrolled in the course due to their interest in biotechnology and agricultural science and valued the relevance of the course content to their graduate work and/or undergraduate degree majors.

- **Manageable Course Load**. Both graduate students and undergraduate students found the courseload manageable.

  " *Yes, it was manageable.*

Engagement and Interaction.

- **Engagement.** Students emphasized the importance of instructor-facilitated dialogue, opportunities for student inquiry, and ongoing assessment as key activities contributing to students' engagement in the learning process. Students also noted that interest in course material factors into students' engagement.

  " *Overall, learning environment was good. I have learned how to employ CRISPR tech in plants. Especially Q&A sessions made me to be more attentive in class.*

- **Inclusive Learning Environment**. Students commended the instructor's approach of beginning each class with casual questions to foster engagement, then skillfully connecting these seemingly unrelated topics to the day's course material.

Learning Preferences.

- **Positive Teaching Methods**. Students held diverse views of what constituted the most effective teaching methods, but generally concurred that combining various approaches, such as lectures, hands-on activities, and group discussions, yielded better learning results than a single method.
  - " *I prefer interactive lecture & hands-on.*
  - " *Combination is best. Lectures first, and hands-on next.*
  - " *Combination is a good pathway for better learning.*
  - " *Lecture & hands-on activities + group discussions too.*
- **Negative Teaching Methods**. Students noted that exclusive use of lecture format, particularly when combined with reading slides word-for-word, hinders student learning and engagement.
  - " *Explain with whole text in PPT.*
  - " *Just PowerPoint lectures and book reading for the full length class.*
- **Active Learning**. Students highly favored hands-on learning to deepen their understanding of course content.
  - " *The practical gives you information to put a name to it. The practical gives you hands on experience with tools you may not have used before.*
- **Assessment**. Students showed appreciation for multiple types of assessments that supported learning including tests and quizzes.
  - " *The quizzes, I think that really helps like to check your knowledge.*
  - " *If it's a 85% loss? She would back up and go over it again.*
  - " *Benchling, Blogs, definitely tests [are] helpful in measuring understanding of material.*
- **Group Work**. Students expressed negative attitudes towards group work, often citing issues such as unequal workloads, dominated group dynamics, and minimal contributions from some members.
- **Class Size**. Students perceived smaller class size as more conducive to learning.

Development of workforce readiness skills.

- **Skill Development**. Students were asked to indicate how courses can be designed to cultivate work-readiness skills in students and then to indicate how courses at TSU and/or the AGSC course supported the enhancement of these skills. However, students' feedback referred to specific examples for how the AGSC 4630/5630 course enriched different work-readiness skills.

  Students recognized that multiple course components enhanced their communication, teamwork, and critical thinking skills.

  > “ *The assignments like blog posts & discussion on ethics of CRISPR tech helped develop soft skills.*

  > “ *"The goal was to write about a novel technology with a disease or an issue that's being fixed, and you had to write in a jargon that can be understandable to the layman…and you know, that's challenging and it kind of makes you think about how, how would you rephrase that given [a different audience].*

  > “ *And so the soft skills are transferable to any environment...*

  > “ *Yes, by writing blog posts, will make us think to make them understand to layman.*

  > “ *Open discussion and the practical like calls for teamwork and communication skills"*

- **Benchling.** Students indicated that additional skills gained through the course included use of Benchling (a cloud-based platform for biotechnology research and development) to complete their lab notebooks.

GSC 4630/5630 Focus Group Protocol / Semi-Structured Questions

Focus group script: Hi, I am Robin Taylor, an external evaluator for the NSF HBCU-UP program to develop a CRISPR-Cas9 gene-based editing technology curriculum at TSU. I am the Principal and Senior Evaluator of RTRES Consulting, a small business I established to support programs to use data effectively to assess their projects. The purpose of this focus group is to collect information about your learning and teaching preferences as well as your experience with the new CRISPR-Cas9 gene editing curriculum. I will summarize the information learned from today's focus group such that what is said cannot be identified or attributed to an individual. I ask that what is discussed today is kept confidential between us, but I cannot guarantee that others in the room will hold to confidentiality. If you are concerned about speaking something in front of the group, I encourage you to write your thoughts down and share them with me separately.

I would like to record today's discussion so I can listen to what was said at a later time and clean up anything I may miss within my notes. I will only do so if everyone is okay with me doing so.

---pause to get agreement or not and audio record only if everyone is okay with doing so. ---

Thank you for agreeing to participate in this focus group.

Before we begin, I will encourage everyone to participate, but no one is required to speak. Your participation is voluntary and you may choose to stop participating at any point and can choose to not answer questions. Some points I'd also like to make:

- There are no right answers – everyone's opinion is important.
- There's no expectation for consensus – people can disagree, but please do so respectfully.
- Please have only one person speak at a time.
- If someone wishes to end their participation, they should feel free to get up and leave without disrupting the group.

Name:

1. How did you learn about the AGSC 4630/5630 Gene Editing with CRISP-Cas9 course?

Learning Preferences.

1. How do you typically learn best? Do you prefer lectures, hands-on activities, group discussions, or a combination?

2. In your experience, what teaching methods have helped you retain information the most effectively?

3. Are there any teaching methods you find particularly confusing or frustrating? Why or why not?

4. What types of assessments do you find most helpful in measuring your understanding of the material? (e.g., Tests, presentations, projects, or a mix?)

Engagement and Interaction.

5. Think about past classes. When did you feel most engaged in the learning process?

6. In your opinion, how can teachers create a classroom environment that encourages active participation?

7. Imagine you are designing your ideal learning environment. What teaching methods would you incorporate?

AGSC 4630/5630 Course Experience.

8. Describe the overall learning environment in this course (positive and negative aspects).

9. Did the workload feel manageable alongside your other courses?

10. Did the course content feel relevant to your overall academic interests or career goals?

Development of workforce readiness skills.

11. Beyond technical skills, how can courses help individuals develop "soft skills" crucial for workplace success (e.g., teamwork, problem-solving, communication)?

12. Do you feel attending TSU and/or completing the AGSC course helped to strengthen your own "soft skills" for future workplace success? Such as…
    Please explain.

    - Collaboration and Teamwork
    - Critical thinking & Problem solving
    - Communication
    - Creativity and Innovation

13. Any additional soft skills you feel were strengthened during your attendance at TSU?

14. Please share any additional comments of feedback regarding the genetic engineering course you took.

Appendix E. Summary of Student Researcher Interviews

One outcome of the NSF HBCU-UP award (#2205542) is to offer undergraduate students practical training in bioinformatics-based design and wet lab techniques for CRISPR-Cas9 gene editing. During the 2023-24 academic year, a total of four students participated in research projects within the labs of Drs. Roy and Taheri. A purpose of the evaluation for the NSF grant is to understand the experiences and outcomes of these student researchers.

METHODOLOGY

To explore impact of participation in undergraduate research projects, identify challenges faced by student researchers, and gain a comprehensive understanding of their experiences, semi-structured interviews were conducted with student researchers involved with grant-supported research projects during the 2023-24 academic year. Students were provided a small monetary compensation for their time.

Fall semester. In December 2023, interviews were conducted for two out of the four student researchers using the zoom video conferencing platform.

Spring semester. In April 2024 interviews were held with all four student researchers. Three interviews were conducted in-person with students on the TSU campus and one interview was rescheduled and conducted via zoom.

Additional interviews were also conducted with faculty research advisors and a lab mentor. Informed consent was obtained from all participants for recording their interviews. Audio recordings were uploaded into Otter.ai, a speech-to-text software application that uses artificial intelligence to transcribe conversations in real-time. These transcriptions were then reviewed for accuracy and were used as a primary reference source for generating this report.

Due to the small number of undergraduate student researchers, information gained through discussions with faculty and lab mentors is used to supplement details about undergraduate research experiences in general. This approach is intended to help maintain confidentiality and anonymity of student responses. While these observations are included to contribute to a broader understanding of undergraduate research experiences, they do not necessarily reflect specific feedback provided by the fours students interviewed in this report. This additional context is included to support reflection and considerations across undergraduate research experiences more generally.

OVERVIEW OF RESEARCH PROGRAM

Student Recruitment

All students supporting research projects with CRISPR-Cas9 funding were recruited through TSU's College of Agriculture Dean Scholars Program. The Dean's Scholars Program is a financial assistance program designed to provide a selective set of academically talented students within the Colleges of Agriculture, Human Sciences, and Life & Physical Sciences opportunities to participate in research experiences during their undergraduate studies.

Faculty members typically initiate contact with students to assess their motivation, expectations, and interests, aligning these with potential project opportunities within their labs. An onboarding process shared by Dr. Roy includes the following steps:

- **Initial Discussion.** A preliminary meeting between the faculty member and student to discuss expectations, goals, and preferences for the research experience.
- **Research Agreement**. A written agreement or plan is established outlining meeting frequency, duration, location, and cancellation policies to ensure a structured research environment.
- **Student Goals.** Students identify specific skills or experiences they hope to gain through the research experience.
- **Faculty Expectations.** The faculty member outlines expectations for the student's development based on their identified skills and experience.
- **Ongoing Feedback and Reflection.** Throughout the research experience, students are encouraged to self-reflect on their career aspirations, feedback preferences, and time commitment.
- **Periodic Reviews**. At the end of each mentoring period, the faculty and student review progress and achievements related to the research experience.

Lab Safety Training

All students are required to complete lab safety training before being permitted to work in a research laboratory. This training covers basic molecular techniques and is essential for all students, regardless of experience level. This training can be fulfilled in two ways:

1. **Online Modules**. Students may complete online training modules and pass accompanying quizzes with a minimum score of 80%.
2. **In-Person Training**. Students can alternatively attend an in-person training session conducted by a safety coordinator.

Undergraduate Research

Once matched with a faculty member and research project, students work directly with a hands-on lab mentor within the lab, (e.g., graduate research assistants or postdocs). They can typically work up to 12 hours per week in the lab, scheduling their time around coursework and other college commitments. Students are encouraged to coordinate their research availability with the lab's operating hours and the schedule of their lab mentors.

Lab mentors will introduce students to the lab facilities, equipment and safety protocols, and generally serve as the students' main contact for:

- **Teaching Lab techniques**. Demonstrating and guiding students through essential techniques like DNA extraction, PCR, gel electrophoresis, and cloning.
- **Explaining scientific concepts**. Breaking down complex biological concepts and theories into understandable terms.
- **Troubleshooting experiments**. Helping students identify and resolve issues that may arise during their research.

Undergraduate student researchers begin with smaller, less complex projects to build confidence and master fundamental research techniques. Weekly lab meetings, designed to provide opportunities for observing research presentations, learn from peers, and participate in discussions are mandatory. In general, project assignments are tailored to students' interests and time constraints.

STUDENT RESEARCHERS

During the 2023-24 academic year, four female undergraduate students participated in CRISPR-related research projects. All four students were pursuing Agricultural Science degrees, with three specializing in Biotechnology and initially considering pre-med. The fourth student was pursuing a double major in Agriculture and Political Science. Given that all students were from out of state, attending the HBCU likely involved increased financial costs. This may be a contributing factor for students participating in the Dean Scholars research work program, as it may help to offset some of the higher tuition costs in addition to providing valuable research experience.

Findings

The undergraduate student researchers expressed overall positive experiences of their involvement with research projects. Benefits of the experiences included academic and personal development as well as professional and career development. Each student described beneficial mentoring relationships with faculty and in-lab mentors, which included guidance, support, and opportunities for discussion. The experience also appears to have strongly influenced one student's choice to consider a career focused more on research in agriculture or biotechnology vs. medicine. While the other three student researchers see transferable benefits of their participation to their own current career trajectories.

In-depth interviews with students revealed that hands-on laboratory experiences significantly contributed to the development of both technical and professional skills. To systematically analyze the interview data, thematic coding was employed to identify key patterns and concepts within the transcripts. This analysis resulted in four primary themes: knowledge acquisition, laboratory techniques, research skills, and professional development. Further subcategories were developed within each theme to delineate specific aspects. To ensure the robustness of the findings, the coded data was examined across all four student participants, allowing for cross-case comparisons. Table 1 presents the thematic coding framework and the frequency of themes across participants. A summary of these findings by the four primary themes follow.

Knowledge Acquisition. All students reported significant knowledge gains from the undergraduate research experience. A cross-sectional analysis of the data revealed a common increase in understanding across core topics in plant science, biotechnology, and gene editing techniques. Evidence of additional knowledge acquisition emerged, particularly among students with greater research exposure.

Research Skills. All students reported growth in research skills particularly in data collection and interpretation across experimental conditions. More experienced student researchers demonstrated additional advancements, including refined information seeking strategies, increased autonomy in research endeavors, and enhanced troubleshooting capabilities. One student researcher is actively developing computational proficiency in Python and Biopython for sequencing data analysis.

Professional Skills. Students demonstrated significant growth in a variety of professional skills through their research involvement. Explicitly mentioned improvements included communication, problem-solving, critical thinking and time management. (The skill development of critical thinking and time management was indirectly inferred from one student's interview – shaded lighter in the table.) Interview data also revealed evidence of enhanced teamwork, adaptability, intellectual curiosity, growth mindset, and student initiative.

Laboratory Techniques. Participants consistently reported gaining proficiency in various laboratory techniques. Essential skills like aseptic techniques, equipment operation, and sample preparation were mastered by all students. More specialized techniques, such as genotyping, microscopy, and sequencing were acquired to varying degrees depending on project requirements and student experience.

Table 1. Thematic coding framework for impacts of student research and frequency of themes across participants.

Knowledge Acquisition				
Deeper understanding of gene-editing techniques	■	■	■	■
Understanding of plant science and biotechnology	■	■	■	■
Ethical considerations	■	■		
Deeper understanding for application of CRISPR-Cas9 in agriculture	■	■		
Molecular biology fundamentals	■	■		
Research methodology	■	■		
DNA sequencing	■			
Research skills				
Data collection (gathering and recording experimental data	■	■	■	■
Data analysis (interpreting results)	■	■	■	■
Information seeking	■	■	■	
Independent research	■	■		
Confidence in troubleshooting basic issues	■	■		
Python and BioPython to analyze sequencing data	■			
Professional Skills				
Communication and Presentation	■	■	■	■
Problem-solving	■	■	■	■
Critical Thinking	■	■	■	▫
Time management	■	■	■	▫
Collaboration and Teamwork	■	■	■	
Adaptability	■	■	■	
Intellectual curiosity	■	■	■	
Lifelong learning	■	■		
Initiative	■	■		
Metacognition	■			
Lab Techniques				
General laboratory practices	■	■	■	■
Improved understanding of lab terminology and equipment	■	■	■	■
Aseptic techniques (prevent contamination)	■	■	■	■
Sample preparation	■	■	■	■
Pipetting	■	■	■	
PCR (Polymerase Chain Reaction)	■	■	■	
Gel electrophoresis	■	■	■	
Plate pouring and handling	■	■		
DNA extraction	■	■		
Microscopy	■	■		
Sequencing	■			
Sequence alignment	■			
Centrifugation	■			

Faculty members and laboratory assistants were found to be open and encouraging to support students' questions and concerns about their roles in the lab. Lab assistants serve a pivotal role in mentoring students as they are more accessible and available to provide immediate assistance, but faculty members were also noted as being approachable and demonstrate willingness to spend time answering students questions and addressing concerns.

Challenges

An additional intention for interviewing students was to understand challenges and issues students encountered within their undergraduate research experiences. While feedback from students was overwhelmingly positive, the following themes demonstrate some potential challenges revealed directly or indirectly through interviews with the students, faculty advisors or lab mentors, and review of literature on undergraduate student research experiences. Themes are grouped by scheduling, academic, research-specific, and personal/professional challenges. Best practices or approaches used to address these challenges are also provided when appropriate.

Scheduling. Undergraduate students often juggle demanding academic coursework with other commitments, limiting their availability for research. Restricted access to university research labs, particularly during standard work hours, presents additional scheduling challenges. These challenges are not easily addressed if research labs include hazardous materials or complex equipment that impact safety concerns, or if staffing is limited. Addressing this challenge may include exploring opportunities for students to work in the labs during evenings or weekends, or place more emphasis on the restricted scheduling when working to identify best fits between students and research projects.

Academic. Undergraduate students enter their research experiences with varying levels of scientific literacy. For many, participating as researchers is a novel and new experience. They may struggle with identifying equipment and understanding terminology utilized within the lab. Scientific jargon can be a barrier for new researchers, and can lead students to spend unnecessary time deciphering commonly used metrics, abbreviations, or terms. Over time, students increase their scientific literacy through the support of mentors and by actively seeking to clarify unfamiliar terms and abbreviations. Creating a cheat sheet of terminology could be helpful in facilitating students' focus on learning about the research projects. By providing a reference tool, students can more easily understand the language used in the lab, allowing them to dedicate their time and energy to mastering the research process.

Heavy academic workloads can negatively impact student researchers' ability to effectively manage their time and research. While faculty advisors and lab mentors often prioritize students' coursework, students who rely on financial support from their research may be less likely to reduce their involvement, even when they feel overwhelmed.

Research-Specific. Failures and setbacks are an inevitable part of research and scientific inquiry. These challenges can arise from a variety of factors, including experimental design flaws, technical errors, unexpected variables, theoretical limitations, and statistical fluctuations. While frustrating, these setbacks can offer valuable learning opportunities and lead to new discoveries. By understanding and embracing the potential for failure, researchers can develop resilience and ultimately contribute to scientific progress. Student researchers engage in various laboratory techniques, and learn through trial and error. They quickly discover the importance of aseptic techniques, equipment operation and proper sample preparation. The expectation of failure within the lab can enhance students' grit and resilience. This understanding can help them to persevere through challenges and continue to learn from their experiences.

Personal. Undergraduate students often face personal challenges while conducting research. They are developing effective time management skills to balance research with other academic and personal commitments. Students may experience self-doubt or struggle to stay motivated, particularly during challenging periods in their research, academic workload, or personal life. Faculty and mentors can provide significant support to students facing personal challenges. Support strategies can include active listening and empathy, problem-solving and guidance, flexibility and understanding, as well as mentorship and role modeling.

Communication. Finally, conveying complex research findings to diverse audiences and in various formats can be a significant challenge. Researchers often struggle with using overly technical language, simplifying complex topics, meeting the expectations of different audiences, adapting to format limitations, creating effective visuals, and navigating cultural differences. To overcome these challenges, researchers must tailor their communication, use clear and concise language, employ effective visuals, practice storytelling, and seek feedback. While students may have opportunities to improve their written, oral, and visual communication skills through coursework, additional opportunities to practice communicating their research findings are widely beneficial. These opportunities can help students develop the skills they need to effectively convey their work to a variety of audiences.