

ARTICLE FOR SUBMISSION

Understanding the impacts of a solar/astro- physics research experience for undergraduates on undergraduate students

R. Fleming^a, C.J. Graves ^a, and A.Takeda^a

^a Montana State University, Bozeman, Montana

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ABSTRACT

During the summer, Montana State University (MSU) located in Bozeman, Montana hosts a number of research experience for undergraduates (REU) programs. There are various benefits to entering an REU program as a sophomore or junior year undergraduate student: increased knowledge of specific subject matter, introduction to research, and entry into a larger scientific community. The Physics Department at MSU has one such program focused on Solar physics/Astrophysics which has run for 23 years. In 2024, the program received 7 students from around the United States. This REU is structured as a course-based research program where students have class two days out of the week with the rest of the time devoted to research. Classes are physics-based, with a solar/astrophysics focus, at the start of the REU and then shift toward professional development. For this year, a system of formative assessments were used to track student progress over their time at the MSU solar physics/astrophysics REU. Formative assessments are a new classroom-based technique to check student understanding. These assessments are not traditional exams and focus on deeper knowledge gained over memorization. Additionally, an outreach component was reintroduced after a hiatus caused by the COVID 19 pandemic. Students were taught different facets of public outreach and had to develop a collaborative presentation which focused from the Sun and beyond to present to teenagers at the local Young Men's Christian Association (YMCA). Results yielded improved confidence in material and presentation skills as well as improvements to the program.

CONTACT R. Fleming. Email: rhiannonfleming@monana.edu

KEYWORDS

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

1. Introduction

Research is an important piece of any undergraduate education in science, technology, engineering, and mathematics (STEM). Students need hands-on learning experiences beyond the traditional classroom, primarily since upper-level science courses often focus more on theory than practical application. Summer research experiences for undergraduates (REUs) provide an ideal opportunity to address this gap. Free from the constraints of coursework, REUs offer extended time for immersive, hands-on research. Perhaps the best time is during a summer research experience for undergraduates (REU). During the summer, there is an extended period and typically no undergraduate classes. There are twenty-eight National Science Foundation (NSF) funded astronomy/geospace focused REU programs across the nation [1]. Montana State University (MSU) Physics Department operates one of the summer REU programs funded by the NSF targeted toward undergraduates interested in solar physics and/or astrophysics [2]. The MSU REU grants the opportunity to work with a professional research scientist, provides light but specific coursework, and a tasked challenge. This challenge is a research project designed to educate and create a foundation for a student to become a research scientist or ascertain if research is their preferred path. At the time of application, a student will choose which research area they wish to explore. Student selection is highly competitive for the program as MSU's Solar/Astro REU is made of a small professor pool.

The pinnacle of the REU at MSU is highlighted by the professor's dedicated lectures and mentoring. Student cohorts range from 8 - 10 students which allows for individual attention. These students apply from around the United States. MSU Solar Physics considers student aptitude through student essays and faculty/staff recommendations. As part of the REU, students receive hour-long lectures twice a week. These lectures have been taught since the inception of the REU. Lectures at the beginning of the summer are physics-based at an undergraduate level and then transition toward pro-

fessional development later in the summer. Additionally, as part of the 2024 REUs on campus, new professional development courses were taught once a week. In the past, there was an opportunity for students to engage in outreach. Presently, MSU does not always provide that opportunity as few professors are willing to do public outreach. Outreach has not been part of the program since the COVID-19 Pandemic.

This Capstone focused on the 2024 Solar Physics/Astrophysics REU. The 2024 REU was different for a few reasons as I assessed techniques, through formative assessment, to accurately track student progress through the summer and make adjustments or improvements to the program. First, formative assessments were added to coursework. Formative assessments are not commonly used during the MSU REU. There was an 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. Introducing formative assessments was an active, parallel track of student progress. Formative assessment will also monitor the effectiveness of professors' lectures which could lead to an evolution of the program. This program has changed little since its inception over two decades ago and now is the chance to monitor student progress with the material and their confidence in their knowledge. The potential benefits to undergraduates were enhanced learning, an easier transition into the scientific community, and better interpersonal connections made.

The second difference in the 2024 MSU REU was an outreach-focused component where students were expected to participate in community outreach. Opportunities to engage the public were encouraged before the Pandemic and were once more offered this past year. Two opportunities were given. First, the students that focused on solar physics presented a poster at the Hinode17/IRIS14/SPHERE3 Joint Science Conference held in Bozeman July 23 through 27th, 2024 at the end of the REU. Second, a local Young Men's Christian Association (YMCA) hosted an Astronomy Day for teenagers. Every student participated by creating a multimedia presentation from the Sun beyond our solar system. Additionally, students participated in classes on public speaking and conference etiquette. The public speaking class focused on age-specific conversation, anxiety coping mechanisms, and outreach presentation building.

A second class centered on conference speaking and poster building. An open space was offered for students to build presentations and practice outside of class.

2. Literature

This reserach created a new paradigm for the MSU Solar/Astro REU program. Over the course of May through the end of the REU, I put formative assessments into place to evolve classroom understanding for both students and lecturers. Outreach is now encouraged and REU participants have an expedited introduction to public speaking and to the scientific community. The opportunities for presenting at a conference are not frequently available, often due to funding, but did serve as an opportunity for the budding scientists to be involved in the solar scientific community. In general, my goal was to refine the REU by including new assessment techniques and reactivating outreach opportunities and to observe the effects of an entire summer REU on students.

2.1. Understanding research experience for undergraduates

Undergraduate research experiences are a steppingstone for budding students in Science, Technology, Engineering, and Mathematics (STEM). To facilitate exposure, universities created Research Experience for Undergraduates (REU) programs. The experience differs from university to university as well as differences when comparing science REUs and engineering REUs [3, 4]. There are many reasons for partaking in an REU. These programs are coursework/research programs, targeted toward students who are minorities or without access to research, and seek to increase student interest in science or technology and to improve overall student self-confidence. Additionally, REUs benefit the science community by encouraging students to pursue graduate degrees, finding new mentors, and increasing undergraduate retention in STEM undergraduate programs [3–5]. REU programs create numerous opportunities.

2.2. Opportunities for undergraduates

For undergraduate students, there are not always opportunities to engage in research. Many universities cannot offer research in-house or provide enough slots for in-house research for each student in the program [6]. Part of a REU program is research and the other part is coursework. Over the years, funding has opened to create programs and spaces for students; in addition to funding, faculty need time to develop summer research projects or teach the group of REU students [3]. Funding has improved and so have the efforts to improve opportunities for minorities in STEM [7]. 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 provided based on contribution and collaboration [8]. Once finding scientific culture, students have reported increased confidence in their own skills and understanding of the material [3, 6, 7]. A place in the local scientific community can aid a budding scientist to relieve some of the intimidation that can arise in science.

Self-confidence is an important focus of REU programs. Once students are engaged, the main goal of an REU program is building student confidence. This can translate to on-the-job experience in the case of an engineering REU or scientific research development for a science REU [4, 5]. Starting with mentors, students can implement the skills acquired during an REU in the future to create a network of people. Networks are a safety net of experience and knowledge for STEM leading to self-confidence in personal work. The REU programs give students self-confidence and a mentor [5]. Therefore, REU programs can play a major role into developing science-based relationships.

Undergraduate students in an REU program have the unique opportunity to study and research a more in-depth topic than a typical university class. Therefore, these students gain a deeper view of a few science topics. Students who elect to pursue STEM initially, often stay in STEM throughout their undergraduate studies as a result of partaking in outreach [9]. Additionally, students in an outreach program develop a sense of belonging in the scientific community as the students must collaborate with colleagues and mentors [9, 10]. Not only do students gain a deeper understanding of the subjects they study, but outreach is a platform to learn communication skills. Anxiety coping, changing wording with experience level, and improvisation are a few of those

new communication skills. Outreach programs are an excellent space for students to learn how to communicate [11]. Communication opens doors to better job opportunities and community partnerships. REU programs provide students with a safe space to learn how to communicate clearly. There are numerous opportunities for undergraduate students in an REU program such as specific coursework, finding a scientific community and mentor, and improving communication skills through outreach.

2.3. Faculty and university advantages

Faculty who participate in mentoring may have a positive experience and learn more about their students. Empathy in science is needed to improve scientific research culture [7]. In this case, ‘empathy’ is describing interpersonal communications and interactions between scientists; scientists in the physical sciences tend toward being introverted [12]. This behavior could destroy the sense of belonging sought by new scientists [10]. Ultimately, 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 [4, 6, 7]. Universities perceive student retention as a short-term positive. Undergraduates are more likely to stay and finish a program after attending an REU program [6]. 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.

Not only can REUs allow students to participate in research and specialized coursework, but also serve as an introduction to outreach [9]. REU programs benefit the scientific community as undergraduates earn the opportunity to partake in research, gain a mentor and network, and potentially increase self-confidence [10]. Faculty receive a revised perspective and gain access to relationships with future science professionals. Outreach combined with mentorship shows improved student access to resources, relationships, and scientific communities at large.

2.4. Understanding outreach impact on undergraduate students

Outreach is entering the surrounding community to educate children about science and is part of the REU experience. Undergraduate-led outreach shares some of the same benefits as greater REU, 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. Finally, the community impact of outreach can change the course of younger students' career trajectories.

2.5. 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 [11, 13, 14]. There are several steps for students to use to learn how to create presentations, talks, and activities for all audiences. The first is 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 [13, 14]. New educators bring a vibrancy to the community and an excitement for science. After engaging the budding outreach scientists, the next step is to 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 [13, 14]. Class time for personal presentations allows for discussion on misconceptions as well. The general public holds a great deal of misconceptions about STEM [13]. Finally, students will be able to enter the community with their presentations. Presenters will interact with classrooms, other educators, and the general public [11, 13, 14]. After the course and presentations, students will then be able to decide if they care for public outreach and would like to incorporate the activity more in the future.

2.6. Local and scientific community benefits

Outreach brings enthusiasm to science. 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 [15]. Elementary students who cherish the experience of having a new educator enter the classroom often share the experience with parents and siblings leading to repeated interactions with outreach educators and new topics [16]. Community interaction also increases children's teachers' awareness of current science research. Once a child interacts with science, a common outcome is a greater interest in and excited, possibly short-term, aspirations in having a science career [17]. Even though most of the responses are generated in the short term, the awareness of science in younger students and the excitement of student outreach educators has an impact on the scientific community.

Student positive experience is imperative to the development of young scientists. Science, as an evolving field, needs new minds. A result of outreach is a greater number of undergraduate students interested in becoming faculty or teachers. Therefore, there is a higher enrollment of students in graduate programs [14]. These students can then become mentors for undergraduates or high school students as communication has already been established through outreach. Not only are there more students progressing into graduate studies, but more students are entering undergraduate STEM programs. Elementary students showed increased interest in STEM from outreach efforts [16, 17]. Overall, an inspiring look into the future of science using outreach.

An REU program that includes outreach is an invaluable experience for the targeted undergraduate students as well as for both the local and scientific communities. The undergraduate students receive the ability to hone scientific and public speaking skills, acquire a mentor/colleague network, develop a sense of scientific belonging, and build self-confidence in their work. The local community benefits from enthusiastic young scientists, new knowledge, and the availability of specialized knowledge. Finally, the STEM community can flourish from new ideas, active communicators, and more energetic people. REUs are an important stepping stone on the path to an impactful

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

^aThese surveys/interviews happened over multiple days for student ease of response.

STEM career.

3. Materials and Methods

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 [18]. Self-reported Likert scale surveys were another tool used to determine student improvement. Finally, student interviews, student journals, and researcher observations helped track student progress.

3.1. 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. As the summer progressed, student interest continued. Students were given assessments each week of the 10-week program Table 1.

3.2. Detailed Information on Materials

Week one introduced the first of the three Self-confidence Likert scale surveys A.1. For anonymity, these surveys were given and recorded by Google Forms without email

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.

collection. This survey aimed to establish a baseline of student confidence with: a) physics, b) Sun and star background, c) research experience, and d) public outreach. Questions remained the same throughout the other two surveys given after all physics related classes finished (halfway through the experience) and at the end of the REU. Another Likert survey was conducted by the primary investigators of the REU at the end of the REU experience. Three CATs were introduced and handed out the other weeks around the self-confidence surveys. Two CATs proved helpful understanding impacts and one did not work as expected.

The two remaining CATs were used to study both objectives. Students were given the Chain Note CAT first A.2. This CAT is used as a stop during class to get a “snapshot” of student understanding or focus. Each student receives a note card at the beginning of class and at some point during class, a question is passed around written on an envelope. A student has a minute or less to write down their answer and pass the envelope to the next student. Three rounds of the chain note assessments were conducted during the solar/astro- physics-based courses. These courses were specifically picked for this assessment Table 2.

Chain Note 1 was handed out during “The Stellar Atmosphere” mainly because this was the students’ first physics/star-based class. Many of the students are not from the area, introducing a shock, so a “check-in” felt warranted. The goal of chain note 2 was to glean student background without directly asking since these students are from different universities. This relieves a bit of anxiety and judgment on the student and informs actual comfort level with more advanced/specific materials. Open-mindedness was the goal of the final chain note. Many students work with satellites and telescopes for observation without knowing the instrument’s inner workings or the job that others have to make data collection possible. A willingness to learn shows students open mindedness and possibility for extension into other fields. Over all, interaction between

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 /SUB shopping allowance (CATcard)
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

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 A.3. In this case, students were required to write about their research after learning how to give elevator pitches during the campus wide REU course and after teaching them solar physics/astrophysics specific public speaking/outreach techniques. Students tend to use jargon to hide their uncertainty with the material. Therefore the main objective of direct paraphrasing was to search for jargon. After the first round of direct paraphrasing, students were taught to find jargon and replace those words with standard language for all audiences, other than in-field presentations.

Finally, at the end of the REU experience, students were interviewed and asked to take one final Likert-type survey written by the REU primary investigator known as the REU Exit survey A.4. 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 experienceA.5. The exit survey contained 16 questions, 14 aligned with previous exit survey questions dating consistently back to 2015 Table 3.

Students were given the survey via Google Forms during the final week of the program. In addition, the researcher kept a journal of observations from group meeting

presentations and during a few classes. This journal was a record of performance, especially during presentations. Performance not only highlights confidence levels in real time but also the improvement in understanding of the topic at hand. Students also provided journals voluntarily. Journals and personal observations are used sparingly.

4. Results

The seven tools used for data collection yielded a multitude of results for each of the three prongs: student impact, professional development, and program improvements. Self-reported results were able to be analyzed statistically as responses were numerical in nature. All of the qualitative responses were considered by theme depending on the nature of the responses. For instance, jargon versus common language was the theme of the direct paraphrasing responses. First, let's look into the program's student impact.

4.1. Student Academic Impacts Analyzed

The best indication of student impact from the program is the result of the Likert-type Self-confidence survey given three times throughout the summer. These surveys had five responses: 'not confident', 'slightly confident', 'moderately confident', 'highly confident', and 'extremely confident. For ease of analysis and coherence to be compared to the REU exit survey, the 'not' and 'slightly' confident and the 'highly' and 'extremely' confident categories were combined. This left three responses behind: low confidence (score: 1), medium confidence (score: 2), and high confidence (score: 3). After the simplification of the data, responses from surveys 1, 2, and 3 were compared using normalized gain [19]. Responses were compared to high, medium, and low improvement with some responses being positive and some being negative Figure 1.

For the first survey, results were as expected, students came in with varying, but trending lower, levels of confidence. Improvement is minimal between responses 1 and 2 after the physics/sun and star lectures. Between responses 2 and 3, the students reported a mix of confidence levels without a great shift in high (score: 3) confidence levels. Again, this result was anticipated as students were moving into their research further and started field-specific outreach and professional development courses. Fi-

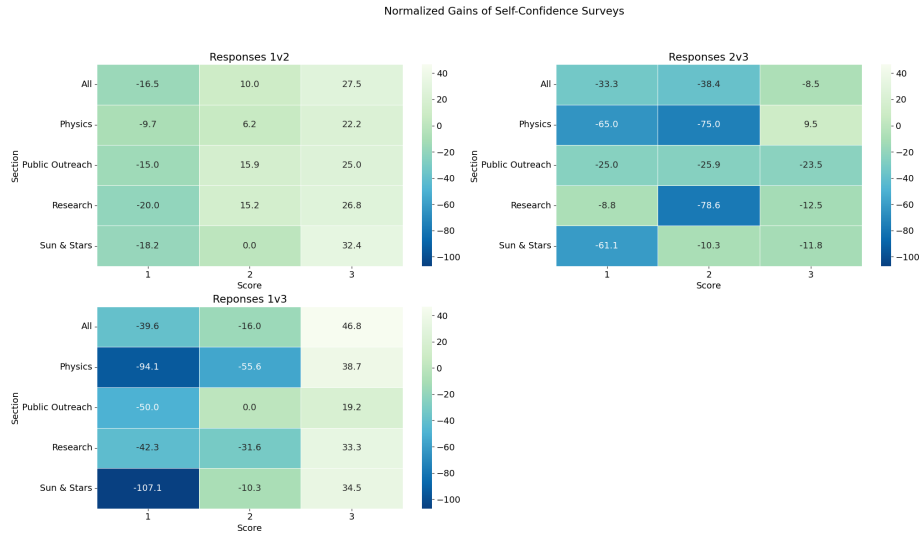


Figure 1. Three heat maps indicate student ($N=7$) confidence levels between responses using normalized gain. More positive scores are indicated with very light green and more negative scores with dark blue.

nally, the gains in between responses 1 and 3 were as hoped: a clear shift in confidence levels from low to high. The deeper the negative scores in the low (score: 1) section, the less the students responded with uncertainty of their understanding. In hand, the lighter green the scores in high (score: 3) the greater the improvement in confidence. 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 ($p = 0.000482$) between these responses, the beginning and the end of the program, numerically show statistically significant student improvement. Each subcategory of the survey allowed for a window into improvement with physics being the next almost statistically significant ($p = 0.079888$) development between responses 1 and 3.

Throughout the lectures, 6 total, given to the students there were three chain note CATs handed out to glean student thoughts. Student response varied between CATs due to different questions asked (appendix). The first chain note responses were mainly students focused on their research assignments. Since this chain note was taken during the second week of the REU, mixed focus was expected. Some students were focused on class but noted that mathematics was not expected. Specifically using terms such

as “not being in the mindset”. However, diagrams were appreciated. These feelings transferred into the second CAT where students were asked if the material was being understood. Visualization of concepts 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. Expanded applications also applied to the students’ professional development.

4.2. Student Professional Development Evolution

The REU program, and all programs on campus, teach students to become confident in their presentation of material, being an actual in person presentation/poster to writing. Often, student development is not recorded, however, direct paraphrasing is one such tool to employ. After the ‘Elevator Pitch’ course, students were asked to turn in pitches 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, or jargon. The number of jargon words from all students was recorded Figure 2.

Jargon used properly can be effective to the correct audience, however, not to anyone outside of the general fields these words come from. After instruction, students were given another direct paraphrasing prompt which was considered for jargon and common language. The number of jargon words to common were drastic: a ratio of five common words to two jargon words overall. Student evolution continued in results from individual interviews.

After the REU experience, four students (n=4) out of the seven voluntarily participated in a Webex conducted interview. Questions were then analyzed for similar themes per student answer (appendix). Student responses proved as a reflection of the rest of the surveys, self-responses and analyzed. For instance, the first question asked about student confidence left first hand answers about how comfort levels changed and experience grew. The students also noted how their presentation style changed with ‘big picture’ thinking and feedback from mentors during the editing process. Re-

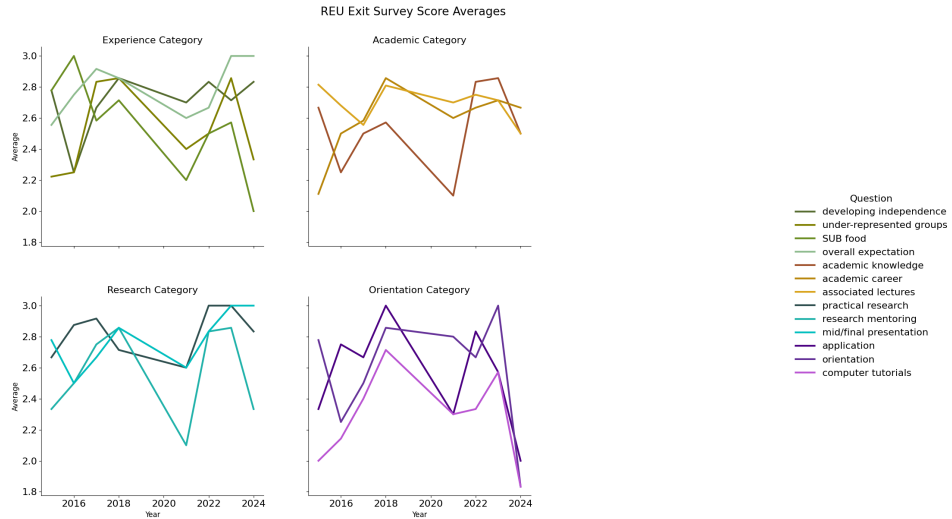


Figure 3. This graph depicts the REU Exit Survey results from 2015 - 2024 with data gaps in 2019 and 2020. There are 14 total questions asked and divided into categories: experience, academic, research, and orientation.

the divisions outlined in the previous section, the results show a decrease in satisfaction in many parts of the program Figure 3.

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. Students also reported in this survey that more effort toward building community would be appreciated.

In all, the results reflect personal observation, especially in the students' professional development. Uncertainty recorded in the first group presentation among peers evaporated with experience and time. The students also mirrored their confidence during the YMCA presentations, pivoting when they needed to. Students' reactions to courses were also visible in observation. Over the science based courses, attention would shift between active and passive depending on the lecturer and material, specifically differences between equations/mathematics and visual representation.

5. Discussion

As the summer progressed, student participation in this study was enthusiastic and helpful to the evolution of the students themselves and the program as a whole. This is the first instance of student improvement being tracked during this REU program. Traditionally, there was only the exit survey but that granted little understanding for where students came in at square one. Running multiple check-in assessments yielded clear results both positives and faults of the students' understanding and the program's operation. An impactful example is student response to lecture materials being taught.

5.1. Student Impacts

5.1.1. Academics

This REU does not focus heavily on the lecture series in favor of creating more time for research, however, understanding the concepts being researched is paramount to student success. A three part self-confidence survey yielded continuous results in student evolution based on established checkpoints already built into the program. The students' confusion and need for additional help was outlined in the first result to the second result of the self-confidence survey where there was little progress in understanding the material. Not only can the material being taught be reflected in the self-confidence survey, but also in the chain note surveys given in class. These stops helped to understand where the students struggled but also where they felt secure in their knowledge. Pairing the two assessments allowed for finding a weak spot in the program which is reflected in the academic portion of the exit survey. Aside from the academic evolution of students, the self-confidence survey showed improvement to student professional development.

5.1.2. Professional Development

One of the two categories that monitored students' professional development was 'research'. Increased confidence in research experience shows later in the experience as research presentations become steadily more confident through observation. Results

from the self-confidence survey also show a shift from low confidence to high confidence between the first and third surveys. Not only do the self-reported results show student improvement in confidence of their research, but also through observation. Each group presentation the students were observed for presentation technique and confidence. The students in the beginning were hesitant about the assigned topics using phrases such as 'uh' or 'um' which decreased significantly over the summer with each of the three presentations **probably should cite this**. Eye contact increased as did the students' ability to answer questions about their research without the support of individual advisors. Research self-confidence improvement and ability to present extended into students' ability to present to a different audience.

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 and some showed an interest in outreach. From the self-confidence survey, there were still mixed feelings about public outreach but did still show a shift toward higher confidence. Such can be seen by the minimal color shift between surveys one and three Figure 1. Despite the self-reported minimal shift results, the researcher analyzed results show a clear development in communication skills.

The power of the direct paraphrasing results shows this development the best. Phrases such as 'energetic loops' or 'magnetic processes' do not have real-life meaning except for those in specific fields Figure 2. Even with that caveat, specific fields can use these and other phrases in separate ways. Students learning how to explain these concepts within the field of reference is imperative to evolving their communication skills. As a result of classes in outreach, students learned to translate jargon into clear concepts that others outside their niche field will understand. Impacts were also introduced leading to phrases in the later Direct Paraphrasing assessment such as 'daily lives', 'light', and 'distance' which did not appear previously. Not only did students' use of language amongst themselves improve, but also in a presentation setting.

During the trip to the local YMCA, the students had to improvise from their planned program due to the age group being much younger than anticipated. This specifically meant being comfortable with the presentation material to describe concepts less detailed than anticipated. In student exit interviews, students reported being at ease

with the sudden change. Two of the students directly said that they would want to continue doing outreach and working on their skills associated. The result of student interaction with the public has increased the professional development of these REU students and helped to boost confidence in their ability to explain/understand their research topics.

5.2. Program Evolution

After reviewing all of the results, there are a few changes that were considered based on the findings. The main considerations are a change to the lecture calendar, fostering a sense of community, and continuing to incorporate public outreach into the program. A change to the lecturing schedule was considered and acted upon first.

From a combination of likert type surveys (Self-confidence Survey and REU Exit survey), the lectures were found to be a weak spot. Between the first and the second, post lecture, 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 response matching 2017 in lowest satisfaction. The students further reported this weakness through the Chain Note assessment. Although the exuberance of the professors was appreciated, students reported loss of focus during lectures. There were reports of googling concepts and focus regained after a graphic/video was produced. Some of the students reported that physics concepts were too high level 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. Specifically, the lecture series was proposed to be elongated from six lectures to eight with lectures before group presentation being set aside to allow for student practice of their presentations.

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. A scientific community is impactful and leads to student success. Therefore, 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, mathematic, or coding problems without feeling as separated.

Finally, after the success of the outreach initiative, reintroduced after the last initiative in 2018, there was encouragement to continue. Students in their exit interviews and the REU exit survey reported enjoying the courses taught on impromptu public speaking and the time to build their YMCA presentations. The YMCA visit was also generally enjoyed, as reported in the interviews. This effort could be another way to generate interest in the local community for what the REU program is doing and what MSU is currently working on.

5.3. Final Thoughts & Future Work

After the conclusion of the REU program, the result was undergraduate students who grew their knowledge, confidence, and professionalism. Students gave the program helpful feedback and the research done can be utilized in the future.

Acknowledgments

I guess I'll write something?

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.

Funding

I wasn't really funded to do this, John?

Notes on contributor(s)

I guess I write a blurb about myself?

6. References

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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

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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?
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A.5. Student Interview Questions

Table A9. Questions Asked

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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?
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