UNDERSTANDING THE IMPACTS OF THE MONTANA STATE UNIVERSITY SOLAR PHYSICS/ASTROPHYSICS RESEARCH EXPERIENCE FOR UNDERGRADUATES

by

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of

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DEDICATION

I’m dedicating my work to a few instrumental people in my life that helped me to get this far after feeling quite lost from the fallout from my PhD. First, my parents, Jon and Carrie Fleming, who lovingly sent me to college for meteorology for me to turn around and study space and education; they stuck with me throughout my dreaming and helped me to get where I am. Second, to my advisor, Dr. Aki Takeda, without whom I’d be confused about where to go next. And finally to my partner, Dan Vazquez, who held me and helped me from high point to low point with all the love he could give; I don’t think I can describe how much his support meant to me while earning my degree.

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ABSTRACT

Research experience for undergraduates (REU) programs have a long history of bettering student performance and knowledge in science, technology, engineering, and mathematics (STEM). While long-standing programs have been associated with reported student improvement, many REU programs have conducted little to no assessment of student opinions. The Montana State University solar and astrophysics REU program, for instance, had only a single student opinion survey. While helpful, this single survey does not encompass the entirety of students' experience from beginning to end. In 2024, a seven student cohort served as a case study for five additional tools to track student progress and confidence from the start to the end of the program. A student-led outreach mini-seminar series was also reintroduced. This mini-seminar series focused on building student ability to present their research to a general audience; a local Astronomy Day for children. The now six total tools allowed the researchers to establish student change in confidence with research, material taught, and outreach over the course of the REU through a mixed-method data regime. The analysis yielded three conclusions: REU programs benefit from formative assessments, students desire a stronger sense of community, and student-led outreach enriches the experience.

INTRODUCTION

Context of Study

For the past 23 years, Montana State University (MSU) Physics Department has hosted a solar physics/ astrophysics research experience for undergraduates (REU). This program is held in the summer from Memorial Day until the first week of August. The program is funded through the astronomy/geospace portion of the National Science Foundation's (NSF's) REU program. This competitive program has a 10:1 applicant-to-admission ratio (J Qiu, personal correspondence, Jan 16. 2025). Participants select a research focus, work with faculty mentors, and attend biweekly seminars covering astrophysics and professional development—core elements of the program since its inception. Students also attend an REU wide, as MSU hosts multiple REU programs, focused on professional development. There were seven students selected for the 2024 MSU solar/astro- physics REU program; all seven volunteered to participate in this action research.

After the focus questions section is a journal article submitted to the Journal of College Science Teaching that includes: an introduction/literature review, materials and methods of the case study, a review of results, and a discussion/conclusion. Note that this professional paper does continue after the references cited. After the Value section, there is a section of appendices. Appendix A is all of the questions asked to the students not included in the article. Appendix B includes all IRB approvals: initial and two amendments. Appendix C contains the two poster presentations I presented of this research.

Focus Question

Based on the past observations of the previous classes of the MSU Solar Physics/Astrophysics REU, the purpose of this research was to answer the question: how does a summer research experience for undergraduates (REU) impact students?

From this main research question, I considered two sub questions:

1. How will outreach experience impact student confidence and public/science interactions?
2. Can the MSU Solar Physics/Astrophysics be improved through observations gathered through formative assessments and student success?

JOURNAL ARTICLE

Fostering undergraduate self-confidence and community in solar and astrophysics: The impact of research experiences and public outreach

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submitted: April 20, 2025

1 Introduction

1.1 Context of Study

Undergraduate research is a vital part of science, technology, engineering, and mathematics (STEM) education, and summer provides a prime opportunity for hands-on experience. The National Science Foundation (NSF) funds 28 astronomy/geospace REU programs nationwide, serving approximately 280 students per year (United States National Science Foundation,n.d.). Around eight of these students attend the Montana State University (MSU) solar physics/astrophysics REU. This competitive program, running for 23 years, has a 10:1 applicant-to-admission ratio (Montana State University Solar Physics, 2024; J Qiu, personal correspondence, Jan 16. 2025). Participants select a research focus, work with faculty mentors, and attend biweekly seminars covering astrophysics and professional development—core elements of the program since its inception. Students also attend an REU wide, as MSU hosts multiple REU programs, focused on professional development.

There were seven students selected for the 2024 MSU solar/astro- physics REU program; all seven volunteered for this case study. The study was created with the goals to 1) delve into student self-confidence during the traditional layout and 2) find any benefits of running a simultaneous student-led outreach program. To track student progress a series of formative assessments were introduced.

1.2 Formative Assessments in REU Programs

The use of formative assessments in an REU program is not a new concept, however rare. Here, formative assessments are defined as a tool designed to be used in the traditional classroom as a feedback mechanism between summative assessments, presentations, tests, etc (Angelo & Cross, 1993). Formative assessments provide near-immediate feedback to educators, targeting specific concerns or weaknesses. While more common in traditional classrooms, REU programs should adopt them more widely to enhance student experiences and program effectiveness (Labrador et al., 2008; McDevitt et al., 2020). Many REUs do have a form of assessment, but generally, nothing standardized. Flexibility in REU programs is good for individual programs, but leaves a vague sense of student improvement (Follmer et al., 2015). REU goals are often written in only the goal of research improvement in students leading to science language and not emotional response for students (Aberson & Barry, 2009; McDevitt et al., 2020). Such is true of the MSU solar/astro- physics REU program where there is an Exit Survey and nothing more than the mentors' own assessment of their own student(s). In 2024, the number of assessments increased from one to six. Now, assessments will provide more concrete examples to the evolution of students.

1.3 Understanding a Research Experience for Undergraduates

Opportunities for undergraduate research are limited, as many universities lack the capacity to offer in-house research or enough slots for every student (Auchincloss et al., 2017).

However, expanded funding and faculty support have led to the creation of research programs, fostering small research communities and enhancing STEM opportunities for minorities (Bangera & Brownell, 2017; McLaughlin, n.d.). These diverse communities help combat the intimidating culture of science, where respect is earned through contribution and collaboration (Jegede, 1997). REUs introduce students to this culture, boosting confidence and easing the transition into the broader scientific community.

1.3.1 Self-confidence in REU Participants

Building self-confidence is a key focus of REU programs, aiming to strengthen students' confidence in their knowledge, which can apply to future engineering or research careers (Escobedo et al., 2023; Reisel, 2023). Mentorship plays a crucial role in this process, helping students create networks that support their growth. These networks provide valuable experience and knowledge, fostering self-confidence in STEM work. REU programs also help develop science-based relationships, with faculty reporting positive experiences and gaining insight into their students. By encouraging future professionals to pursue graduate degrees and research, REUs play a key role in advancing STEM culture (Auchincloss et al., 2017; Bangera & Brownell, 2017; Reisel,2023).

1.4 Outreach Impact on Undergraduate Students

Outreach refers to engaging with the local community to educate both children and adults. In the process of creating and presenting scientific content, undergraduate students inspire enthusiasm that resonates with the community. Students develop a sense of belonging, including students in underrepresented groups, through working with fellow students and mentors (Clark et al., 2016; Kubota, 2021; Lyon et al., 2023). Additionally, outreach not only sparks increased academic interest in undergraduate students but also contributes to higher undergraduate student graduation and graduate enrollment, creating a cycle that provides more mentors for future students (Gustine et al., 2006; Lyon et al., 2023).

A student-led outreach project as part of an REU highlighted similar benefits to the participating undergraduates such as increased self-confidence, enhanced science understanding, and community cooperation (DelVescovo et al., 2020; Kubota, 2021). These small projects within REU programs help students translate research into accessible language for public audiences—a skill increasingly important for advancing science literacy (DelVescovo et al., 2020). Therefore this case study included undergraduate students educating middle school aged children and adult chaperons during an Astronomy Day.

1.4.1 Outreach as a Class

In preparation for Astronomy Day, students received instruction in public speaking and outreach techniques. The class offered a supportive space to share ideas and practice activities before presenting to a broader audience. Three key steps helped create a student-led presentation for the children at Astronomy day (Alexander et al., 2011; Gustine et al., 2006; Rao et al., 2007)

1. Engage through hands-on activities: These activities not only captivate the mind but also demonstrate the value of outreach and its connection to the broader community.
2. Prepare presentations: Students share their work in class, receiving peer feedback to refine and improve their presentations.
3. Interact with the community: Students present to classrooms, other educators, and the public.

The following sections outline the methodologies used to assess student demographics (2.1) and impressions of the REU program (2.2). The results section, 3, presents key findings on student confidence, scientific community engagement, and outreach experiences. Finally, the discussion (4) and conclusion (5) highlight the broader implications of these findings and recommendations for future program development.

2 Materials And Methods

2.1 Demographics and Treatment Outline

Seven students participated in the case study, with no demographic data collected due to exempt status under Montana State University's IRB. Six assessment tools were used: the original Exit Survey, three researcher-designed tools inspired by Angelo and Cross (Self-confidence Survey, Chain Note CATs, and Directed Paraphrasing CATs), interviews, and a personal journal. All responses were anonymous, collected via nameless handwritten forms or Google Forms without email tracking. Assessments were administered weekly over the 10-week program (Table 1)

Table 1: The dates associated with when each formative assessment was handed to students.

Date	Assessment
May 26[a]	Self-confidence Likert Survey 1
June 6	Chain Note Assessment 1
June 11	Chain Note Assessment 2
June 18	Direct Paraphrasing 1
June 25	Chain Note Assessment 3
July 2[a]	Self-confidence Likert Survey 2
July 18	Direct Paraphrasing 2
July 23[a]	Self-confidence Likert Survey 3
July 31[a]	Student Interviews
August 2[a]	REU Exit Survey

Surveys/interviews happened over multiple days for student ease of response.

2.2 Methodology

Measuring the impact of an REU on student self-confidence is challenging. Using present tense and excluding a "null opinion" option enhances analysis (Aberson & Barry, 2009). The Self-confidence Survey assessed student confidence at baseline, mid-experience, and final stages across four areas: (a) physics, (b) Sun & star knowledge, (c) research experience, and (d) public outreach (Figure 1). Students chose from five response options, with the two lowest and highest scores combined to create three categories: low, medium, and high confidence. Responses were compared using normalized gain and a paired t-test for statistical significance ($p<0.05$) (Hake, 1998)

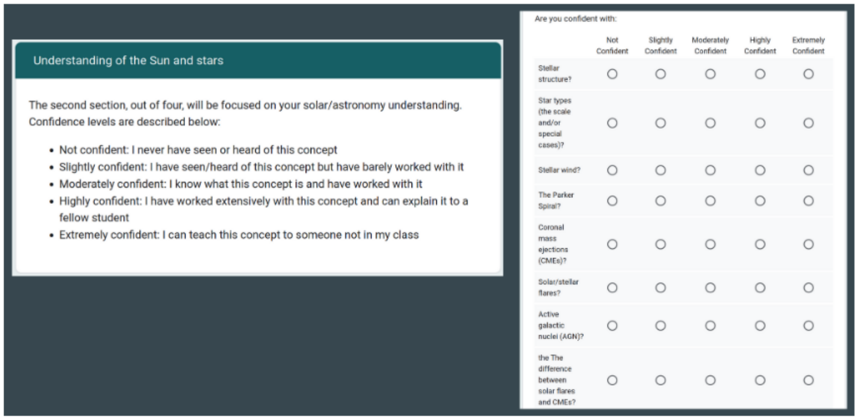


Figure 1: An example of the Self-confidence Survey questionnaire format from the Sun & Stars section. The left side provides definitions of each confidence level to clarify the scale; the right side presents the question in a Likert-scale format.

The Chain Note CAT measured student focus during astrophysics lectures (Angelo & Cross, 1993). At the start of each class, students received a blank note card. A question was passed on an envelope and students had a minute to answer before passing it on (Figure 2). Three rounds of this assessment were conducted during solar/astrophysics seminars, with responses analyzed for overall themes (Table 2).

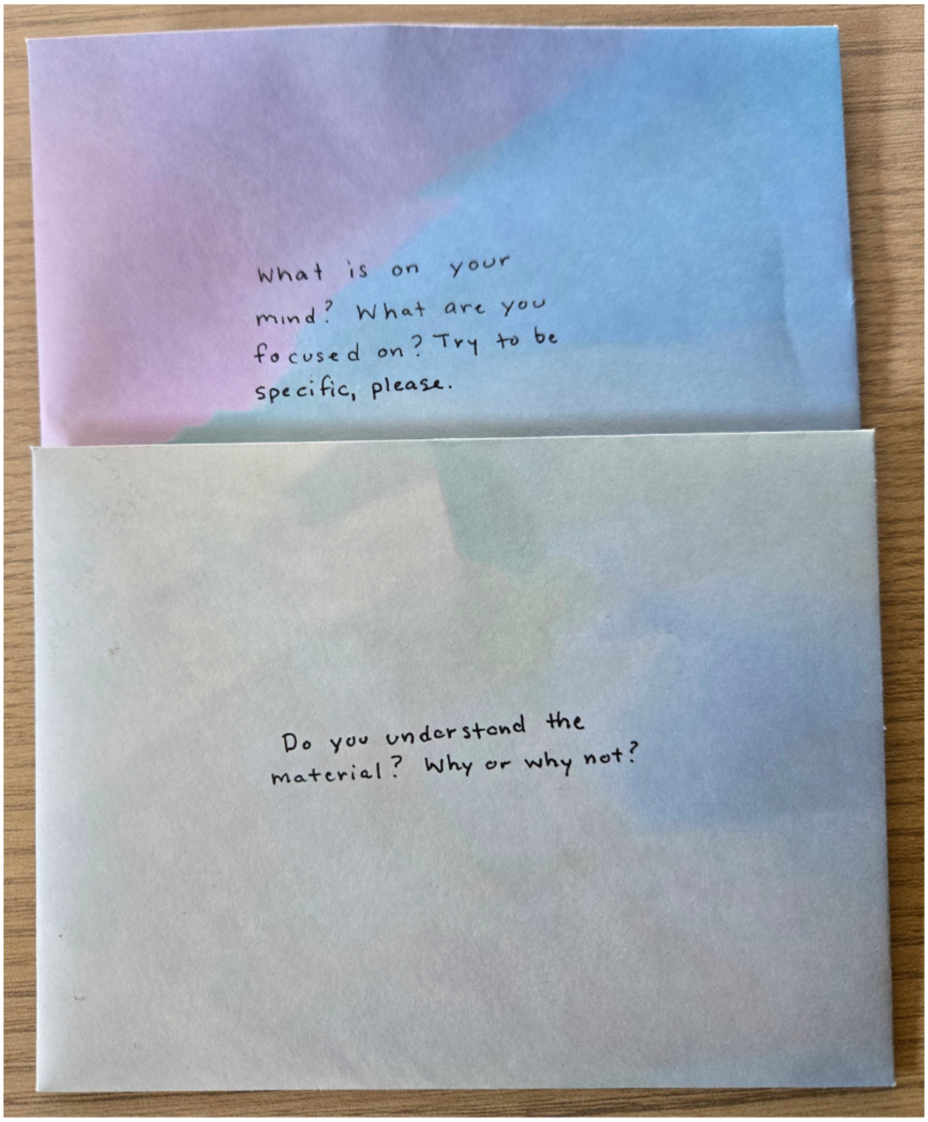
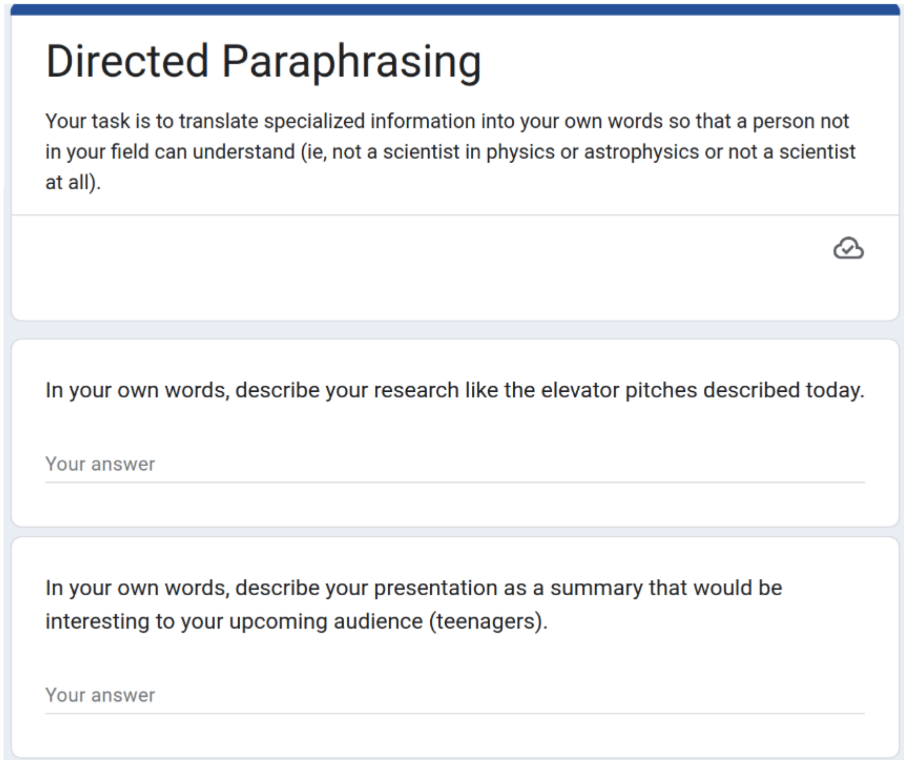


Figure 2: Two of the three questions distributed to students; the third—"Do you feel the information is useful for your current or future research?"—was administered via Google Forms.

Table 2: A quick description of each focus during class taught on the day the Chain Note assessment was administered.

Class Administered	Researcher Considerations
The Stellar Atmosphere	Looking into student focus
The Magnetic Sun	Student understanding of difficult material
Observing Techniques	Student open mindedness beyond their research

The Directed Paraphrasing CATs had students describe topics in their own words as a skill and performance check (Angelo & Cross, 1993). Students wrote about their research twice: first, after REU-wide seminars, and again after the solar/astrophysics seminar focused on public speaking. Responses were analyzed for jargon versus standard language (Figure 3).



Directed Paraphrasing

Your task is to translate specialized information into your own words so that a person not in your field can understand (ie, not a scientist in physics or astrophysics or not a scientist at all).

In your own words, describe your research like the elevator pitches described today.

Your answer

In your own words, describe your presentation as a summary that would be interesting to your upcoming audience (teenagers).

Your answer

Figure 3: The two Directed Paraphrasing Classroom Assessment Techniques (CATs) administered to students. Each was preceded by the same preamble. Although conducted at different times, they are presented together here for clarity.

The Exit Survey, the only original student opinion survey, contained 16 questions (14 aligned with prior years' questions back to 2015) (Table 3). This survey had a 3 point scale: 3-fully satisfied, 2-moderately satisfied, and 1-not satisfied. Responses were analyzed using a weighted average as per years previous. Two new questions about public outreach were added.

Table 3: The fourteen consistent statements evaluating the REU program from 2015 to 2024, categorized by topic. These statements were written by PI Dr. Jiong Qiu and answered on a 3-point scale, with 3 indicating full satisfaction and 1 indicating no satisfaction.

Question Category	Question
Academic	Demonstrated how academic knowledge acquired in classes applies to real-world research problems
Academic	Help students make informed decisions about attending graduate school and pursing a career in academia or research
Academic	Solar/Space/Astrophysics Lectures
Experience	Develop independence, creativity, and interest in physics and astrophysics graduate study
Experience	Encourage STEM participation of under-represented groups in STEM research
Experience	Food/Cafeteria shopping allowance
Experience	Did the REU meet your overall expectations
Orientation	The application process (information on projects, mentors, procedures for application, acceptance, travel to/from Bozeman)
Orientation	Orientation (kickoff meeting, first-day orientation, REU social lunch)
Orientation	Computer and programming tutorials
Research	Research mentoring (clarity of research goals, methods, accessibility and support of mentors, group meetings)
Research	Develop and strengthen practical research skills
Research	Mid-term and final research presentations

Four students volunteered to be interviewed via Webex about their evolution in class understanding and public outreach experience. Interviews were analyzed for common themes. Additionally, the researchers maintained a journal of observations, focusing on student performance during research presentations, noting confidence levels and improvements in understanding.

3 Results

Normalized gain analysis of the Self-confidence Survey revealed a clear increase in student confidence across all four areas from the start to the end of the program. Initial surveys (pre- and mid-) showed generally low and mixed confidence levels, with little shift toward high confidence (score: 3). By the final comparison (pre- vs. post-), a clear shift from low to high confidence emerged (Figure 4). The paired t-test showed no statistically significant changes, except in public outreach between mid- and post- surveys (p = 0.04).

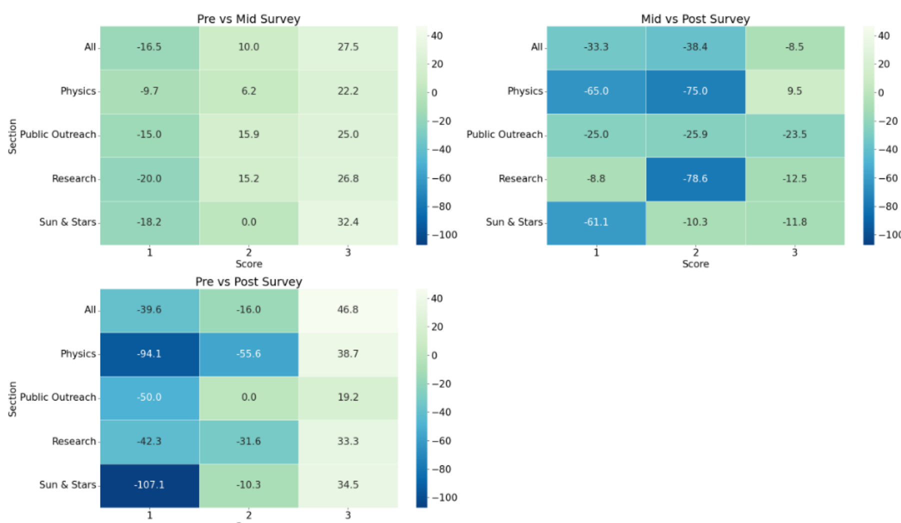


Figure 4: Normalized gain analysis of the pre-, mid-, and post- Self-confidence Surveys. Three heat maps display student (N=7) confidence levels across a three-point scale. Positive scores are represented by very light green, while negative scores are depicted in dark blue. The anticipated results suggest that the left column (labeled 1, low) will appear dark blue, and the right column (labeled 3, high) will be light green.

Responses from the first Chain Note CAT, conducted in week two before the initial research presentations, reflected students' focus on their new research assignments. Some admitted they were not yet engaged with seminar content. In the second round, students reported researching seminar topics for clarity, though engaging visuals and instructor enthusiasm helped maintain interest. The final Chain Note indicated that students recognized broader applications of the material beyond the classroom.

The first Directed Paraphrasing CAT revealed heavy jargon use, with phrases like “the energetics of solar flares” and “X-ray corona and radio jet” dominating. By the second CAT, more standard language appeared, where students used clearer phrases such as “how the Sun impacts daily life and history” (Figure 5). The overall ratio shifted to five standard words for every two jargon terms.

Figure 5: Two word bubbles: the left displays a list of jargon terms from student responses (Directed Paraphrasing 1), while the right shows common terms from student responses (Directed Paraphrasing 2). Word size corresponds to frequency of use.

Exit Survey results showed a decline in satisfaction across several program areas, with Orientation receiving the lowest ratings. Although most students agreed the program met expectations, this was gathered via a yes/no question rather than a satisfaction scale. For the first time, students evaluated outreach and professional development seminars, giving them a 2.5 out of 3 where 3 is fully satisfied (Figure 6). Qualitative feedback suggested more focus on community building.

Figure 6: REU Exit Survey results from 2015 to 2024, with data gaps in 2019 and 2020 marked by dashed lines. Four categories—experience, academic, research, and orientation—encompass 14 questions. Responses were measured on a 3-point scale, where 3 indicates the highest satisfaction and 1 the lowest. 2024 results (N=6) were averaged similarly to previous years for consistent comparison.

4 Discussion

This case study highlights key priorities for REU programs: fostering confidence, building community, and offering public outreach and guided presentation opportunities, which students responded to positively.

4.1 Student Self-confidence and Community Building

Students demonstrated increased confidence following their REU. While Self-confidence Survey results were generally not statistically significant, normalized gains indicated a shift toward higher confidence in their research capability. Additional increases were observed during group research presentations. The researchers noted after the midterm presentations "all around increase of confidence in materials and presentations skills". Students also noted a change in confidence during the student-led outreach presentation. One student specifically remarked about being able to "doing a lot more on the fly of how to restructure [the presentation]".

Although the overall outcome was positive, some students experienced faltering confidence in the academic portion of the program. Through the Chain Note CATs, students revealed issues during the seminar series. From the tight timeline of the seminar schedule, anxieties rose from needing to practice research presentations. Students reported not being in the right mindset to focus on the academic seminar. Additionally, a certain academic background level was expected. This led to students searching for missing background knowledge during the academic seminars. Through the Exit Survey, students' responses conferred with the Chain Note CATs: the lectures were moderately received. Comparison of pre- and mid- Self-Confidence Surveys showed minimal change in confidence in physics and Sun & star knowledge, despite completing the solar/astro- physics seminar series.

Building a strong community is crucial to student success. Without aid in community building, students struggled with a sense of belonging (Kubota, 2021; Thomson et al., 2015). Students in this case study expressed a desire for a stronger sense of community in the Exit Survey. The students ranked the Orientation category with the lowest scores, with "general orientation" scoring the lowest it has in years. Struggles with a sense of community were observed, especially during the first and second weeks, where students reported nervousness and "not being in the right mindset" when responding to the first Chain Note CAT.

Despite reported the need for greater community, the individual mentorship was well received by the students. This was especially true for research presentations where mentors pushed their students to focus on the big picture of the research. One student noted that the "results of why your research is important and what you're supposed to highlight the most" was most important when building research presentations. Mentoring earned an average score in the Exit Survey. However, student Self-confidence Survey reports in research showed a definite increase when compared to the pre- and post- Self-confidence Surveys normalized gain analysis.

4.2 Public Speaking and Outreach Experience

There was a change in students' use of language after enacting the student-led outreach courses. The added courses allowed students to transition from research presentations to their student-led outreach presentation at Astronomy Day with ease. Student improvement was drastic between the first and second Directed Paraphrasing CATs along with the only statistically significant increase of confidence in the Self-confidence Survey paired t-test between the mid- and post- surveys when the student-led outreach seminars were taught. A decrease in jargon was the main indication where students described instruments instead of naming them: "really precise lasers" before using "interferometer". Reformation in student language was seen in the final run through of the student-led presentations as students could give immediate feedback in the information presented. As a result, students reported being at ease during the Astronomy Day presentation. One student said "I think during my presentation I felt pretty comfortable" and "I saw myself in some of these kids". Students reported being satisfied with the solar/astro- physics courses in the Exit Survey. The student response during interviews was also positive with respect to the student-led outreach experience. One student informed the researchers that while they had previous public speaking courses "I haven't had anything specifically on outreach". Students valued understanding broader context and briefness when considering their younger audience during Astronomy Day.

Students reported a desire to continue with outreach after leaving the REU program. One student commented that “This is something I would have loved to have as a kid, but I never got that opportunity because there was not a whole lot of like outreach like that back when I was a kid”, highlighting the greater enthusiasm for outreach initiatives. The student-led outreach initiative enhanced the professional development of these REU students, boosting their confidence in explaining and understanding their research topics. This effort serves as another way to generate interest in the local community about the work being done by the REU program and MSU.

4.3 Use of Formative Assessments

After the conclusion of the REU, the researchers found a wealth of knowledge unlocked by the formative assessments. Students gave a great deal of feedback that proved useful toward bettering the solar/astro- physics REU program. This case study proved that formative assessments, while time consuming for the proctor, adds valuable insight through both quantitative and qualitative means. The pre- and post- Self-confidence Surveys and Chain Note CAT keyed into important shifts in styles of teaching and student anxiety around research presentations. Student perceptions filled a void around the Exit Survey leading to encouragement to change the REU’s schedule structure and efforts towards community building. Finally, interviews and Directed Paraphrasing responses showed that students benefit from a student-led outreach project in confidence in their own knowledge and presentation skills.

5 Conclusion

Findings from this research are [as follows]:

1. Student self-confidence in their research and knowledge is a priority of REU programs and should have a tool to track student progress.
2. Students want a greater focus on community building especially in the first weeks of an REU program.
3. Students found presenting science to the public enjoyable; outreach classes and a supportive environment further encouraged confidence and communication skills.

The tools were generalized and left for future use for program coordinators.

The REU program enhanced students' knowledge, confidence, and professionalism while generating new ideas for future iterations. Following the successful reintroduction of the outreach initiative strong support emerged for its continuation. To foster community, the PI integrated dedicated time for student discussions on research and programming. Orientation will now include expanded community-building activities beyond brief introductions.

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Data Availability

The data that support the findings of this study are openly available in the Qualitative Data Repository at https://doi.org/10.5064/F6HH7SDG.

Disclosure statement and AI usage

The authors report there are no competing interests to declare. ChatGPT was used for language improvement through the ChatGPT-4o model to condense writing while maintaining fluency.

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VALUE: REASONING AND REFLECTION

Claims for the Study

From the study, a number of conclusions were reached. First, prioritizing student confidence and community was an important focus. The MSU solar/astro- physics REU was doing well with student success, however students want for community presented a large hole. Another conclusion was that the students found use for outreach and the outreach classes. Finally, the importance of using formative assessments during the REU was pleasantly unexpected.

Students reported increased confidence following the REU, especially in research skills, as shown by normalized gains, though most Self-Confidence Survey results were not statistically significant. Group presentations further boosted confidence. However, some students struggled with the academic portion. Chain Note CATs revealed that the fast-paced seminar schedule caused stress, making it difficult for students to focus or feel prepared. Some lacked the expected background knowledge and had to catch up during seminars. Exit Surveys echoed these concerns, showing moderate reception of the lectures. Confidence in physics and solar/astrophysics knowledge showed little change from pre- to mid-program.

Building a strong community proved essential, yet students expressed a desire for more in the Exit Survey, ranking Orientation the lowest, with “general orientation” receiving its poorest score in years. Early weeks showed signs of nervousness and disconnection, as reflected in the first Chain Note CAT. Students, because of a greater voice in the program, reported their need for community—something more acutely missing than mentors initially realized. Numerous studies support the importance of community in fostering success among young scientists.

Despite these challenges, individual mentorship was positively received, particularly during research presentations where mentors encouraged students to focus on the broader impact of their work. One student emphasized the importance of highlighting research significance. Mentorship earned average Exit Survey scores, but Self-Confidence Surveys showed clear gains in research confidence from pre- to post-program.

The undergraduate student outreach courses led to noticeable changes in students' language and confidence. These sessions eased the transition from research presentations to public outreach at Astronomy Day. Between the first and second Directed Paraphrasing CATs, students showed marked improvement, and the only statistically significant gain in Self-Confidence Surveys occurred from mid- to post-program during these seminars. Students reduced jargon, describing tools more accessibly (e.g., "really precise lasers" before saying "interferometer"). Final presentation run-throughs allowed peer feedback, and students reported feeling comfortable presenting. Additionally, students were exposed to outreach initiatives and presentation building. The result of the class and outreach experience at Astronomy Day gave students a boost of confidence in their knowledge and ability to communicate science. Exit Surveys and interviews reflected satisfaction with the outreach experience. Students valued making content accessible for younger audiences and expressed a desire to continue outreach after the REU. The outreach initiative enhanced students' professional development and connected the REU program with the broader community.

The MSU solar/astro-physics REU program greatly benefited from incorporating an external perspective to track student well-being and analyzing formative assessments. This support allowed mentors to go beyond their own perspectives in understanding student needs after the program concluded. Despite being time-intensive, formative assessments offered valuable quantitative and qualitative insights. Tools like Self-Confidence Surveys, Chain Note CATs, and Directed Paraphrasing captured shifts in teaching effectiveness, student anxiety, and confidence—especially around research and outreach presentations. These assessments filled gaps left by the Exit Survey and prompted improvements to the program's structure and community-building efforts. While this study enhanced the 2024 program, it also set a foundation for improving the experience of future cohorts. The success of this case study may encourage NSF and other REUs to adopt formative assessments as a vital part of program development.

Consideration for Future Research

Already, the new cohort of students of this REU are benefitting from this study. First, a new emphasis on community building was contributed by both myself and the coordinator of the program. For instance, students asked for a stronger community base. I led an introduction session using a post card icebreaker which included the new cohort, support staff, and mentors. Additionally, specific time was slotted for students to work together for the first few weeks in their office to encourage both use of the office and a culture of collaboration. Materials were deindentified from last year and left so that this year and future years could use the Self-confidence Survey (simplest to run the program) and/or the other metrics created. Third, the program embraces the student-led outreach initiative, and I have been asked to come back and lead their seminars. This year is focused on impromptu public speaking and building hands-on presentations, not just slide-show presentations.

Impact of Research on the Author

Coming into this Capstone, I knew I wanted to make a difference in the REU program after not being able to participate in one as an undergraduate student. This was my third year interacting with students and helping with the solar/astro- physics REU. As a result of the research, I discovered a new subset of research in education. As an outreach educator and with no traditional classroom teaching, I learned a great deal about student interaction and how to teach subjects such as outreach that do not have as much guidance.

The greatest evolution came in how I interacted with students being both their teacher and their observer. All seven students in the cohort were engaged and curious, nor did the students hold back their opinions. While the students enjoyed the seminars I taught about outreach based on literature, students wanted more descriptions and an adjusted timeline to the class. After the class and traveling to Astronomy Day, I found that the students, like myself, could pivot quickly as a result of my impromptu outreach and their own increase of comfort with the materials. I was also able to pivot myself when schedules needed to be rearranged or updating my questions to the IRB. Not only did I have the opportunity to grow with my students, but I was able to share those experiences.

Impacts of REU programs are important as cited numerous times previously, but there is still little voice from programs about teaching styles, outreach, and community building. I started out hoping to be a voice for these concerns and was able to display my findings in numerous places. The Hinode 17/IRIS 14/SPHERE 3 conference was my first opportunity to present my findings to my colleagues in the solar community. My passion and exuberance for the content awarded me the best graduate poster and many passing professionals citing their excitement for my research. I worked to make sure that the tools I used covered a few strategies with mixed-method data analysis. At the astronomy/geospace NSF REU private investigator (PI) workshop I again shared my findings as all the data collection was over. I also learned a great deal about the other REU programs in the same group as ours. The lessons I learned I will be bringing back to the solar/astro- physics REU program in 2025. Notably, the community building exercises during the first week using postcards as an unusual icebreaker. Finally, I was excited to have submitted my first first-author publication. After the data collection was done, I learned how to find data repositories, work with the staff, write a story of my research, and submit a journal article. None of which I could have done without the cohort of students I worked with, the data collection strategies I employed, and the literature I had read from others before me.

APPENDICES

APPENDIX A

DATA COLLECTION MATERIALS

Self-confidence Likert-type Surveys

Table A1. The wording to describe what each confidence level means.

Confidence Level	Description
Not	I have never seen or heard of this concept
Slightly	I have seen/heard of this concept but have barely worked with it.
Moderately	I know what this concept is and have worked with it
Highly	I have worked extensively with this concept and can explain it to a fellow student
Extremely	I can teach this concept to someone not in my class

Table A2. Physics confidence questions asked

Are you confident with:	Question
	Electromagnetic fields?
	The right-hand-rule?
	Hydrostatics?
	Dipole fields?
	Magnetic fields?
	Nuclear fission?
	Orbital mechanics?
	Optical phenomena?
	Polarization?

Table A3. Sun and star confidence questions asked

Are you confident with:	Question
	Stellar structure?
	Star types (the scale and/or special classes)?
	Stellar wind?
	The Parker Spiral?
	Coronal mass ejections (CMEs)?
	Solar/stellar flares?
	Active galactic nuclei (AGN)?
	The difference between solar flares and CMEs?

Table A4. Research confidence questions asked

Are you confident with:	Question
	Writing computer programs?
	Finding bugs within a program?
	Reading in data?
	Analyzing data using software such as excel or a programming language?
	Coding in Python?
	Coding in Interactive Data Language (IDL)?
	Considering why the results are the way they are?
	Finding new project paths during your projects?

The first survey had an associated question: How many research projects have you had part in? This question was multiple choice and not aligned with the likert scale.

Table A5. Public Outreach confidence questions asked

Are you confident with:	Question
	Presenting your work to colleagues?
	Presenting your work to mentors?
	Explaining your work to others not in your major?
	Speaking to an audience?
	Creating an impromptu speech?
	Creating an interactive presentation?
	Speaking to the local community?
	Speaking to a group of high school students?
	Speaking to a group of middle school students?
	Speaking to a group of elementary school students?

REU Exit Surveys

Table A8. REU Exit Survey Questions Asked in 2024

1. Develop independence, creativity, and interest in physics and astrophysics graduate study
2. Demonstrate how academic knowledge acquired in classes applies to real-world research problems
3. Develop and strengthen practical research skills
4. Encourage participation of under-represented groups in STEM research
5. Help students make informed decisions about attending graduate school and pursuing a career in academia or research
6. The application process (information on projects, mentors, procedures for application, acceptance, travel to/from Bozeman)
7. Orientation (Kickoff meeting, first-day orientation, REU social lunch)
8. Computer and programming tutorials
9. Solar/Space/Astrophysics Lectures
10. Public speaking and outreach sessions
11. Tuesday professional development series
12. Research mentoring (clarity of research goals, methods, accessibility and support of mentors, group meetings)
13. Residence Hall facilities
14. Food/SUB shopping allowance (Cat Card)
15. Mid-term and final research presentations
16. Did the REU program meet your overall expectations?

A3: Student Interview Questions

Table A9. Questions Asked

1. At the beginning of the REU, did you feel as though you could speak about your research in front of a crowd? This could be children or adults.
2. Now knowing what you know, did your style of presentation change from the beginning of the REU to the end? Think of your presentations in group meetings, the midterm presentations, and the final presentation.
3. Could you create a presentation for scientists effectively? How about a group of non-scientist adults? Children?
4. How did your comfort level change between presenting to your scientific peers versus the YMCA teenagers?
5. How did you feel while presenting to the teenagers at the YMCA? What emotions did you experience?
6. Did you find the “how to be a scientist” classes helpful? How so? Did you have a specific “ah ha!” moment about a communication skill?
7. Are you going to attend a conference with your research? Write a paper?
8. Did you find the outreach and communication courses helpful or monotonous?

APPENDIX B

IRB APPROVAL

IRB APPROVAL – INITIAL

Hello Fleming, Rhiannon,

Your protocol was reviewed by the IRB and has been approved.

PI: Fleming, Rhiannon

Approval Date: 5/22/2024

Title: UNDERSTANDING THE IMPACTS OF THE MONTANA STATE UNIVERSITY SOLAR PHYSICS/ASTROPHYSICS RESEARCH EXPERIENCE FOR UNDERGRADUATES

Protocol #: 2024-1502-EXEMPT

Review Type: Exemption

Expiration Date: 5/22/2029

Work described under this protocol may now commence. The PI is responsible for ensuring that the protocol accurately describes research practices being conducted.

> Review Category designation determined by the IRB can be found in the final section of your protocol.

> Any changes must be submitted via Amendment prior to implementation.

> Per the Common Rule, research only requires Interim (annual) Review by the IRB if 1) it was reviewed via Full Committee or 2) is regulated by the FDA.

> All research is subject to post approval monitoring.

> All protocol types must be renewed 5 years after approval.

> Inform the IRB once your research is complete so that the protocol may be inactivated.

Please contact your IRB Program Manager with any questions or if you are in need of assistance.

Thank you for your diligence in the care of human subjects research participants.

Institutional Review Board for the Protection of Human Subjects | Office of Research Compliance | Montana State University

IRB APPROVAL – AMENDMENT

Hello Fleming, Rhiannon,

Your protocol was reviewed by the IRB and has been approved.

PI: Fleming, Rhiannon

Approval Date: 7/24/2024

Title: UNDERSTANDING THE IMPACTS OF THE MONTANA STATE UNIVERSITY SOLAR PHYSICS/ASTROPHYSICS RESEARCH EXPERIENCE FOR UNDERGRADUATES

Protocol #: 2024-1502-EXEMPT

Review Type: Amendment

Expiration Date: 5/22/2029

Work described under this protocol may now commence. The PI is responsible for ensuring that the protocol accurately describes research practices being conducted.

> Review Category designation determined by the IRB can be found in the final section of your protocol.

> Any changes must be submitted via Amendment prior to implementation.

> Per the Common Rule, research only requires Interim (annual) Review by the IRB if 1) it was reviewed via Full Committee or 2) is regulated by the FDA.

> All research is subject to post approval monitoring.

> All protocol types must be renewed 5 years after approval.

> Inform the IRB once your research is complete so that the protocol may be inactivated.

Please contact your IRB Program Manager with any questions or if you are in need of assistance.

Thank you for your diligence in the care of human subjects research participants.

Institutional Review Board for the Protection of Human Subjects | Office of Research Compliance | Montana State University

IRB APPROVAL – AMENDMENT II

Your protocol was reviewed by the IRB and has been approved.

PI: Fleming, Rhiannon

Approval Date: 2/21/2025

Title: UNDERSTANDING THE IMPACTS OF THE MONTANA STATE UNIVERSITY SOLAR PHYSICS/ASTROPHYSICS RESEARCH EXPERIENCE FOR UNDERGRADUATES

Protocol #: 2024-1502-EXEMPT

Review Type: Amendment

Expiration Date: 5/22/2029

Work described under this protocol may now commence. The PI is responsible for ensuring that the protocol accurately describes research practices being conducted.

> Review Category designation determined by the IRB can be found in the final section of your protocol.

> Any changes must be submitted via Amendment prior to implementation.

> Per the Common Rule, research only requires Interim (annual) Review by the IRB if 1) it was reviewed via Full Committee or 2) is regulated by the FDA.

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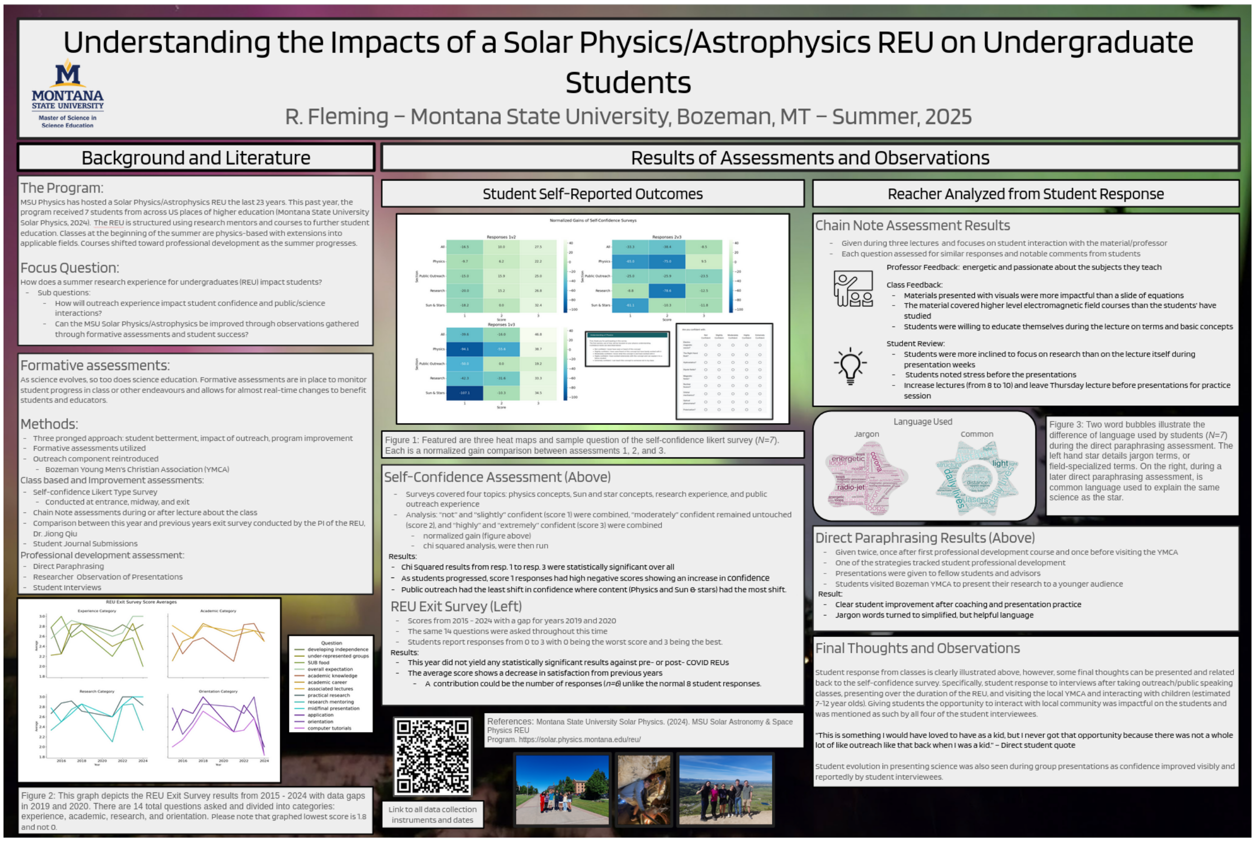
APPENDIX C

ADDITIONAL PRESENTATIONS

HINODE 17/IRIS 14/SPHERE 3 JOINT SCIENCE CONFERENCE POSTER SESSION –

BOZEMAN, MT JULY 2024

Note: Poster received the Best Graduate Student Poster award



Understanding the Impacts of a Solar Physics/Astrophysics REU on Undergraduate Students

R. Fleming – Montana State University, Bozeman, MT – Summer, 2025

Background and Literature

The Program:

MSU Physics has hosted a Solar Physics/Astrophysics REU the last 23 years. This past year, the program received 7 students from across US places of higher education (Montana State University Solar Physics, 2024). The REU is structured using research mentors and courses to further student education. Classes at the beginning of the summer are physics-based with extensions into applicable fields. Courses shifted toward professional development as the summer progresses.

Focus Question:

How does a summer research experience for undergraduates (REU) impact students?
- Sub questions:
  - How will outreach experience impact student confidence and public/science interactions?
  - Can the MSU Solar Physics/Astrophysics be improved through observations gathered through formative assessments and student success?

Formative assessments:

As science evolves, so too does science education. Formative assessments are in place to monitor student progress in class or other endeavours and allows for almost real-time changes to benefit students and educators.

Methods:

- Three pronged approach: student betterment, impact of outreach, program improvement
- Formative assessments utilized
- Outreach component reintroduced
  - Bozeman Young Men's Christian Association (YMCA)

Class based and Improvement assessments:
- Self-confidence Likert Type Survey
  - Conducted at entrance, midway, and exit
- Chain Note assessments during or after lecture about the class
- Comparison between this year and previous years exit survey conducted by the PI of the REU, Dr. Jiong Qiu
- Student Journal Submissions

Professional development assessment:
- Direct Paraphrasing
- Researcher Observation of Presentations
- Student Interviews

Figure 2: This graph depicts the REU Exit Survey results from 2015 - 2024 with data gaps in 2019 and 2020. There are 14 total questions asked and divided into categories: experience, academic, research, and orientation. Please note that graphed lowest score is 1.8 and not 0.

Results of Assessments and Observations

Student Self-Reported Outcomes

Figure 1: Featured are three heat maps and sample question of the self-confidence likert survey (*N*=7). Each is a normalized gain comparison between assessments 1, 2, and 3.

Self-Confidence Assessment (Above)

- Surveys covered four topics: physics concepts, Sun and star concepts, research experience, and public outreach experience
- Analysis: "not" and "slightly" confident (score 1) were combined, "moderately" confident remained untouched (score 2), and "highly" and "extremely" confident (score 3) were combined
  - normalized gain (figure above)
  - chi squared analysis, were then run

Results:
- Chi Squared results from resp. 1 to resp. 3 were statistically significant over all
- As students progressed, score 1 responses had high negative scores showing an increase in confidence
- Public outreach had the least shift in confidence where content (Physics and Sun & stars) had the most shift.

REU Exit Survey (Left)

- Scores from 2015 - 2024 with a gap for years 2019 and 2020
- The same 14 questions were asked throughout this time
- Students report responses from 0 to 3 with 0 being the worst score and 3 being the best.

Results:
- This year did not yield any statistically significant results against pre- or post- COVID REUs
- The average score shows a decrease in satisfaction from previous years
  - A contribution could be the number of responses (*n*=6) unlike the normal 8 student responses.

Link to all data collection instruments and dates

References: Montana State University Solar Physics. (2024). MSU Solar Astronomy & Space Physics REU Program. https://solar.physics.montana.edu/reu/

Reacher Analyzed from Student Response

Chain Note Assessment Results

- Given during three lectures and focuses on student interaction with the material/professor
- Each question assessed for similar responses and notable comments from students

Professor Feedback: energetic and passionate about the subjects they teach

Class Feedback:
- Materials presented with visuals were more impactful than a slide of equations
- The material covered higher level electromagnetic field courses than the students' have studied
- Students were willing to educate themselves during the lecture on terms and basic concepts

Student Review:
- Students were more inclined to focus on research than on the lecture itself during presentation weeks
- Students noted stress before the presentations
- Increase lectures (from 8 to 10) and leave Thursday lecture before presentations for practice session

Figure 3: Two word bubbles illustrate the difference of language used by students (*N*=7) during the direct paraphrasing assessment. The left hand star details jargon terms, or field-specialized terms. On the right, during a later direct paraphrasing assessment, is common language used to explain the same science as the star.

Direct Paraphrasing Results (Above)

- Given twice, once after first professional development course and once before visiting the YMCA
- One of the strategies tracked student professional development
- Presentations were given to fellow students and advisors
- Students visited Bozeman YMCA to present their research to a younger audience

Result:
- Clear student improvement after coaching and presentation practice
- Jargon words turned to simplified, but helpful language

Final Thoughts and Observations

Student response from classes is clearly illustrated above, however, some final thoughts can be presented and related back to the self-confidence survey. Specifically, student response to interviews after taking outreach/public speaking classes, presenting over the duration of the REU, and visiting the local YMCA and interacting with children (estimated 7-12 year olds). Giving students the opportunity to interact with local community was impactful on the students and was mentioned as such by all four of the student interviewees.

"This is something I would have loved to have as a kid, but I never got that opportunity because there was not a whole lot of like outreach like that back when I was a kid." – Direct student quote

Student evolution in presenting science was also seen during group presentations as confidence improved visibly and reportedly by student interviewees.