

ARTICLE FOR SUBMISSION

## Encouraging community building and outreach through solar/astro-physics research experience for undergraduates

R. Fleming<sup>a</sup> and C. J. Graves<sup>a a</sup> Montana State University, Bozeman, Montana

### ARTICLE HISTORY

Compiled March 11, 2025

### ABSTRACT

There are various benefits to joining a Research Experience for Undergraduates (REU) program as a sophomore or junior: increased subject knowledge, research exposure, and entry into a larger scientific community. The Physics Department at Montana State University (MSU) in Bozeman, MT, runs a solar/astro-physics program that has operated for 23 years. In 2024, seven students from across the U.S. participated in research, lectures, and public outreach. This year, formative assessments—a classroom technique for active feedback—were used to track student progress. These included Likert-type surveys and classroom assessment techniques (CATs). Additionally, participants were interviewed, and the researcher kept a journal of observations. Quantitative data was analyzed using normalized gains, Chi-Squared tests, and weighted averages for confidence/satisfaction, while qualitative data was examined for common themes. Results showed improved confidence in material and presentation skills. The REU also received suggestions to enhance student satisfaction with community engagement and to continue the outreach program.

## KEYWORDS

Solar physics; astrophysics; formative assessments; Research Experience for Undergraduates (REU); outreach; community

## 1. Introduction

### *1.1. Context of Study*

Research is an important piece of any undergraduate education in science, technology, engineering, and mathematics (STEM). During the summer, the absence of undergraduate classes provides an opportunity for research experiences. The National Science Foundation (NSF) funds 28 astronomy/geospace focused research experiences for undergraduates (REU) programs across the nation (United States National Science Foundation[1]. The Montana State University (MSU) Physics Department has run an NSF-funded REU program for 23 years, focusing on undergraduates interested in solar physics and astrophysics[2]. At the time of application, a student chooses which research area they wish to explore. Student selection was highly competitive for the program, roughly 10 applicants to 1 admission, as MSU's Solar/Astro REU is made of a small professor pool (J Qiu, personal correspondence, Jan. 16, 2025). Student cohorts range from 8-10 students which allows for individual attention. The MSU solar/astro- physics REU program considers student aptitude through student essays and faculty/staff recommendations. This REU program offers students the chance to work with professional research scientists, attend focused seminars, and complete a research project designed to build a foundation for a research career or assess their interest in the field. Students receive hour-long lectures twice a week, starting with undergraduate-level astrophysics and transitioning to professional development. Since the program's inception, these lectures have been a core component.

This research focused on the 2024 Solar Physics/Astrophysics REU. The 2024 REU was different for two reasons: 1) introducing formative assessments and 2) reintroducing community outreach. Formative assessments were created with feedback in mind. Feedback allows educators to understand their students' thought processes over their acquired knowledge[3]. Formative assessments are not commonly used during the MSU

REU. There was a REU Exit Survey and nothing more. After recognizing the NSF's increased emphasis on formative assessments, PI Dr. Jiong Qui pushed for including these techniques throughout the REU program to report student progress which led to an evolution of the two decade old program.

The second difference in the 2024 MSU REU was an outreach-focused component where students were expected to participate in community outreach; a local Young Men's Christian Association (YMCA) hosted Astronomy Day. Every student participated by creating a single multimedia presentation starting with the Sun and expanding beyond our solar system. Additionally, students participated in lectures on public speaking, science professionalism, and conference etiquette. REU-wide lectures covered science professionalism (public speaking, lab culture, note-taking), while REU-specific courses focused on public speaking (age-specific conversation, anxiety coping, outreach presentations) and conference etiquette (poster building, scientific discussions). As a result of this study, this REU program and others can enter a new phase, strengthening its research focus while fostering connections with both the scientific community and the local public.

### *1.2. Understanding research experience for undergraduates*

There were not always opportunities to engage in research for undergraduate students. Many universities lack the capacity to offer in-house research or sufficient slots for every student[7]. Over time, funding has expanded to create programs and research opportunities, while faculty have dedicated time to developing summer projects or teaching REU students. This financial and faculty support has fostered small research communities and enhanced efforts to improve STEM opportunities for minorities[4, 8]. Increased diverse backgrounds continue the building of these small scientific communities.

The culture of research is often intimidating and there are no obvious entry points. Scientific culture is based around a distinct group of people where respect is developed based on contribution and collaboration[9]. REUs allow for new miniature communities. Exposure to scientific culture has been linked to increased student confidence in their skills and understanding[4, 7, 8]. This new, small culture leads into the greater

science community. A place in the local scientific community can aid a budding scientist to relieve some of the intimidation that can arise in science.

Building self-confidence is a focus of REU programs. Once engaged, the goal is to strengthen students' confidence in their knowledge, which can translate to on-the-job experience in engineering REUs or scientific research development in science REUs[5, 6]. Good mentorship is a starting point for confidence building. Students can implement the skills acquired during an REU in the future to create a network of people starting with a mentor[6]. Networks are a safety net of experience and knowledge for STEM which leads to self-confidence in personal work. Therefore, REU programs can play a major role in developing science-based relationships.

Faculty who participate in mentoring often report a positive experience and learn more about their students. Personal connection between scientists is needed to improve research/scientific culture[8]. STEM is a continually progressing field requiring adaptable minds willing to engage in discussion of new ideas. REU programs encourage future professionals to pursue graduate degrees and continue research[5, 7, 8]. Although many REU students travel for the program from their home universities, the excitement for STEM remains and carries through the finalizing of an undergraduate's education.

### ***1.3. Outreach impact on undergraduate students***

In this context, outreach involves engaging with the surrounding community to educate both children and adults about STEM. Undergraduate-lead outreach shares some of the same benefits that the greater REU does such as increased self-confidence, enhanced scientific understanding, and scientific cooperation[10]. By developing public specific classes during REU programs, budding scientists can become outreach educators. Students who elect to pursue STEM initially, often stay in STEM throughout their undergraduate studies as a result of partaking in outreach[11]. The public serves as an extension of the scientific community, as seen in community science initiatives. Students in outreach programs develop a sense of belonging by collaborating with colleagues and mentors([10, 11]).

### *1.3.1. Outreach as a class*

A nurturing environment for student outreach educators can be found in the form of a class or a club. Students have the opportunity to share ideas and activities in a safe space before presenting to a larger audience. There are three steps for students to use to learn how to create presentations, talks, and activities for all audiences[12, 14, 15]:

- (1) A hands-on activity to build engagement: not only do hands-on activities engage the mind, these activities also illustrate the usefulness of outreach and why scientists would want to venture into the surrounding community
- (2) Prepare their own presentations: each presentation and activity is shared in the class and is examined by peers with open discussion to improve or change the work
- (3) Interact with the community through their presentations: student will interact with classrooms, other educators, and the general public

Communication opens doors to better job opportunities and community partnerships.

### *1.3.2. Local and scientific community benefits*

Students who volunteer often go above and beyond in creating scientific content and exude excitement for their subject. The general community responds well to such excitement. Positive identity with science can transfer onto others by including minority groups who are traditionally excluded from subjects such as STEM[16]. Elementary students who enjoy the experience of a new educator often share it with family, leading to repeated interactions with outreach educators and exposure to new topics, while also increasing teachers' awareness of current science research. These interactions can spark greater interest in science and, at times, short-term aspirations for a science career[17, 18]. Even though most of the responses are generated in the short term, the awareness of science in younger students has an impact on the scientific community.

Student positive experience is imperative to the development of young scientists. A result of outreach is a greater number of undergraduate students interested in becoming educators. Therefore, there is a higher enrollment of students in graduate programs[15]. These students can become mentors for undergraduates or high schoolers, building on

connections made through outreach. This has led to more children advancing into graduate studies and entering undergraduate STEM programs[17, 18]. Overall, an inspiring look into the future of science using outreach.

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***

The seven students involved in the survey did not submit any demographics based on Montana State University Institutional Review Board approval. Participation was voluntary, but encouraged. At the study’s conclusion, new IRB approval allowed student data to be submitted to a data repository. Understanding student impacts required a number of tools. Two of the seven tools used in the study were classroom assessment techniques (CATs). CATs are used to assess student understanding and training of thoughts over knowledge and memorization. Consequently, CATs do reveal students’ knowledge, but indirectly. These CATs were developed for the college classroom and have since moved into primary education [3]. Self-reported Likert scale surveys were another tool used to determine student improvement or program impact. Finally, student interviews, student journals, and researcher observations helped track student progress. Students were given assessments each week of the 10-week program Table 1.

### ***2.2. Detailed Information on Materials***

Week one introduced the first of the three Self-Confidence SurveysA.1. For anonymity, these Surveys were given and recorded by Google Forms without email collection. This Survey assessed student confidence at three stages—baseline, mid-experience, and final comparison—across four areas: (a) physics, (b) Sun and star knowledge, (c) research

experience, and (d) public outreach. The analysis strategy for understanding student changes progressed as follows. Students could choose from five response options. The two lowest (not confident and slightly confident) and the two highest (highly confident and extremely confident) scores were combined, resulting in three final categories for analysis: low confidence, medium confidence, and high confidence Figure 1. After the simplification of the data, responses from the pre, mid, and post Self-Confidence Surveys were compared using normalized gain and a Chi squared statistical significance test[19].

Another numerical, self-reported survey was also considered. The REU Exit Survey was given at the end of the experience and contained 16 questions, 14 aligned with previous Exit Survey questions dating consistently back to 2015 A.4. Students were given the survey via Google Forms during the final week of the program. This was the first year the students were given the survey virtually instead of physically with a proctor. Results from the REU Exit Survey, note that there is no Pre-Survey provided by the REU program, were averaged together across the responses as per the past Exit Surveys, including the two new questions not compared to years previous.

Two classroom assessment techniques (CATs) were introduced and handed out the other weeks around the Self-confidence Surveys. Students were given the Chain Note CAT first A.2. This CAT is used as a stop during lecture to get a snap-shot of student understanding or focus. At the beginning of class, each student received a blank note card. During the lecture, a question was passed around in an envelope, then students had a minute or less to write their answer before passing the envelope to the next student Figure 2. Three rounds of the Chain Note assessments were conducted during the solar/astro- physics-based seminars. Picked for their content and timing: 1) Stellar Atmospheres: the students' first physics-based seminar, 2) The Magnetic Sun: student academic background and comfort level, 3) Observing Techniques: open-mindedness for subjects not exactly aligned with the summer research. Table 2. Overall, interaction between professor and student has an impact on student understanding and success.

The second CAT was introduced once students began professional development courses given to students through Google Forms. Direct Paraphrasing challenges students to write short descriptions of a topic Figure 3. Since students tend to use jargon

to hide their uncertainty with the material, the main objective of Direct Paraphrasing was to search for jargon. Students were required to write about their research twice: first, after learning to give elevator pitches in the campus-wide science professionalism REU course, and again after the solar/astrophysics REU lecture, which focused on public speaking and outreach techniques specific to solar physics and astrophysics.

Finally, four out of the seven students were interviewed via Webex for transcription purposes. Interviews were voluntary and focused on the student's evolution and emotions around classes taught, both general and specific to their research, and YMCA public outreach experience A.5. Questions were then analyzed for similar themes per student answer. The researcher also maintained a journal of observations from group meetings and select classes, recording performance, particularly during presentations. Each of the three group presentations was assessed for presentation techniques and student confidence. Performance not only highlights confidence levels in real time but also the improvement in understanding of the topic at hand. Personal observations are used sparingly.

### **3. Results**

The best indication of self-reported student impact from the program is the result of the Self-confidence Survey. Navy blue scores represented negative responses, indicating a shift toward confidence if they appeared in the low-confidence (score: 1) column. Conversely, lighter green scores were positive, with higher values reflecting greater confidence improvement. The first survey results aligned with expectations, showing varying but generally low confidence levels among students. Minimal improvement was observed between responses 1 and 2 following the physics and Sun and star lectures. Between responses 2 and 3, confidence levels remained mixed, with little shift in high (score: 3) confidence. This outcome was anticipated, as students were still deepening their research and had not yet begun field-specific outreach and professional development courses. A transition from negative, low confidence scores to positive, high confidence scores is evident in the final normalized gain comparison between 1 and 3 Figure 4. This data was also tested for significance using the Chi squared test (p



$<0.05$ ). Almost all of the results were statistically insignificant, except the confidence levels overall between response 1 and 3. The significance of confidence ( $p = 0.0005$ ) between these responses, the beginning and the end of the program, numerically show statistically significant student improvement. Clearly, the largest increase of confidence is in physics, as is the next almost statistically significant result ( $p = 0.08$ ). The smallest self-reported improvement was in public outreach. Despite the low response rate, one student shared in an interview: “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”.

Although the surveys conducted by the researcher showed an overall positive experience from the students, the REU Exit Survey told a slightly different story. Following the divisions outlined in the previous section, the results show a decrease in satisfaction in many parts of the program Figure 5. Despite the lower scores from most questions, the overall expectations were met. This is mainly due to the question not being written like a scaled question, but a yes or no question. The other questions were all scaled questions based around satisfaction. Note that the worst category was the orientation category Table 3. Students also reported in this survey that more effort toward building community would be appreciated. Mentorship in research was well received, particularly regarding edits for group meeting presentations. Students noted in the interview that mentor feedback and a focus on big-picture thinking significantly improved their presentation style. Additionally, this was the first year students provided feedback on the public speaking/outreach classes and the REU-wide program, resulting in a satisfaction rating of 2.5 out of 3 for both courses. This feeling was reflected in the interviews where all of the students reported liking the REU-specific courses, but found some boredom in the lab-specific courses taught by the REU-wide program.

The Chain Note assessment aided in understanding student reactions to the seminar series. Responses toward the first Chain Note were mainly focused on their new research assignments. Since this Chain Note was taken during the second week of the REU and the first group research presentation was oncoming; mixed focus was expected, especially “not being in the mindset”. These feelings transferred into the

second CAT where students were asked if the material was being understood. Visualization of concepts and lecturer enthusiasm seemed to hold the most impact on students, especially since four out of the six students, one student was absent from lecture, mention looking up information or not having the expected background information. Two responses that indicated understanding did not elaborate like the students who did not understand. Finally, the last Chain Note showed understanding of expanded applications such as knowing that some material can be used beyond the classroom.

After the Elevator Pitch course, taught by the REU-wide seminar series, students were asked to turn in pitches using Direct Paraphrasing which were then analyzed under a laymen eye; essentially picking any words that would not be in common vernacular or phrases that are field specific, such as “the energetics of solar flares” and “X-ray corona and radio jet”. The number of field specific, jargon, words from all students was recorded. There were few common language phrases at this time. After instruction, another Direct Paraphrasing prompt was considered for jargon and common language. General terms that replaced jargon words were collected for review Figure 6. The number of jargon words to common were drastic: a ratio of five common words to two jargon words overall. A key focus was engaging a general audience with phrases like “how the Sun can impact our daily lives and the course of history.” Generating interest in a science talk is just as important as the content itself. REU students found value in understanding the larger context, getting to the point quickly, and considering the age of the teenage audience. They appreciated having class time to prepare their presentations. Although the expected teenage audience turned out to be primarily 7-12 years old, the students quickly adapted and felt comfortable adjusting their presentations to suit the young audience’s experience level.

#### **4. Discussion**

The results of this study highlighted a few key focus points. First, students had a positive experience with public outreach and guided presentation lectures, which should be encouraged in a REU program. Second, REU programs that do not emphasize

scientific community-building should consider making it a priority.

#### *4.1. Public Speaking and Outreach Experience*

As a result of two different support classes, REU-wide and this REU-specific, the students in the solar-/astro- physics REU greatly improved their public speaking ability. Increased confidence in research experience shows later in the experience as research presentations become steadily more confident through observation. From personal observation, students' increased confidence was evident, leaving a note in the midterm presentations, two weeks after the first, "all around increase of confidence in materials and presentations skills". Students increased descriptions over jargon and could answer questions more readily. From the Self-confidence Surveys and the REU Exit Surveys, there were mixed feelings about public outreach but did still show a shift toward higher confidence. The Direct Paraphrasing CAT also showed vast improvement on language use and ease of explaining difficult topics in friendlier wording. Finally, students agreed via interview that the outreach experience was interesting; a student stating "I thought it was pretty useful because we did like I haven't had like anything specifically on outreach". Therefore, there are clear benefits to students having seminars in public outreach.

As a result of outreach classes, students learned to translate jargon into clear concepts understandable to those outside their niche field. During the seminars, students had time to present their YMCA talks, receiving both compliments and criticism. This peer feedback helped refine their language for presentations aimed at a range of age levels. With guidance provided in a supportive environment, the sudden shift in age groups for the YMCA presentations was almost seamless. This meant becoming comfortable with the presentation material and adjusting to describe concepts in less detail than originally planned. Students reported feeling at ease during the interviews after understanding the new age group. Two students directly expressed a desire to continue doing outreach and further developing their skills. Student interaction with the public has enhanced the professional development of these REU students, boosting their confidence in explaining and understanding their research topics. Following the success of the outreach initiative, reintroduced after its hiatus in 2018, there was

strong encouragement to continue. This effort could serve as another way to generate interest in the local community about the work being done by the REU program and MSU.

#### ***4.2. Program Evolution***

After reviewing all of the results, the MSU solar/astro- physics REU program moved to change two other pieces: 1) changing the lecture calendar and 2) fostering a sense of community.

From the combination of quantitative surveys (Self-confidence Surveys and REU Exit Survey) and the Chain Note CAT, the lectures were found to be a weak spot. Between the pre- and mid- Self-confidence Survey results, confidence had not greatly improved. Furthermore, the results of the REU Exit Survey showed a decrease in satisfaction with the courses being taught, the responses matching 2017 in lowest satisfaction. Students further highlighted this weakness through the Chain Note Assessment. While they appreciated the professors' enthusiasm, students reported losing focus during lectures. Some students mentioned Googling concepts and regaining focus after a graphic or video was introduced. Additionally, a few students felt that the physics concepts were too advanced for their current undergraduate year. Students also lost focus and were anxious before the group presentations. This discovery led to a discussion of slowing lectures, increasing the number of lectures to expand on material, and restructuring when lectures are given.

In addition to academics, students wanted a sense of community which was claimed to be lacking especially in the beginning of the REU program. This was most heavily seen in the REU Exit Survey open ended questions. Students also reported this informally to mentors and the researcher. A scientific community is impactful and leads to student success. Without aid in community, students struggle with a sense of belonging[10]. At the beginning of the program, there will be activities added to introduce mentors and students beyond a simple introduction. Additionally, the REU program considered requiring work space time where all of the students in this REU program were to work in the same office space. This would allow students to brainstorm solutions to physics, mathematics, or coding problems without feeling as separated.

## 5. Conclusion

After the conclusion of the REU program, the result was undergraduate students who grew their knowledge, confidence, and professionalism and a program with new ideas to exercise next year.

- (1) Outreach classes and a nurturing environment for learning boosts confidence and enhances presentation ability in students.
- (2) The opportunity to present science to the general public was both interesting and enjoyable.
- (3) Students want a sense of community within the REU experience and the program should help foster the community.
- (4) Lecture style seminars should slow down for student understanding.

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

## 6. In text figures and tables

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

Date	Assessment
May 26 <sup>a</sup>	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 <sup>a</sup>	Self-confidence Likert Survey 2
July 18	Direct Paraphrasing 2
July 23 <sup>a</sup>	Self-confidence Likert Survey 3
July 31 <sup>a</sup>	Student Interviews
August 2 <sup>a</sup>	REU Exit Survey

<sup>a</sup>These surveys/interviews happened over multiple days for student ease of response.

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

Class Administered	Class Description
The Stellar Atmosphere	The outer layers of stars and the Sun are investigated
The Magnetic Sun	A look into the complex magnetic fields that drive solar phenomena, notably solar flares.
Observing Techniques	Explaining satellite usage with a focus on solar satellites.

**Table 3.** All of the questions analyzed from the REU Exit Survey handed out by the PI of the program, Dr. Jiong Qiu. These are the same questions asked from 2015 to 2024 with a gap for 2019 and 2020.

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 pursuing 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

### Understanding of the Sun and stars

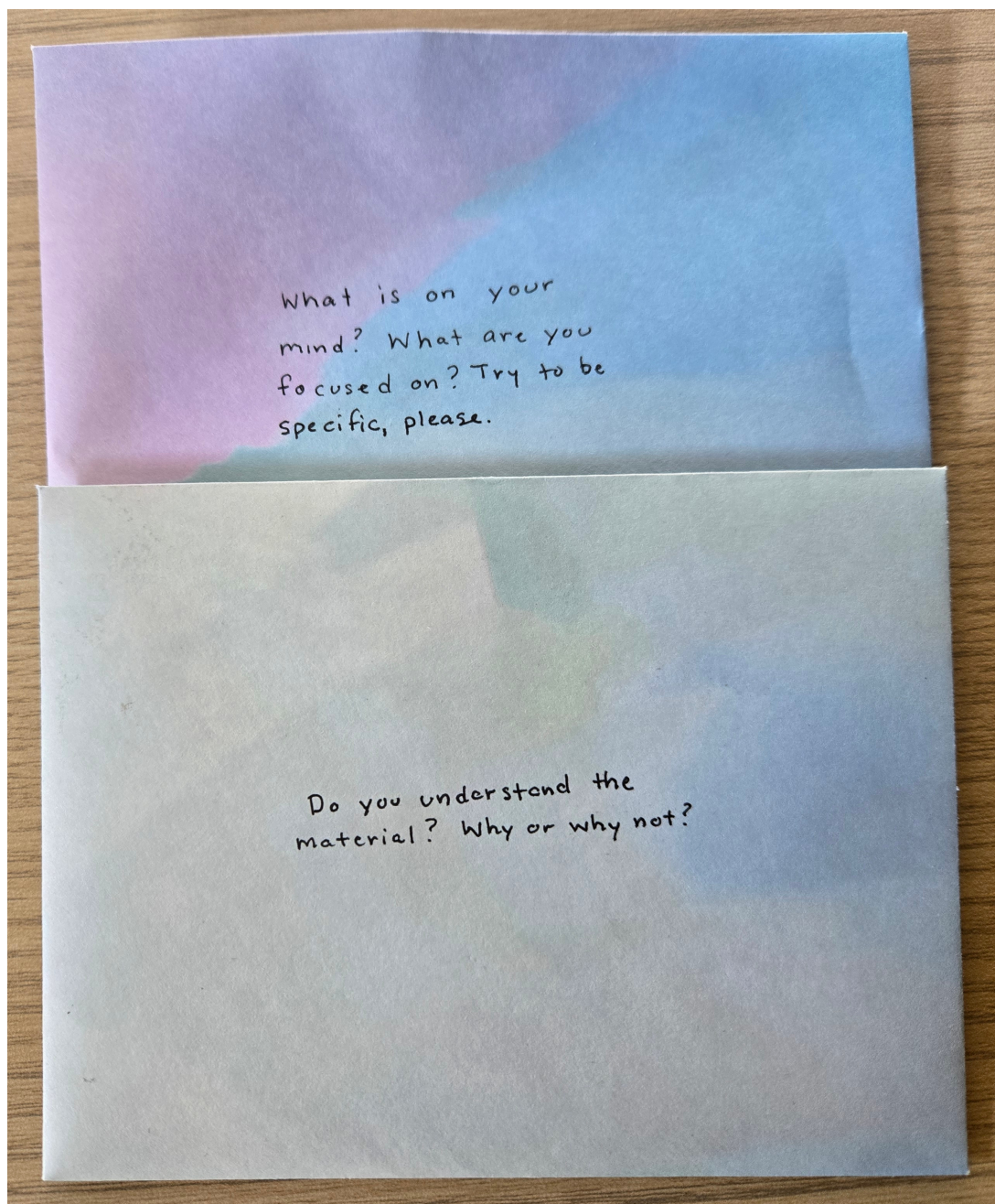
The second section, out of four, will be focused on your solar/astronomy understanding. Confidence levels are described below:

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

Are you confident with:

	Not Confident	Slightly Confident	Moderately Confident	Highly Confident	Extremely Confident
Stellar structure?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Star types (the scale and/or special cases)?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Stellar wind?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
The Parker Spiral?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Coronal mass ejections (CMEs)?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Solar/stellar flares?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Active galactic nuclei (AGN)?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
the The difference between solar flares and CMEs?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

**Figure 1.** An example of the format of the Self-confidence Survey questionnaire from the Sun and Stars section. On the left, there is a description of what each confidence level means to dissolve any confusion about the scale. The right features the question in Likert-scale format.



**Figure 2.** Two of the three questions that were given out to students. The other question was given via Google Forms. Question positions can be found in Table 3.

# Direct Paraphrasing

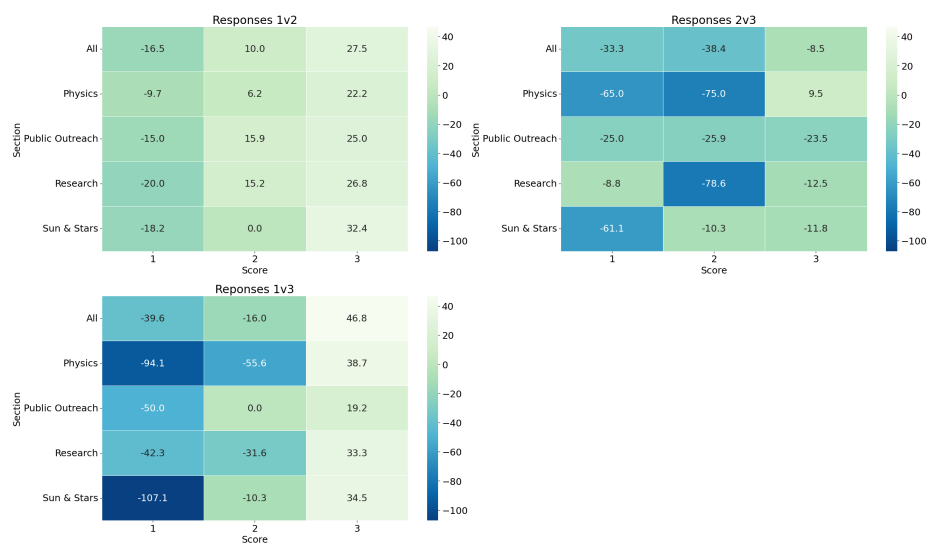
Your task is to translate specialized information into your own words that a person not in your field can understand (ie, not a scientist in physics or astrophysics or not a scientist at all).

Not shared

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

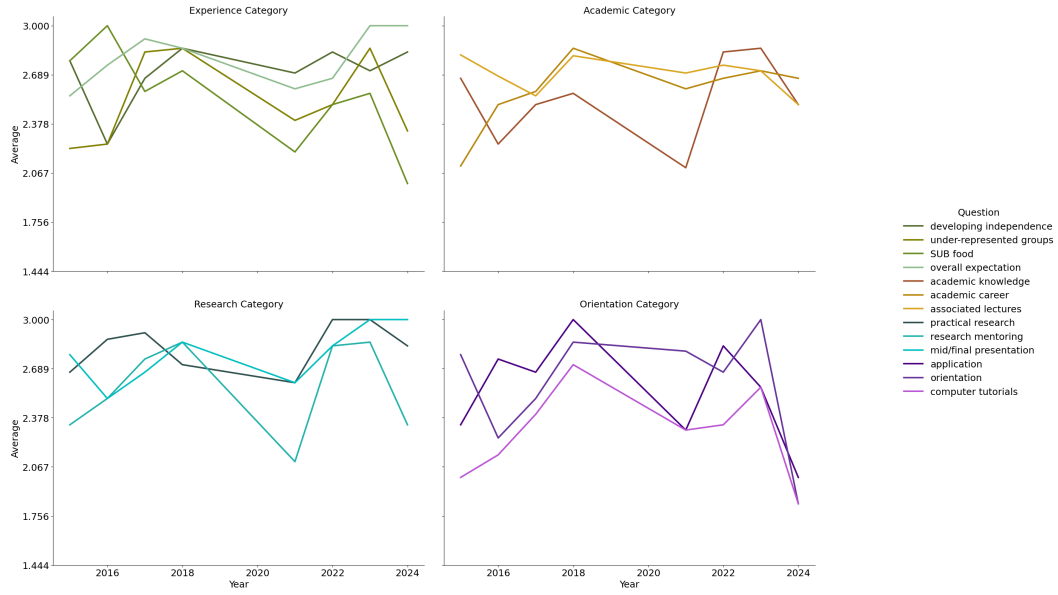
Your answer

**Figure 3.** This is the second of the two direct paraphrasing questions. Both can be found here A.3



**Figure 4.** Three heat maps indicate student ( $N=7$ ) confidence levels between responses using normalized gain analysis between each of the Self-confidence Surveys. Responses refer to the averaged student answers from the survey. More positive scores are indicated with very light green and more negative scores with dark blue. Anticipated results are that the left column labeled 1 (low) are dark blue and the right column labeled 3 (high) are light green.





**Figure 5.** 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. Results from 2024 ( $N=6$ ) were averaged in the same manner as those from previous years for a fair comparison between years.



**Figure 6.** Two word bubbles: the one on the left is a list of jargon words found in student responses (direct paraphrasing 1) and the right is a list of common words found in student responses (direct paraphrasing 2). The larger the words, the more often used.

## Acknowledgments

Thank you to Dr. Jiong Qiu for the support and use of the REU program for this research as well as support while presenting the material to others. Thank you to Dr. Jamie Cornish for the all of the advice and helping to set up the YMCA trip. Thank you to Dr. Anne Lofink for the support during the REU program and listening to the results of this project to improve the program in the future.

## Disclosure statement

Placeholder in case I need this. ADD USE OF AI FOR LANGUAGE IMPROVEMENT

## Funding

Unfunded research.

## Notes on contributor(s)

I guess I write a blurb about myself?

## 7. References

### References

- [1] United States National Science Foundation. (n.d.) *REU Sites: Atmospheric and Geospace Sciences*. [https://www.nsf.gov/crssprgm/reu/list\\_result.jsp?unitid=10020](https://www.nsf.gov/crssprgm/reu/list_result.jsp?unitid=10020)
- [2] Montana State University Solar Physics. (2024). *MSU Solar Astronomy & Space Physics REU Program*. <https://solar.physics.montana.edu/reu/>
- [3] Angelo, T.A. & Cross, K.P. (1993). *Classroom assessment techniques: A handbook for college teachers* (2nd ed.). Jossey-Bass Publishers.
- [4] McLaughlin, J. (n.d). Developing course-based undergraduate research experiences. *PennState Undergraduate Education: Undergraduate Re-*

- search and Fellowships Mentoring. <https://urfm.psu.edu/mentors/developing-course-based-undergraduate-research-experiences>
- [5] Reisel, J. R. (2023). Engineering Student and Faculty Perspectives on Undergraduate Research Experiences. *Journal of STEM Education: Innovations & Research*, 24(3), 23–28.
  - [6] Escobedo, P., Garcia, D., Cascelli, L., Chavira, G., Flores, G. E., Constantine Brown, J. L., Boyns, D., & Ainsworth, A. T. (2023). Comparing undergraduate research experiences before, during, and after the COVID-19 quarantine: The successful adaptation of the BUILD PODER Summer JumpStart program. *PLoS ONE*, 18(12), 1–19. <https://doi.org/10.1371/journal.pone.0295901>
  - [7] Auchincloss, L.C., Laursen, S.L., Branchaw, J.L., Eagan, K., Graham, M., Hanauer, D.I., Lawrie, G., McLinn, C.M., Pelaez, N., Rowland, S., Towns, M., Trautmann, N.M., Varma-Nelson, P., Weston, T.J., & Dolan, E.L. (2017). Assessment of course-based undergraduate research experiences: a meeting report. *CBE-Life Sciences Education*, 13(1), 29-40. <https://doi.org/10.1187/cbe.14-01-0004>
  - [8] Bangera, G. & Brownell, S.E. (2017). Course-based undergraduate research experiences can make scientific research more inclusive. *CBE-Life Sciences Education*, 13(4), 602-606. <https://doi.org/10.1187/cbe.14-06-0099>
  - [9] Jegede, O.J. (1997). School science and the development of scientific culture: a review of contemporary science education in Africa. *International Journal of Science Education*, 19(1), 1-20. <https://doi.org/10.1080/0950069970190101>
  - [10] Kubota, T. (2021, April 13). Stanford plant biologists help develop guide for science outreach. *Stanford News Service*. <https://news.stanford.edu/2021/04/13/guide-science-outreach/>
  - [11] Lyon, E.G., Kochevar, R., & Gould, J. (2023). Making it in undergraduate STEM education: the role of a maker course in fostering STEM identities. *International Journal of Science Education*, 45(11), 946-967. <https://doi.org/10.1080/09500693.2023.2179376>
  - [12] Rao, S., Shamah, D., Collay, R. (2007). Meaningful involvement of science undergraduates in K-12 outreach. *Journal of College Science Teaching*, 36(6), 54-58.
  - [13] Thomson, N.D., Wurtzburg, S.J., Centifanti, L.C.M. (2015). Empathy or science? Empathy explains physical science enrollment for men and women. *Learning and Individual Differences*, 40, 115-120. <https://doi.org/10.1016/j.lindif.2015.04.003>
  - [14] Alexander, H., Waldron, A.M., Abell, S.K. (2011). Science and me: a student-driven science outreach program for lay adult audiences. *Journal of College Science Teaching*,

- 40(6), 38-44.
- [15] Gustine, J., Smith, M., Manahan, D. (2006). A service-learning model for science education outreach. *Journal of College Science Teaching*, 36(1), 22-26.
  - [16] Clark G, Russell J, Enyeart P, Gracia B, Wessel A, Jarmoskaite I, et al. (2016). Science Educational Outreach Programs That Benefit Students and Scientists. *PLoS Biology* 14(2). <https://doi.org/10.1371/journal.pbio.1002368>
  - [17] Olesik, S.V. (2009). Science outreach: an important endeavor for active scientists. *Analytical and Bioanalytical Chemistry*, 394, 1233-1236. <https://doi.org/10.1007/s00216-009-2793-x>
  - [18] Kurtines, W.M, Montgomery, M.J., Eichas, K., Ritchie, R., Garcia, A., Albrecht, R., Berman, S., Ferrer-Wreder, L., & Lorente, C.C. (2008). Promoting positive identity development in troubled youth: a developmental intervention science outreach research approach. *An International Journal of Theory and Research*, 8(2), 125-138. <https://doi.org/10.1080/15283480801938515>
  - [19] Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, 66(1), 64-74.

## Appendix A. Data Collection Materials

### A.1. Self-Confidence Likert Survey

**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?

### ***A.2. Chain Note Assessment***

**Table A6.** Chain Note Assessments Given

Class Administered	Question
The Stellar Atmosphere	What are you currently focused on (this can be class, lunch, outside, etc.)?
The Magnetic Sun	Do you understand the material? Why or why not?
Observing Techniques	Do you feel the information is useful for your current or future research?

### ***A.3. Direct Paraphrasing***

**Table A7.** Chain Note Assessments Given

Class Administered	Prompt
Elevator Pitch	In your own words describe your research like the elevator pitches described today.
YMCA Presentation Building: Final Session	In your own words, describe your presentation as a summary that would be interesting to your upcoming audience(teenagers).

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

#### A.4. REU Exit Survey

**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?

---

#### A.5. 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?

---