Proceedings of the ICBBG2025
2025 International conference on Bio-mediated and Bio-inspired Geotechnics
18-20 May, 2025 | Tempe, Arizona, USA
https://doi.org/10.53243/ICBBG2025-53

Shaping High School Students' Educational and Career Paths Through University Engineering Lab Experiences

Leah S. Folkestad, Ph.D.[1] and Jean S. Larson, Ph.D.[2]

[1]Center for Bio-mediated and Bio-inspired Geotechnics, School of Sustainable Engineering and the Built Environment, Arizona State University, P.O. Box 873005, Tempe, AZ 85287-3005; E-mail: folkestad@asu.edu
[2] Center for Bio-mediated and Bio-inspired Geotechnics, School of Sustainable Engineering and the Built Environment, Arizona State University, P.O. Box 873005, Tempe, AZ 85287-3005; E-mail: jean.larson@asu.edu

ABSTRACT

Engaging in hands-on laboratory experiences at a young age develops essential skills, such as problem solving and critical thinking, while steering students to pursue degrees and careers in STEM fields. Eleven high school students participated in a Young Scholars Program offered at three universities during the spring and summer terms of 2024. The in-person, mentored research experiences exposed students to engineering fields while they contributed to a research team. Students worked with geotechnical experts, collaborated in a lab, shared knowledge at public outreach events, and produced and presented a research poster. Participants reflected weekly on what they learned, the next steps, suggested improvements, and shared their plans to pursue degrees and careers in the field. The format of the program will be described, along with participant reflections on the program's impact on knowledge, skills, and educational trajectory.

INTRODUCTION

Engaging in hands-on research experiences during high school develops skills in communication, problem solving, leadership, and research while guiding students towards pursuing degrees and careers in science, technology, engineering, and mathematics (STEM) fields. Eleven high school students participated in a Young Scholars Program (YSP) offered at three universities during the spring and summer terms of 2024. Through mentored research experiences, participants learned about the biogeotechnical engineering field while contributing to a research team. Participants worked with student mentors, collaborated in a lab, shared knowledge at public outreach events, and produced and presented a research poster. Participants reflected weekly on what they learned, the next steps, and suggested improvements. The program format and impact on participant knowledge, skills, and educational trajectory are described.

Program Overview

The YSP immerses high school students in technical research and exposes them to the university experience, specifically within the scope of the National Science Foundation (NSF)-funded Engineering Research Center for Bio-Mediated and Bio-Inspired Geotechnics (CBBG). By participating in hands-on, mentored experiences in cutting-edge laboratory research, Young Scholars are introduced to the biogeotechnical engineering field, connect with engineering professionals, build desired skills, and contribute to on-going CBBG research. Students learn about

possible undergraduate degree programs, graduate school, internships, and career options with the goal of stimulating Young Scholars' interest in pursuing education and careers in engineering.

The program is offered in a hybrid format, with an asynchronous component (eLearning modules, discussion boards, assignments, etc.) using the Learning Management System, Canvas, and the messaging application, Slack. A synchronous, in-person component includes training, lab experiences, research team meetings, invited speakers, and presentations. Participants connect with mentors and participants at other CBBG university partners via video conferencing on Zoom.

Research Questions

This study was designed to address two research questions:

1. *How does this program expose high school students to research experiences and STEM fields*?
2. *How do early research experiences impact/shape the direction of educational and career paths of high school students*?

PARTICIPANTS AND PROJECTS

The CBBG YSP opportunity is available to students interested in STEM, who are local to one of the four CBBG university partners: Arizona State University (ASU), Georgia Institute of Technology (GT), New Mexico State University (NMSU), and University of California, Davis (UCD). Innovative, sustainability-minded, local high school students interested in the disciplines of microbiology, biology, geochemistry, geology, civil engineering, plant science, soil science, geoenvironmental science, engineering education, or related areas, are selected to participate in this paid program. Since 2016, a total of 58 high school students have participated in the CBBG YSP, with an average of six each year. Over the 2024 spring and summer terms, 11 high school students, along with 18 faculty and student mentors, participated in the program. Eight high school students were hosted in the spring and three were hosted over the summer. Three of the project teams were composed of more than one Young Scholar, while the rest each hosted one student.

Most participants learned of the program through their teacher or through general outreach. Former CBBG Research Experiences for Teacher (RET) program participants identified high school students who showed special interest in a CBBG lesson they developed and implemented. Other applicants heard about the opportunity through resource fairs, after school programs, and other outreach events. Two participants found out about the program from a CBBG industry partner.

During the application and selection process, participants rank and are matched with a research project that aligns with their interests. Details of the 2024 projects offered during spring and summer are listed in Table 1 below.

Table 1. 2024 CBBG Young Scholar Projects

Site	Project	YSP	Mentors
ASU	Using the Fungus Among Us for Soil Improvement	2	4
ASU	Screw it Up, Screw it Down: Bio-inspired Helical Self-burrowing Robot	2	2
ASU	Microbial Chain Elongation Mediated Dehalogenation and Carbon Transformation	1	2
ASU	Plant Extracted Polymer for Dust Control	3	3
GT	3-D Printing of Bio-inspired Digital Twin Artifacts	1	2
GT	Spiderweb Geogrids	1	2
NMSU	Bio-cementation to Mitigate Erosion in Sandy Sloped Ground	1	3
	Total	**11**	**18**

FORMATIVE METHODS

To gather evidence of student learning and make necessary modifications in real-time, a variety of formative data were collected through program applications, video introductions and discussions, participation in outreach, weekly updates, mid-program survey, assignments, presentations, and posters.

Program Applications

Program applications were checked for alignment with the program and to see if applicants would be a good match. Participants were asked why they would like to participate in the program, list courses that are relevant to biogeotechnical engineering research, and to describe their academic and professional goals. Those who have a general interest in STEM will benefit from the exposure to engineering research.

Orientation and Pre-work

Prior to the start of the program, participants completed safety and lab-specific training, viewed project overview videos, posted a video introducing themselves, and met with their research team. The purpose of the orientation and pre-work is to generate enthusiasm for biogeotechnical engineering and prepare participants for the program. Participants viewed 15-minute Project Overview Videos created by mentors introducing each research project. This approach exposed participants to all research projects across the Center, not just the project they were working on during the program.

Research Team Meetings

To create a sense of community among participants, mentors, and research teams, Young Scholars posted a three-minute video about themselves to the discussion board in Canvas. Participants shared a positive or funny educational story and were asked to respond to others. Mentors also posted an introduction video and replied to participant introductions. This gave the mentors a chance to learn about the Young Scholars before the initial meeting. During the first research team meeting, students and faculty mentors discussed and answered questions on their project.

Modules

Participants completed five modules focused on different topics (career connections, creating research posters, graduate school, and professional networking), often with a guest speaker.

Module 1 | CBBG Research and Projects: Participants learned about CBBG, biogeotechnical research, and the seven specific projects. They met the CBBG team, mentors, and other program participants, and toured the labs.

Module 2 | Research Project Summary: Participants continued their research, learned to summarize evidence-based research, and began working on the Project Details and Background and Rationale sections of their Research Project Summary. All participants learned about particle size and soil mechanics while performing a sieve analysis.

Module 3 | Research Posters: While continuing their research, participants learned about creating a research poster and presenting academic research. Participants wrote the Research Objectives section of their Research Project Summary. Some participants had the opportunity to participate in outreach activities (field trips, demonstrations to community, lab tours, etc.).

Module 4 | Career Connections: Participants learned about what it is like to be an engineer, engineering career pathways, and entrepreneurship. Participants completed a draft of their poster and the Methods and Materials section of their Research Project Summary.

Module 5 | Presenting Academic Research: Participants learned about presenting and writing research and completed the Results and Conclusions section of their Research Project Summary. Mentors reviewed research posters. At the end of the program participants finalized their poster for printing and shared their research findings through poster presentations.

Weekly Module Updates

Students provided weekly updates that were administered through a quiz in Canvas as part of the program's formative evaluation. This feedback loop helped to immediately address any issues. Participants were asked to reflect on the same four questions each week: 1) *What did you learn this week/module?* 2) *What do you plan to accomplish next?* 3) *What did you enjoy the most about this week/module?* and 4) *What can we do to improve your experience?*

Mid-program Survey

After the first few weeks, participants completed a 15-minute survey asking their current satisfaction with the program, collaboration, research experience, interaction with project staff, and mentor support. Students were asked to describe one or two experiences that they consider to be successful or challenging and if the issues were resolved.

Field Research and Outreach

Participants were given the opportunity to join in field research and outreach activities such as lab tours, field testing, collecting samples, and sharing research with the public. These experiences allow participants to practice clearly communicating their understanding of the research.

Final Deliverables

Using the Research Project Summary template, participants summarized their research (Project Details, Background and Rationale, Research Objectives, Methods and Materials, Experimental Results, and Research Conclusions). Results from the summary were directly aligned to the research poster and presentation templates. Through these final program deliverables, participants shared their research findings and were asked to reflect on their experience.

SUMMATIVE METHODS

The program's effectiveness and impact were measured through a post-program survey and focus group interview. The evaluation leveraged the Multi-ERC Instrument Inventory (MERCII), which was developed by several members from CBBG and five other ERCs as part of an NSF-funded Research in the Formation of Engineers (RFE) grant, to expand data collection tools to evaluate university and pre-college programs (Melo de Lyra et al. 2023).

Post-program Survey

At the end of the program, participants completed a 20-minute survey asking about the program's impact on their skills and academic and career trajectory. For questions in the *Understanding of the CBBG*, *Communication Skills*, *Leadership and Innovation*, and *Research Skills* sections, participants rated the program impact on a five-point Likert scale: Not at all = 1; Very little = 2; Somewhat = 3; Quite a bit = 4; and A great deal = 5. The *Educational Trajectory* items included closed-ended questions in addition to a five-point Likert scale (Not at all certain = 1; Slightly

certain = 2; Moderately certain = 3; Very certain = 4; Completely certain = 5), which asked participants to indicate plans for future degrees. The *Program Satisfaction* section asked participants to rate to what extent they agree or disagree with statements related to their experience, using the following Likert scale: Strongly disagree = 1; Disagree = 2; Neither disagree nor agree = 3; Agree = 4; and Strongly agree = 5. Open-ended questions allowed participants to provide recommendations to improve the program and commented on challenges or successful aspects of their experience.

Focus Group Interviews

The 60-minute focus group was based on the MERCII Focus Group Protocol (Zhao et al. 2022). Questions focused on two areas:

Impact on Skills: The following questions will focus on your knowledge, skills and/or abilities related to the CBBG program. Tell me about some of the things you've learned through your participation in the CBBG Program. What about research skills, problem solving skills, and/or communication/collaboration skills? What have you learned related to biogeotechnical engineering?

Program Satisfaction: Please provide examples of how you will use these things you've learned moving forward. What specific CBBG activities had the greatest impact on your learning?

FORMATIVE RESULTS AND DISCUSSION

Data from various activities were analyzed throughout the program to ensure student learning and to modify the program as necessary.

Program Application

Reasons reported for wanting to participate in the Young Scholar program were around innovation, research, and to enhance skills. Participants were looking for hands-on experience in a lab and to solve real-world problems while learning about the engineering profession. Some participants wanted to experience college, explore majors, prepare for future studies, work with a mentor, and learn from an expert in engineering.

Applicants were asked to rank the available projects on each campus to help in assigning them to projects that match their interests. After all offers were sent to the participants, one of the projects was moved to a different campus so several Young Scholars ended up joining another project. Hosting several students on one project ended up being one of the strengths of the program, according to both Young Scholars and their mentors.

Participants recognized the interdisciplinary nature of the field of biogeotechnics, citing high school courses and topics they completed that they believe would be relevant to the program. Although most courses were STEM courses and included many AP and Honors-level, participants indicated interest in topics not always offered at the high school level, including engineering, robotics, biomedical sciences, and technology.

Students' academic goals after high school were to pursue bachelor's and advanced degrees in STEM fields including civil, chemical, environmental, aerospace, biomedical engineering, chemistry, biochemistry, and mathematics. Some participants mentioned the goal of applying to one or more of the CBBG member universities. Professional goals ranged from undecided with general goals of "*problem solving, critical thinking, pushing the bounds, exploring, innovating, helping others, protecting the environment, and making a positive difference in the world*" to

specifics like "*working for a biomedical company, becoming a medical doctor, intersecting engineering with medicine and becoming a professor of nuclear chemistry*."

Mid-program Survey

Halfway through the spring program, Young Scholars were asked to describe a successful experience. Participants enjoyed learning to use lab equipment, receiving clear instruction, creating samples, and conducting a sieve analysis. Participants were challenged by scheduling conflicts, difficulties with machinery, and overwhelmed by the thought of creating a research poster. "*Creating a poster … seemed a bit overwhelming. However, through the help of my mentor, this poster became much easier as I was provided with both an example of a poster and different resources.*" Challenging experiences were resolved through practice, examples, resources, and mentor assistance.

Spring mentors did not have the opportunity to participate in mentor training and some were first-time mentors. "*I think that perhaps starting earlier and having a more organized schedule for each group would be really helpful…like mine in particular started a little late due to scheduling conflicts and such.*" One participant suggested mentors provide a "*better system for lab hours and working with mentors.*"

While working with mentors to improve the scheduling for the spring participants, it became clear that the program is more effective during the summer.

Field Research and Outreach

In response to feedback and to enhance our goal of immersing participants in the lab experience, several opportunities to participate in outreach were made available during the program. Contributing to outreach activities allowed participants to take a leadership role, practice what they have learned, reflect on their experience, and be an expert on something. Students reported that the research "*makes me feel as though I am contributing to a larger picture in a helpful way.*"

Several Young Scholars volunteered in the spring at a large outreach event for the public called ASU Open Door. Students spent five hours alongside their mentors helping younger children with hands-on activities and explaining CBBG research. Participants showed leadership and were able to verbalize what they were learning to an audience of non-experts.

Young Scholars were also given the opportunity to participate in field trips. Students at Georgia Tech joined a field trip to Rafael Bras' farm to collect ants, observe ant nests, and cast a nest to bring back to the lab. ASU teams visited a test site in Pinal County, Arizona near Casa Grande and the rainfall simulator at the CBBG Soils Lab, located on the ASU Polytechnic Campus. These experiences showed Young Scholars ongoing research they have been performing in the lab, at a larger scale.

Module Updates

Participants reflected weekly on what they learned, the next steps, and suggested improvements. This feedback allowed those running the program to immediately address any issues as they arose. It also helped teams stay on track with their research to finish in a relatively short timeframe.

Module 1 | CBBG Research and Projects: Participants reported that they met with their research team and read research to learn the fundamentals and techniques of their specific project and biogeotechnical engineering. Participants also began to decipher why some methods are better than others while looking at environmental and economic impacts. The highlights for most participants

were meeting other researchers and participants, becoming familiar with the lab, and beginning research. Next steps involved meeting in person, touring the lab, and continuing to read research. Other than reporting their enjoyment of the program after the first module, suggestions for improvement revolved around logistics of navigating the Canvas course, requirements, and transportation. These needs were addressed before students started the next module.

Module 2 | Research Project Summary: Participants had a better understanding of the research background and were able to summarize and formulate objectives for their research. Participants enjoyed hands-on time in the lab using lab equipment and instruments. Some participants prepared samples, interpreted data, created tables, and graphed results. Students planned to continue preparing samples, testing in the lab, and collecting data. One team planned to create a different sample for each team member and determine which would be the most effective. Another research team required a one-week waiting period for samples to grow and planned to run tests the following week. Participants worked with their mentors to answer questions and learn from their expertise. The Young Scholars enjoyed exploring the university campus, working in the lab, and visiting other labs. Some teams had limited time in the lab and identified the importance of using the time wisely. Some learned to overcome scheduling issues, accept unexpected changes, and be patient. In response to a suggestion to build a stronger community across the three universities, participants were invited to become more active in the CBBG Young Scholars Slack channel.

Module 3 | Research Posters: While continuing their research and writing their research objectives, participants learned to create a research poster and present academic research. Some participants had the opportunity to participate in outreach activities (field trips, demonstrations to the community, lab tours, etc.) described above. This week, participants controlled a robot with code, observed microbe growth patterns, tracked ants' movement, and cooked up resin for a soil crust. Several participants who needed to restart their experiment, learned to practice patience and problem-solving. Highlights for participants included troubleshooting research, working in the lab with minimal assistance, creating a process video, tracking changes, finishing tests, and the rainfall simulator field trip. Although the Young Scholars are contributing to an ongoing research project, one participant reported feeling they were, "*...just simply recreating a project that has been already made by the PhD students, so it feels a little strange."*

Module 4 | Career Connections: As participants hurried to finish up their research, guest speakers and CBBG YSP alumni shared their educational and career paths. In the lab, participants learned the administrative aspects of research, analyzed data, displayed data in graphs, discovered flaws, and explored ways to improve the research. Some Young Scholars enjoyed printing a 3D model and learning new software for testing. Overall, the Young Scholars looked forward to seeing their research come together and to discovering future research plans.

Module 5 | Presenting Academic Research: Participants completed testing, compiled data, analyzed results, and finalized posters. The highlight for many was looking back at all the work they completed, reviewing results, and obtaining helpful feedback from mentors. Although the program was officially over, participants expressed interest in furthering their research, getting updates on their project results, and presenting their posters at the CBBG Year 9 Annual Meeting. The spring program allowed many participants to continue their research with their mentor through the summer.

SUMMATIVE RESULTS AND DISCUSSION

Program evaluation data from document reviews, the post-program survey, and focus group interviews revealed areas of success and insight for program improvement.

Document Review

Observation of posters and poster presentations showed Young Scholars successfully defined the Project Details, Background and Rationale, Research Objectives, Methods and Materials, and Experimental Results sections while demonstrating the knowledge and skills they obtained from the research experience.

Post-program Survey

Participants reflected on the program's impact on their understanding of CBBG, communication skills, leadership and innovation skills, research skills, and educational trajectory.

Understanding of CBBG: All participants' understanding of the CBBG mission, fields of study, how research helps address real-world issues, problems addressed by CBBG, and potential career pathways were at least somewhat impacted. Prior to the start of the program, participants completed a module overviewing the CBBG mission to impact real-world issues along with the field of study. The module on career pathways and guest speakers provided expected career details.

Communication Skills: Participants reported that the program at least somewhat improved their oral, written, and visual communication skills, along with their ability to communicate with others and work on a research team. Some participants felt that networking across CBBG partner universities and with industry improved very little or did not at all improve. These findings were also reported in the Mid-program Survey where Young Scholars at two of the three universities felt disconnected from the other program participants, reporting that "*communication was choppy between universities*" and "*I really do wish there was a more concrete time of meeting and place where everything is happening.*"

Leadership and Innovation: The program is designed to impact engineering success to help participants to see themselves as engineers. Young Scholars reported the program improved their ability to be innovative and manage their time efficiently. Participants valued their time in the lab and reported ability to innovate with their own ideas. Although outreach events and poster presentations allowed participants to show leadership and experience conveying technical content, some (perhaps those who did not participate in outreach) felt the program did not allow them to be entrepreneurial or take on leadership roles.

Research Skills: All participants were positively impacted at least somewhat in the following areas: formulating research questions; analyzing research data; interpreting research results; solving research-related problems; collecting data to answer a research question; using research-related tools; making connections between research and industry; and practicing general lab safety. One or more participants reported that they improved very little or did not at all improve in two areas: conducting research independently and making connections between existing literature and research. One participant reported feeling like they were *"repeating their mentor's research."* Since high school students are not permitted to work independently in the lab, guided research experiences are provided. The next iteration of the program will require mentors to provide clear literature that supports the research experience, ahead of time.

Educational Trajectory: Participants reflected on their sustained interest in STEM, future plans, and their educational trajectory. All four participants who responded to this question intend to pursue a degree, professional license, and/or certificate. Three students are at least moderately certain they will pursue a Bachelors, Masters, and Doctoral degree. All four respondents felt they received inspiration to pursue a career in a STEM-related field from their mentor(s). Although the program included a module and guest speakers discussing career pathways, the results revealed that participants did not completely understand the careers as outlined in the survey question (academia, industry, entrepreneurship, government/non-government, education, military, etc.). This did not reflect the specific job titles typically assigned to engineers graduating from CBBG programs.

Focus Group - Impact on Skills

Focus groups revealed themes around spring participant's knowledge, skills, and abilities related to the CBBG program.

Participants' biggest takeaways were **exposure to real-world research tools and graduate student experiences**. *"I didn't really know what professional science looked like. So, it was really cool for me to see advanced technology and understand what science is in real life."* Graduate student mentors exposed participant to *"what it's like to write up an actual thesis."*

Young Scholars **learned to adapt to others' availability and collaborate** on a research team, reporting "*seeing how [working in a lab] looks for ASU students... and adapting for other people."* While summer participants were a "captive audience," spring participants and mentors had school and other commitments that made it difficult to schedule work in the labs.

Participants **learned problem solving and practiced patience** when troubleshooting intricate tests, *"with making the robot… you have to double check everything … check the code … consult a lot of people … try again… and if it doesn't work… do everything all over again."*

Although some Young Scholars found out about the program during a CBBG outreach event or through their teacher, many participants were **learning about the emerging field of geotechnical engineering** for the first time. The program showed participants the connections between the interdisciplinary CBBG fields and how researchers are studying solutions for specific real-world problems.

Participants made **interdisciplinary connections** with bio-mediated or bio-inspired solutions that varied by project. Some focused more on biology, geology, chemistry, or even computer science, "*…with the robot, it wasn't really … bio, … it was more CS and … electronics. And then how that related to biology."*

Two participants **plan to bring what they learned back to their school** district's community garden; implementing biogeotechnical engineering *"to prevent wind erosion [and promote] water retention."* Extending and applying what the students learned during the program to situations at school confirmed the continued impacts of the experience.

Young Scholars learned the most from activities where they met and **collaborated with the CBBG community**. Participants received valuable ongoing research updates when they were away from the lab through "*group chat and meeting grad students in the lab and getting to hear what they're doing."* Cross-collaboration allowed participants to visit and learn from other labs and projects, and the larger CBBG community showed interest in participant's research and progress. "*As I was going to different meetings and meeting people in the CBBG program, everyone was really*

interested in hearing about the Young Scholars Program, and … about my research and what I was up to." These interactions demonstrated the valuable impact of the Center's culture of inclusion, along with meeting one of the program goals to build community.

Finding out more about other research, labs, and tests allowed participants to **expand their knowledge** beyond their assigned project. "*I really enjoyed going to other labs and getting to use some of the seed analysis tests. … I learned a lot from that."*

Focus Group - Program Satisfaction

All Young Scholars **were satisfied** with their experiences, would continue working with CBBG if given the opportunity, and would recommend working with CBBG to others. Participants *"loved the research aspect and performing experiments,"* learned from "*lab challenges,*" discovered "*what it is like to do real research in a lab,*" and made "*valuable connections with professors, doctors, and students*." In fact, several participants inquired about continuing their research over the summer and even during the following academic year.

The most **beneficial aspects of the experience** were exposure to different sciences, working in a research lab, and seeing themselves as engineers. Participants reported, seeing "*myself in environmental engineering,*" "*what a research lab is like,*" and "*different types of sciences and engineering and path I can take.*"

Spring Young Scholars' **recommendations for program improvement** were primarily around planning, time management, and mentorship.

Participants wanted "…*more freedom to complete tests independently but with a very clear outline of what is expected for the project. I wished I knew more about the goal of the project so that I could research more on my own time.*" Participants reported **feeling rushed** at the end of the program and suggested future participants make sure they are, *"on task right away"* and use limited time in the lab wisely.

Some experiences were dependent on the stage and experience of the student mentor. The mentor, "*defines the experience for you… It was a struggle for [mentors in undergrad] to balance their workload, and the Young Scholar Program."* Spring mentors did not have the opportunity to participate in mentor training and some were first-time mentors. To **improve mentorship** going forward, the program will benefit from ensuring new mentors understand expectations and requiring all mentors to complete the robust training and use the mentor resources.

SUMMARY AND CONCLUSION

Young Scholars seized the opportunity to learn more about the biogeotechnical engineering field through mentored lab experiences. Participants learned to use fungus for soil improvement, robots for burrowing, plant polymer for dust control, carbon transformation for groundwater bioremediation, and biocementation to mitigate erosion. Young Scholars led outreach events in the community, produced and presented biogeotechnical research posters, and enrolled as undergraduates at CBBG partner universities. The program inspired participants to continue their research and pursue majors and careers in the STEM fields. Young Scholars added valuable information to the feedback loop that will benefit future iterations of the program around mentor preparation, communication, scheduling, and program offerings.

ACKNOWLEDGEMENTS

This material is based on work primarily supported by the Engineering Research Center Program in the Engineering (ENG) division of the National Science Foundation (NSF) under NSF Cooperative Agreement Number EEC-1449501. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the author(s) and do not necessarily reflect those of the NSF.

The authors wish to thank Dr. Megan O'Donnell from the College Research and Evaluation Services Team (CREST) at Arizona State University for support in collecting this data.

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