An Evaluation of the Citizen CATE Project: Final Report

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Executive Summary

The Citizen Continental-America Telescopic Eclipse (CATE) Experiment was developed at the National Solar Observatory in partnership with universities, high schools, amateur astronomy clubs, and corporations. The CATE experiment used 68 identical telescopes equipped with digital cameras spaced across the path of totality for the Great American Eclipse of 2017. The targeted audience for the Citizen CATE experiment included undergraduate students in STEM disciplines and citizen-scientist volunteers. Program participants included six undergraduate students from four participating institutions: Southern Illinois University, Western Kentucky University, University of Wyoming Laramie, and South Carolina State University. The project involved more than 200 citizen-scientist volunteers across 68 locations, half of whom participated in evaluation data collection activities.

Study Design & Methods

The external evaluation study used a mixed methods design. Evaluators employed multiple data collection methods, including both qualitative and quantitative measures. Mixed methods allowed for comprehensive understanding of how the program affected the volunteers and students who participated.

The study began in January of 2016 and concluded with post-eclipse surveys and interviews in the fall of 2017. Participants in the evaluation included the project principal investigator as well as six undergraduate students and their mentors (who were also co-principal investigators) from four institutions: University of Wyoming-Laramie, University of Southern Illinois, Western Kentucky Universtiy, and South Carolina State University. Participants also included 79 volunteers who participated in training and 103 who completed a post-eclipse survey.

Student measures included surveys, a retrospective pretest, interviews, and observations of the summer REU program. Evaluators also interviewed university mentors and the project principal investigator to examine impacts on students. Citizen-scientist volunteer measures included state coordinator surveys, a training feedback survey, observations of in-person trainings, a citizen scientist post-eclipse survey, eclipse observations and document review.

Outcomes for Citizen CATE Undergraduate Students

Students participated in the Citizen CATE project because it was a unique and exciting opportunity for them to learn about solar science research and be involved in a large-scale experiment.

Key Question:
How well did the project prepare undergraduate students to train other students and citizen volunteers for data collection?

Part of the student team traveled to Indonesia in March of 2016 to practice CATE procedures while imaging the total eclipse that was visible there. In the summer following, the student team worked to apply lessons learned from the Indonesia eclipse to CATE for the U.S. eclipse of 2017 by refining data collection and image processing procedures.

Undergraduate student participants on the CATE team expanded the support and reach of the project by providing a team to train state coordinators and volunteers and to troubleshoot during practice sessions leading up to the eclipse. In-person training sessions and follow-up group practice sessions preceding the eclipse allowed undergraduate students and state coordinators to prepare volunteers for eclipse day imaging.

Key Question:
How well did the Citizen CATE project prepare undergraduate students to collect and analyze solar eclipse data?

Volunteers felt well prepared with respect to safe solar viewing, equipment assembly, software calibration, and imaging procedures. Bi-monthly teleconferences with the project principal investigator provided additional support to state coordinators as they practiced and prepared with their teams.

Key Questions: NASA SMD Objective 1—Improve STEM Education

Did participation in the Citizen CATE experiment increase undergraduate student knowledge and skills related to solar science and research?

Did Citizen CATE undergraduate students gain an understanding of research processes?

Students indicated in interviews and on surveys that CATE increased their project-related skills, such as coding, digital image acquisition and processing, and understanding of how a long time-sequence of the corona could be constructed. They also said that they learned to "process images to see what they needed to see without creating artifacts." Students successfully submitted posters and presentations about their CATE experiences to professional conferences, including the American Astronomical Society and American Geophysical Union annual conferences.

For CATE undergraduates who participated in summer research experience for undergraduates (REUs) and who interfaced with teams of volunteers in leading trainings and supporting teams prior to and at the eclipse, the project provided many opportunities and benefits. Students saw growth in their communication skills through opportunities to write papers for publication and to prepare and present talks and posters at scientific meetings. Students also grew in their ability to communicate science effectively to members of the public. Participation in CATE supported students in thinking and feeling like scientists and gave them an increased understanding of how research is conducted.

University mentors and project principal investigator saw students grow in their ability to problem solve and work through challenges as they acquired significant hands-on experience in taking an experiment through from start to the end of data collection. CATE also helped students to solidify career plans, whether this included the intent to continue in astronomy or pursue other areas of science in their undergraduate or graduate programs.

Outcomes for Citizen CATE Volunteers

Key Question: NASA SMD Objective 2—Improve U.S. STEM Literacy

Did Citizen CATE increase citizen scientists' understanding of scientific processes and Sun-Earth relationships?

For Citizen CATE volunteers, the project offered a highly satisfying way to participate in a significant, large-scale scientific endeavor. Volunteers indicated significant growth in their knowledge of how eclipses happen, characteristics of the solar corona and how scientists study it, NASA studies of the Sun, and how to use and operate equipment to study the Sun. Volunteers also noted significant growth in their skills in conducting education and public outreach with visitors to their sites.

Key Question: NASA SMD Objective 3—Advance National Education Goals

Did participation in Citizen CATE increase citizen scientists' interest and engagement in astronomy?

Volunteers overwhelmingly agreed that CATE helped them to make connections to others with an interest in astronomy and inspired them to share their experiences. The majority indicated that the project sparked their interest in citizen science. Volunteers felt great pride and satisfaction in viewing the beauty of the solar eclipse while making contributions to the field of solar science.

Increasing the Capacity for Solar Coronal Studies

Key Question: NASA SMD Objective 4—Leveraging Partnerships

Did the Citizen CATE experiment increase the capacity for scientists to collect and analyze solar eclipse data?

Citizen CATE worked well with respect to recruiting, training, and mobilizing a large network of volunteers across the country. CATE leveraged parterships with 27 colleges and universities, 8 informal science organizations, 22 high schools, 5 national labs, and 270 volunteers. Through the use of a hierarchy of contacts, from the project investigators to the undergraduate students and the state coordinators to the volunteer teams, the project prepared citizen scientists to take on specific roles on eclipse day and trained them well to prepare for imaging the corona.

After the eclipse, the project team received USB drives with CATE data from 66 of the 68 project teams. During totality, CATE sites captured approximately 45,000 images of the solar corona; teams collected images during more than 80% of the 93 minutes of totality that were available from coast to coast. While some sites were cloudy and some had fewer usable images, the sheer number of images of the solar corona during totality promises to lead to an increased understanding of solar coronal features.

Citizen CATE Outreach

Through pre-eclipse conference presentations; outreach to schools, libraries, and informal education venues; newspaper, radio, and television interviews; and large- and small-scale public events, CATE contributed to the national excitement about the 2017 eclipse. By engaging volunteers in the science of studying eclipses, the project added to the experience of the event for thousands.

With respect to sustaining the impacts of CATE, the project equipment was donated to the observation teams in the hopes that they would continue to use it for scientific and educational purposes. Having the telescopes and laptops is allowing several high school–based teams to start astronomy clubs for their students. Many projects have already begun to use the telescopes to conduct public stargazing events, solar viewing parties, and outreach to classrooms in their areas, thus ensuring that the impacts of the project go beyond the single day of the event. In all, the Citizen CATE project evidenced exemplary characteristics of citizen science.

Acknowledgments

Magnolia Consulting wishes to thank Dr. Matt Penn of the National Solar Observatory for the opportunity to conduct the evaluation of the Citizen CATE project and for his help with evaluation planning and data collection. Joining in the excitement of the solar eclipse has been an incredible experience for those of us at Magnolia who have been involved in the work. We would like to thank the CATE undergraduate student team for their participation in surveys, interviews, and site visits. We also wish to thank the CATE state coordinators for providing us with outreach data and volunteer contacts and for participating in interviews and surveys. And finally, thank you to all of the CATE volunteers who participated in our surveys and interviews.

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Introduction

> *"To share the story, the science, and the adventure of NASA's scientific explorations of our home planet, the solar system, and the universe beyond, through stimulating and informative activities and experiences created by experts, delivered effectively and efficiently to learners of many backgrounds via proven conduits, thus providing a direct return on the public's investment in NASA's scientific research."*
>
> —NASA Science Mission Directorate Vision for Education and Communications (NASA SMD, 2017)

In 2015, the National Aeronautics and Space Administration (NASA) Science Mission Directorate (SMD) released Cooperative Agreement Notice (CAN) #NNH15ZDA004C to further SMD top-level objectives to:

- Enable STEM education
- Improve U.S. scientific literacy
- Advance national education goals
- Leverage efforts through partnerships

Through the CAN, 27 projects were funded to engage in education and public outreach that leverages the excitement of NASA assets and engage learners with content related to heliophysics, earth science, planetary science, and astrophysics. In January 2016, the National Solar Observatory (NSO) received one of the awards, for the Citizen Continental-America Telescopic Eclipse (CATE) Experiment (Figure 1). The CATE experiment design proposed to leverage partnerships with universities, high schools, astronomy clubs, and corporations to engage volunteer teams in imaging the solar corona during the total solar eclipse of August 21, 2017. The NSO contracted with Magnolia Consulting, LLC, an external research and evaluation company, to conduct an external evaluation of the CATE project's educational activities. This final report presents the study design, methods, and findings for the CATE evaluation study.

Figure 1. Citizen CATE solar viewing glasses

Citizen CATE Program Description

The Great American Eclipse

On August 21, 2017, the continental United States experienced a total solar eclipse, dubbed "The Great American Eclipse" by the media. The path of totality (points on the Earth's surface where viewers are in the center of the moon's shadow, thus seeing a total eclipse) stretched across the U.S. diagonally from Oregon to South Carolina. Thousands traveled to the path of totality; thousands of others watched the eclipse via the Internet and television.

The eclipse was not only a great source of excitement and interest among the public, however; it also provided a rare opportunity for studying the Sun. Studying the solar corona, the outermost part of the sun's atmosphere, presents challenges to solar scientists. Under normal conditions, the bright solar surface overpowers the corona, making it difficult to observe. During a total solar eclipse, when the Moon passes between the Sun and the Earth, it obscures the Sun, providing a unique opportunity to measure and study the corona in greater detail (National Solar Observatory, 2017). The Great American Eclipse offered roughly two and a half minutes of totality at each point along the path—precious time in which to observe the corona.

Citizen CATE: A Volunteer Experiment

The goals for the CATE experiment were diverse, ranging from providing an authentic STEM research experience for students and lifelong learners, to making state-of-the-art observations of the plasma dynamics of solar coronal polar plumes, to increasing scientific literacy about eclipses and solar physics. The experiment had several intended outcomes:

1. To increase the research skills of participating undergraduate students;
2. To increase the technical skills of participating undergraduate students with respect to collecting solar eclipse data;
3. To engage students and citizen scientists in an authentic STEM research experience;
4. To increase the technical skills of citizen-scientist volunteers with respect to understanding solar eclipses and collecting solar eclipse data;

Appendix A presents a logic model outlining the program's theory of change.

To maximize the scientific opportunity for capturing images of the solar corona presented by the Great American Eclipse, the Citizen CATE experiment used a cadre of volunteers including high school and university students, amateur astronomers, university faculty members, and solar physicists. Volunteers operated telescopes and took images of the solar corona at 68 sites across the 2,500-mile path of totality (Figure 2).

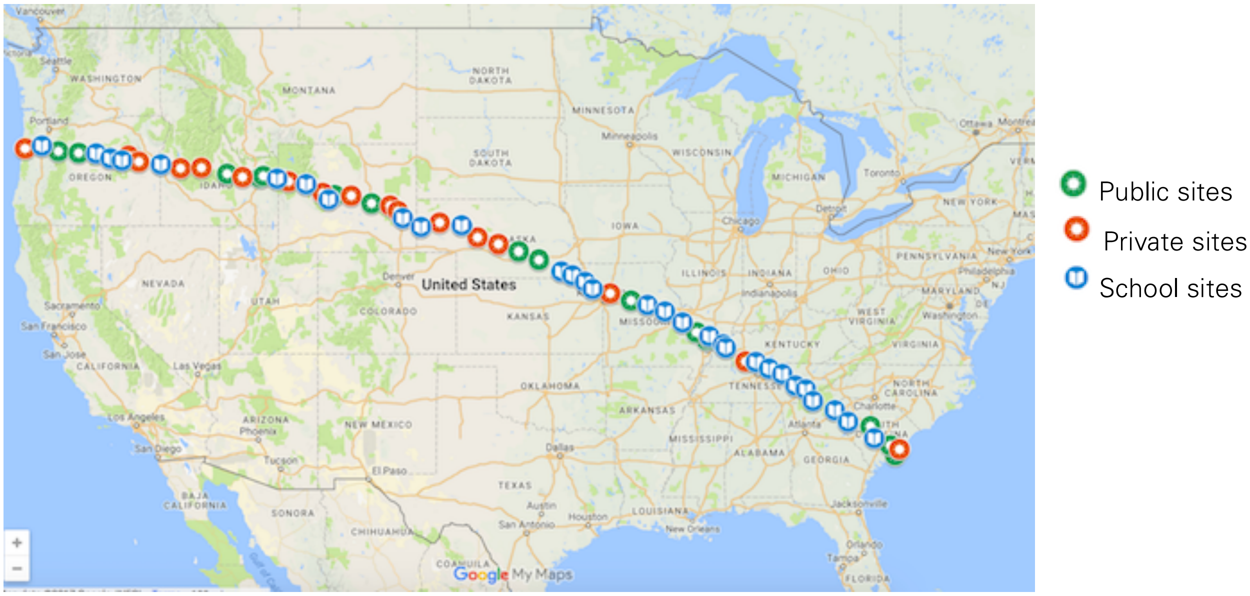

Figure 2. Map of Citizen CATE sites funded through corporate and private donations and National Science Foundation funding

With funds from corporate sponsorships, a National Science Foundation grant, and private donors, each site was equipped with identical equipment, including telescopes, laptops, and image capture software (Figure 3). The CATE research team identified state coordinators for each of the states in which observations would be taken on eclipse day. State coordinators were responsible for communicating with sites in their states, organizing and co-leading CATE trainings, coordinating practices prior to the eclipse, and communicating with sites about data collection on eclipse day. On the day of the eclipse, 62 of the 68 sites captured data. Of those, 40 sites had clear skies; the others had varying levels of cloud cover.

CATE Corporate Sponsors

MathWorks

Daystar Filters

Celestron

Color Maker

Figure 3. Daystar telescopes used in the CATE experiment

CATE Research Experience for Undergraduates

A NASA-funded research experience for undergraduates (REU) provided four institutions (University of Wyoming, Southern Illinois University, South Carolina State University and Western Kentucky University) with funding for undergraduate students to participate in the project. Students from the four participating institutions participated in the summer REU program in 2016 and 2017. Summer experiences were conducted at the National Solar Observatory in Tucson.

Summer 2016

In the summer of 2016, during a ten-week REU, six students attended lectures and participated in field trips to observatories and optics companies (Figure 4). They learned about solar physics, research methods, and ethics in scientific research. Students analyzed the March 2016 Indonesia eclipse data with the intent of identifying issues and refining procedures for the 2017 eclipse and drafted papers for presentation and publication based on the 2016 eclipse data. Students also worked to develop training videos for CATE volunteers to support them in training and practice sessions to prepare for collecting data on eclipse day. In the fall and spring following the 2016 research experience, undergraduates participated in teleconferences from their home universities along with state coordinators.

Figure 4. CATE students tour the Very Large Array during the 2016 summer REU

Summer 2017

Four students participated in the 2017 summer REU.[1] The students participated in teleconferences with CATE state coordinators, analyzed volunteer teams' practice data and provided feedback, and completed scientific investigations related to image processing and data prediction for the 2017 eclipse (Figure 5). Students also worked on posters in preparation for the American Astronomical Society annual meeting in January 2018.

Figure 5. CATE students work on images and data during the 2017 summer REU

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[1] Two students from the previous summer REU had graduated—one became employed while the other began studies at the U.S. Air Force Academy.

[2] Teams reported a total of 270 volunteers on eclipse day; many team members brought along friends, colleagues,

Training CATE Volunteers

Undergraduates and their university mentors had the opportunity to practice CATE procedures and protocols during a solar eclipse in Indonesia in March of 2016. After the Indonesia eclipse, the CATE team refined protocols and procedures in preparation for the 2017 U.S. eclipse (Figure 6).

In April and May 2017, undergraduate students, state coordinators, and the CATE research team worked closely with volunteers in 12 training sessions across nine states. During the training sessions, volunteer teams learned about the goals and science of the project and about safe solar viewing and crowd management. Volunteer teams learned about telescope assembly and use of the image capture software and practiced data uploading procedures (Figure 7). Finally, volunteers had the opportunity to practice data collection procedures during five network-wide training sessions. Formative feedback from training sessions provided the CATE research team with information to guide follow-up training and practice sessions.

After the spring training sessions, state coordinators participated in teleconferences with the project principal investigator to work through logistics and to troubleshoot issues from practice sessions prior to the eclipse. State coordinators interacted regularly with the CATE undergraduates for support in practice and planning for eclipse day.

Figure 6. CATE training timeline

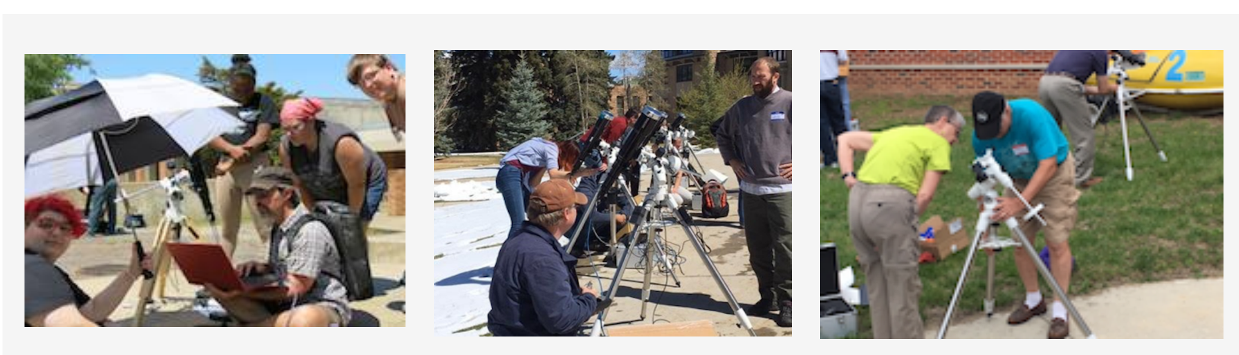

Figure 7. CATE teams practice assembling equipment and collecting data

Evaluation Design

The Citizen CATE experiment was evaluated both internally and externally. Internally, the principal investigator who mentored the undergraduate students continually used formative assessments to determine the technical strengths and weaknesses of students during the training on the equipment and in data processing. External evaluation focused on understanding the effect of participation on CATE undergraduates and citizen-science volunteers. Additionally, one summative evaluation question focused on the project's impacts on solar eclipse data collection.

Methodological Approach

The external evaluation study used a mixed methods design. Evaluators employed multiple data collection methods, including both qualitative and quantitative measures, to ensure findings were as robust as possible (U.S. General Accounting Office, 1990; Zucker, 2009). Mixed methods strengthened the evaluation design by allowing evaluators to triangulate findings from qualitative and quantitative data sources, providing a more comprehensive understanding of program implementation and outcomes than could be obtained through either method alone (Creswell & Plano Clark, 2007; Patton, 2002). Nine overarching evaluation questions—three formative and six summative, guided the study.

Formative Evaluation Questions

1. How well did the Citizen CATE project prepare undergraduate students to collect solar eclipse data? How can training be improved to better meet student needs?
2. How well did the project prepare undergraduate students to train other students and citizen volunteers for data collection?
3. How well did state trainings prepare citizen scientists for participation in data collection activities?

Summative Evaluation Questions

1. Did participation in the Citizen CATE experiment increase undergraduate student knowledge and skills related to solar science and solar science research?
2. Did students gain an understanding of research processes?
3. Did participation in Citizen CATE increase citizen scientists' interest and engagement in astronomy?
4. Did participation in Citizen CATE increase citizen scientists' understanding of scientific processes and Sun-Earth relationships?
5. Did the Citizen CATE experiment increase the capacity for solar eclipse data collection?
6. How did the project align to NASA SMD top-level indicators?

Based on the framework for evaluating citizen science learning outcomes (Phillips & Ferguson, 2014), citizen scientist measures addressed the following:

- Changes in behavior from participating in Citizen CATE,
- Changes in skills related to science inquiry,
- Knowledge of scientific processes,
- Interest in pursuing science topics and activities, and

- Self-efficacy with respect to participating in citizen science.

An evaluation matrix, presented in Appendix B, linked evaluation questions to measures, timeline, and benchmarks.

Study Measures

This study used a combination of quantitative and qualitative methods to collect information regarding student, mentor, and state coordinator perceptions of the Citizen CATE program and its impacts on student learning and on citizen scientists' learning and engagement in astronomy. Throughout the study period, Magnolia Consulting collected descriptive, implementation, and outcome data using following data collection methods:

Student Measures

- Student perception surveys
- Student interviews
- Student retrospective pretest
- Mentor interviews
- REU site visits

Volunteer Measures

- State Coordinator Survey
- Training Feedback Survey
- Citizen scientist training observations
- Citizen Scientist Post-Eclipse Survey
- Eclipse observations
- Tracking of outreach events and participants

A detailed description of the measures is presented in Appendix C.

Institutional Research Review Process

Evaluators worked with the co-principal investigator from the University of Wyoming–Laramie to have the evaluation plan and measures approved by its Institutional Review Board (IRB). The IRB approved the plan in spring 2016 and an amended plan in spring 2017 to include collecting data from high school students. Online surveys included a consent page that described the study process, use of data, confidentiality in reporting, and the voluntary nature of participation. Volunteers indicated consent before being allowed to proceed to the surveys. Evaluators obtained consent from all participating CATE undergraduate students; parental consent for participation in study activities was required for students under 18.

Study Timeframe

The project was awarded in January 2016. The study period extended from January 2016 through December 2017. Citizen-scientist surveys were administered prior to training, after training, and after the eclipse. Undergraduate student surveys were administered at key points in the project after training sessions, annually after REU experiences, and at the end of the project. Students participated in interviews after the summer REU experiences.

Observations were conducted during the summer REU program in 2016 and 2017, at training events, and on eclipse day. Additionally, evaluators conducted interviews with the project principal and co-principal investigators at the end of the project. Appendix D presents a timeline of evaluation activities.

Data Analysis

Data analysis techniques for this study included descriptive and quantitative analysis of data from surveys, interviews, and observations. Triangulating qualitative and quantitative data from multiple sources increased the study's validity and provided meaningful insight regarding various aspects of the effects of program participation.

Qualitative data was imported into *Atlas.ti*, a computer program that facilitates qualitative analysis via data segmentation, coding, and organization (Miles & Huberman, 1994). Evaluators analyzed qualitative data using the techniques of analytic induction (Erickson, 1986). Following a thorough review of the data record from all sources, evaluators generated a set of preliminary assertions regarding the evaluation questions. Evaluators then refined the assertions and established whether each was warranted. Researchers ensured that excerpts from the data record supported each warranted assertion and linked the assertions, themes, and findings in a manner that supported analytic generalization (Glaser, 1978).

Quantitative survey and assessment data were imported into an IBM SPSS Statistics 24™ database. Evaluators analyzed survey data by calculating descriptive statistics such as means, standard deviations, and frequencies. Pre- and posttest measures were analyzed using paired samples t-tests.

Participants

Participants in the Citizen CATE evaluation included undergraduate students and citizen-scientist volunteers.

CATE Undergraduate Students

As part of the NASA-funded component of Citizen CATE, undergraduate students from four institutions participated. Three students participated from Western Kentucky University (WKU). These students were high school students attending the Gatton Academy of Mathematics and Science housed on the WKU campus. Two of these students participated in the first summer (2016) REU program at the National Solar Observatory; the third was most involved in activities on the WKU campus and in working with volunteer teams. One student each participated from University of Wyoming, South Carolina State University, and Southern Illinois University.

Volunteer Survey Respondents

66%	35 or older
66%	Male
50%	Held graduate degrees
40%	Amateur astronomers
47%	Astronomy club members

Citizen-Scientist Volunteers

Evaluators collected demographic information on the 103 volunteers who completed the post-eclipse survey (n=103). Of respondents, 80% indicated that Citizen CATE was the first citizen-science program in which they had participated. Two-thirds were male and 35 years of age or older; 50% had completed a Masters or Doctoral degree. Survey respondents were largely amateur astronomers but also included university faculty, high school teachers, and high school students. Nearly half were participants in local astronomy clubs. Appendix E presents a detailed breakdown of volunteer respondents by demographic characteristics.

Settings

CATE partners included 27 universities and colleges, 22 high schools, 8 informal science education institutions and organizations, and 5 national laboratories. These institutions provided volunteer teams who worked closely with state coordinators and CATE undergraduate students to train for eclipse data collection. A list of CATE partners is presented in Appendix F. Volunteer teams used identical laptops, software, and telescopes to image the solar corona during totality (Figure 8).

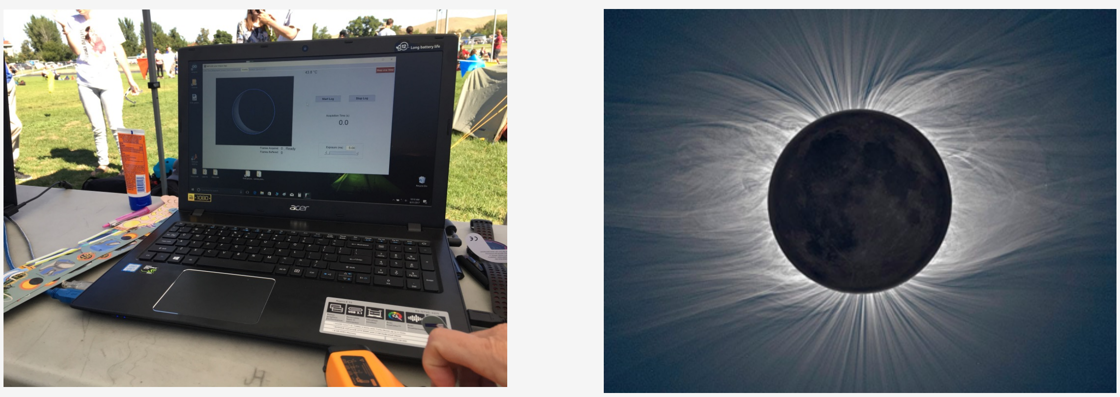

Figure 8. CATE laptop and image of the solar corona

Eclipse Day
Weiser, ID CATE Team

Weiser is a small town in Idaho close to the Oregon border in the path of totality. The town was fully engaged in welcoming eclipse visitors to share in the excitement of the eclipse. The CATE site was set up on the grounds of Weiser High School in a roped off area of the school's athletic field. The rest of the field was filled with eclipse watchers, many with their own telescopes set up and ready. Next to the field, many visitors had set up tents and campers adding to the festive feel of the event. The field began to fill with people of all ages early in the day. Toddlers ran across the grass and were hoisted on parents' shoulders. Many people wore eclipse-themed t-shirts. The town mayor came by to talk with the CATE students and express her appreciation for the town's involvement in the project.

The Weiser CATE team was made up of five high school students and their physics teacher. The student team had trained and practiced for months leading up to the event. While their teacher facilitated and supported their work on the project, he also empowered them to take the lead in running the equipment and collecting the data during totality. The Citizen CATE project principal investigator Matt Penn, along with his wife and daughter set up another CATE computer and telescope next to the student team to collect a second set of data from the prime totality site.

The student team arrived at 8 am to set up the equipment and calibrate the software. As they prepared, a local news team set up cameras to record their participation; students took turns stepping away from the computer for interviews. Students had assigned roles, with one overseeing the data collection, two others on the computer, and others collecting temperature data for the GLOBE project.

10:11 am: The moon shadow entered the sun. The crowd began chattering with excitement and cries of "It's starting!" could be heard around the field. The two CATE teams checked equipment and prepared for the big event.

11:15 am: The air started to feel noticeably cooler and shadows became distorted. Through solar glasses, just a sliver crescent of the sun was still visible. A feeling of excitement and anticipation ran through the crowd as the clock ticked toward totality.

11:25:17: Totality! Cheers erupted from the field as people took off their solar glasses to watch. As the diamond ring appeared, more cheers and "oohs" and "ahs" were heard from the crowd. At totality, the coronal ring was on show and planets and stars hidden in the sun's glare just moments before became visible. After the initial cheers, a hush fell over the crowd as the sense of wonder set in. As totality ended, the two CATE teams set to work again, checking that images were captured and working to upload their data. The students' excitement was evident as one commented, "Seeing the diamond ring was amazing. I had seen pictures and heard about it but being able to see it and us capturing it ourselves was so cool!"

Evaluation Findings: Citizen CATE REU Students

NASA Top-Level Objective: Enable STEM Education

Citizen CATE undergraduate students from the WKU team included three high school students who would graduate during the summer of the eclipse but began with the project as high school juniors. At the start of the project, the University of Wyoming student was a junior undergraduate, the Southern Illinois University student was a senior undergraduate, and the South Carolina State student completed his baccalaureate degree during the first year of CATE. In addition to the NASA-funded CATE students, one University of Arizona undergraduate, funded through a National Science Foundation grant, was also involved in the project and provided feedback on her experiences. Undergraduate students indicated plans to complete bachelor's degrees in physics, computer sciences, and engineering. Post-degree plans included the intent to pursue graduate degrees in the sciences.

The Citizen CATE project utilized undergraduate students extensively in the design and delivery of the project. Students participated in initial trainings in January of 2016, and a subset went to Indonesia to test out data collection procedures and products during the total eclipse in March of that year. CATE students participated in summer REUs during the summers of 2016 and 2017 and assisted in training citizen scientists by conducting in-person trainings, creating volunteer training videos, and troubleshooting with sites during practice sessions prior to the eclipse.

Reasons for Participating in CATE

In interviews, students talked about participating in the Citizen CATE project because it was a unique and exciting opportunity for them. They felt that the REU provided a hands-on way to learn about solar science and solar eclipses. Two noted that the opportunity to visit Indonesia for the March 2016 solar eclipse offered an experience they would otherwise never have had. Students felt that participating was good for their future education plans and careers, and one individual talked about interest in the citizen-scientist outreach aspect of the project. Students commented, "It was unlike anything I've ever done before" and "It was a chance to do science as part of a big-name research project."

Year 1 Summer REU Feedback

The Citizen CATE REU program gave students the opportunity to work with eclipse data from the 2016 Indonesia eclipse. They identified instrumentation issues and considered how to address those issues in preparation for the August 2017 U.S. eclipse. In Year 1, the students were mentored by the project principal investigator and a visiting co-principal investigator, who supported them in producing papers for publication and for presentation at professional association meetings. Evaluators produced a Year 1 interim report for the project team that provided feedback on the students' experiences. Highlights are presented here.

Student Feedback on the Year 1 REU

After the Year 1 REU, students rated the quality of mentoring and the overall REU experience on a five-point scale ranging from 1=*poor* to 5=*excellent* (Figures 9 and 10). The majority of students rated mentoring and the overall REU as *good* or *excellent*. One student rated mentoring as *average* while two rated the overall experience as *average*.

During Year 1, the majority of CATE students rated the REU experience and mentoring as good or excellent.

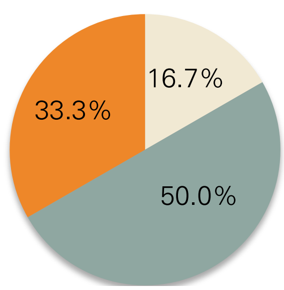

Figure 9. Students' ratings of mentoring during Year 1 REU (n=6)

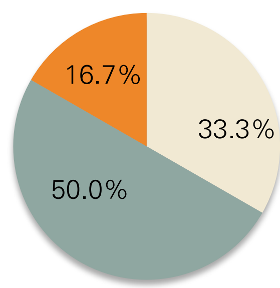

Figure 10. Students' ratings of the overall Year 1 REU experience (n=6)

During the Year 1 REU program, students enjoyed the field trips to observatories and felt they received a unique perspective beyond the "typical tourist experience" of the facilities. They also commented on the camaraderie of the group and appreciated the opportunity to work with students from geographically diverse institutions and communities. High school students felt they had received a valuable, authentic work experience with deadlines, requirements to meet, and the opportunity to contribute to a team research effort. Additionally, one Year 1 student noted that what kept the REU interesting was "the feeling that I am doing something [important]." On the Year 1 post-REU survey, five of the six students (83.3%) *agreed* or *strongly agreed* with the statement, "Through my summer research experience, I made a significant contribution to the CATE project."

Preparing for the 2017 Eclipse

Key Questions:
How well did the Citizen CATE project prepare undergraduate students to collect and analyze solar eclipse data?

How well did the project prepare undergraduate students to train other students and citizen volunteers for data collection?

When asked about their greatest learning from the Year 1 REU, most students talked about gaining experience with coding and learning to process images in preparation for the 2017 eclipse. As one student commented, offering a typical viewpoint:

> *I have coded before, but it's not something I was proficient in. I had never used MATLAB, so now can say I can use it. Understanding how image processing works—I understood we would take seven exposures and stack them to see the corona. It sounds simple, but it's more complicated. So aside from the coding, I learned the processes of how to manipulate images to see what we want without creating artifacts.*

In interviews, students also talked about their learning with respect to solar physics as an area of growth. When asked specifically about the impacts of the first summer experience on their knowledge about solar corona phenomena, the work of solar scientists, and solar observation and analysis, students unanimously stated that they had grown in their knowledge and in their skills. All felt that these skills would help to prepare them for the 2017 eclipse and working with volunteer sites. Aspects of their learning about solar observations and analysis that they specifically noted in interviews included understanding of

- Data acquisition and processing.
- Construction of long time-sequence images of the corona.
- Image manipulation to see what they needed to see without creating artifacts.

Students felt that they came in with a very basic understanding of the Sun and that the readings provided by the research mentor and discussed during the first two weeks of the summer experience greatly increased their understanding of solar physics and solar phenomena. They highly valued the time spent reading and in discussion with their peers and research mentor. One student commented that working both with other students at different stages of their academic careers and with established solar scientists helped him/her "see what they do every day for a living." Students who had not previously been involved with research commented that the project helped them to understand the research process and how teams work together toward a common goal.

> *"I experienced more learning in the coding field. I've also learned a lot about project management—working with sites, wrangling people, addressing concerns, and keeping track of a team."*
> —CATE student

With respect to preparing to work with volunteers for the 2017 eclipse, students identified aspects to data collection in Indonesia that worked well and looked at where problems or issues had occurred. Aspects that worked well in Indonesia included

- Taking enough time ahead of totality to be ready and not feel rushed when it came time to collect the data,
- Choosing sites to minimize foot traffic around the area of the telescope,
- Setting up the telescope and laptop and completing the calibration procedure,
- Using the Fire Capture image software, and
- Setting up on stairs so the stairs could be used as a backdrop for part of the calibration procedure.

Challenges to data collection in Indonesia included

- Overexposed and out-of-focus images,
- Slow upload of data to Dropbox due to file size and slow Internet connections,
- Vibrations from nearby buildings that showed up in the data, and
- The counter disappearing from the laptop so they were unsure they had captured images.

On the Year 1 post-REU survey, students responded to a question about how prepared they felt to train the state coordinators and volunteers on data collection for the August 2017 eclipse. Responses were on a five-point scale from 1=*not at all prepared* to 5 =*very prepared*. Of the six students, two felt *somewhat prepared*, two felt *prepared*, and two felt *very prepared* (*M*=4.00).

When asked what follow-up activities would be most helpful to expand their learning and preparation for the 2017 eclipse students offered the following:
- Coordinating group observations and more practice with the telescopes and data acquisition (*n*=2)
- Development of uniform training materials and procedures (*n*=2)
- Webinars with the project PI and state coordinators (*n=1)*

Effects of Citizen CATE Participation on Undergraduate Students: NASA SMD Top-Level Objective 1

Key Questions: NASA SMD Top-level Objective 1—Improve STEM Education

Did participation in the Citizen CATE experiment increase undergraduate student knowledge and skills related to solar science and research?

Did Citizen CATE undergraduate students gain an understanding of research processes?

To understand how participating in the Citizen CATE project affected participating undergraduate students, evaluators conducted interviews, observations, and surveys with them. Evaluators also interviewed co-principal investigators who mentored the students at their home institutions. Interview and survey questions were aligned to research on potential benefits of undergraduate research experiences including impacts on career decisions, content learning gains, gains in research skills, gains in "thinking like a scientist," enhanced preparation for future studies, and personal gains (Lopatto, 2007; Russell, Hancock &McCullough, 2007; Seymour, Hunter, Laursen, & Deantoni, 2004).

Students' Knowledge and Skills Related to Solar Science and Solar Research

On an annual survey, students rated their level of understanding of solar science research, characteristics of the solar corona, and general astronomy and their knowledge of NASA science. In fall 2016, students reflectively rated their knowledge and skills prior to their participation in CATE and after participating in the summer REU. At the end of Year 2, students again rated their knowledge and skills after working with CATE teams and participating in the eclipse (Figure 11). Due to small samples sizes (*n*=5–6), evaluators present these data descriptively; statistical analyses were not conducted. A detailed breakdown of student responses is presented in Appendix G.

Students' ratings of their knowledge and skills increased from before Citizen CATE to middle of the project and in almost all instances continued to increase until after Citizen CATE (n = 6).

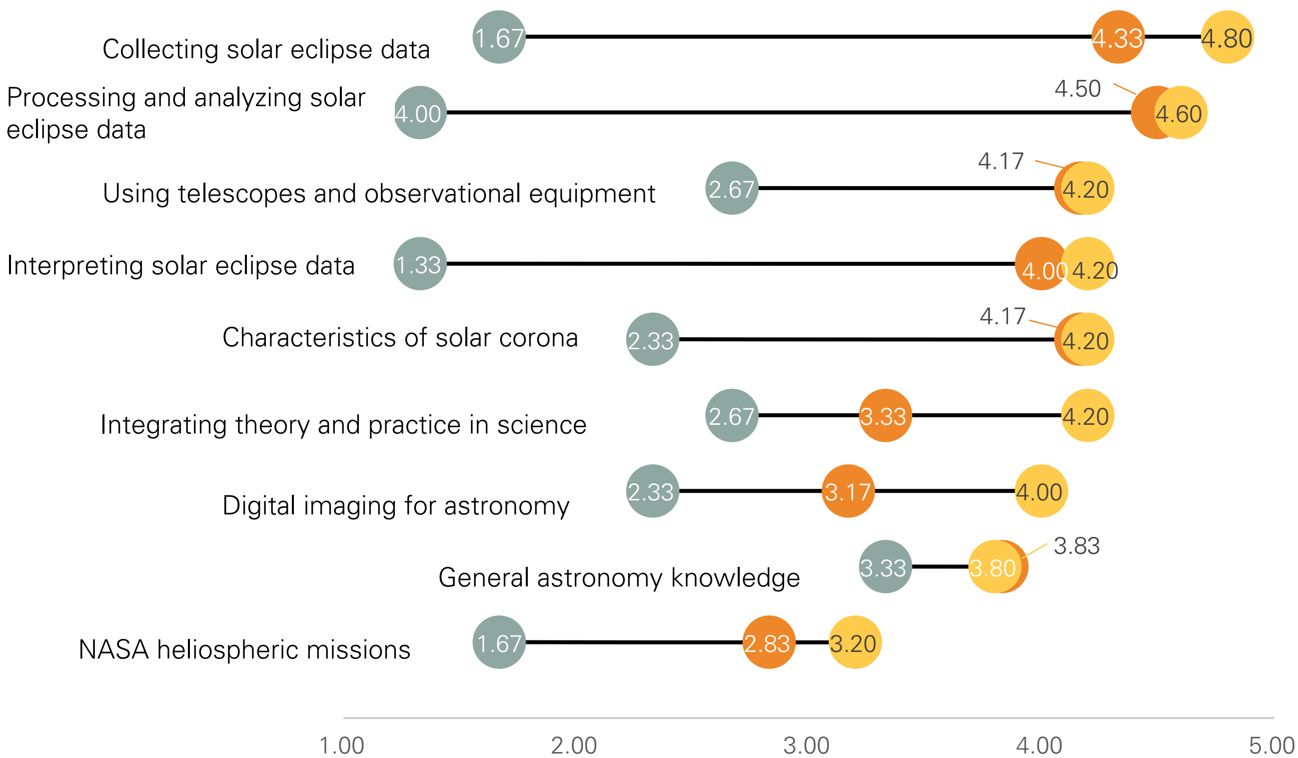

Figure 11. Undergraduate student ratings of impacts of CATE participation on their knowledge and skills n=5 for timepoints one and two, n=6 for timepoint three)

Students indicated significant growth in their knowledge and skills as a result of participating in CATE. Reported gains were greatest for skills related to collecting, analyzing, and interpreting solar eclipse data. Students also reported a large increase in their skills related to understanding the characteristics of solar corona and integrating theory and practice in science, and in their general astronomy knowledge.

In interviews, students talked about specific skills they had gained through their involvement with the CATE project. One student felt that his/her greatest growth was in understanding "science and research equipment in general." This student commented, "Before CATE, I had never done any image processing; I didn't kmow anything about the Sun or the corona. Now I now more than my peers."

Students felt that they came into the project with a very basic understanding of the Sun and the solar corona. Through the first REU lectures, readings, and work with project investigators they gained a more in-depth understanding. As one stated,

> *I knew a basic level before. I had two astronomy courses in college but there wasn't much focus on the Sun. Not as in-depth [as this experience] as to why things happen in the corona and why we should be interested in them.*

With respect to the work of solar scientists, students commented that in addition to their own work on CATE, field trips to observatories in Year 1 gave them a better understanding of what solar scientists do. One said, "The Kitt Peak and Sunspot field trips made me see that [solar science] is an in-depth science and it's really interesting."

Students' Abilities to Conduct Research and Present Findings

In fall 2016, students reflectively rated their understanding of research and ability to communicate research prior to CATE and after participating in the summer REU. At the end of Year 2, students again rated their knowledge and skills after working with CATE teams and participating in the eclipse (Figure 12).

As shown Figure 12, students felt their greatest gains from before to after participating in CATE were with respect to writing research papers, preparing posters for research conferences, and teaching others to collect and analyze data. Students who had not previously been involved with research commented that the project helped them to understand the research process and how teams work together toward a common goal.

Students' ratings of their abilities mostly increased from before the project to the middle and end of the Citizen CATE project (n = 6).

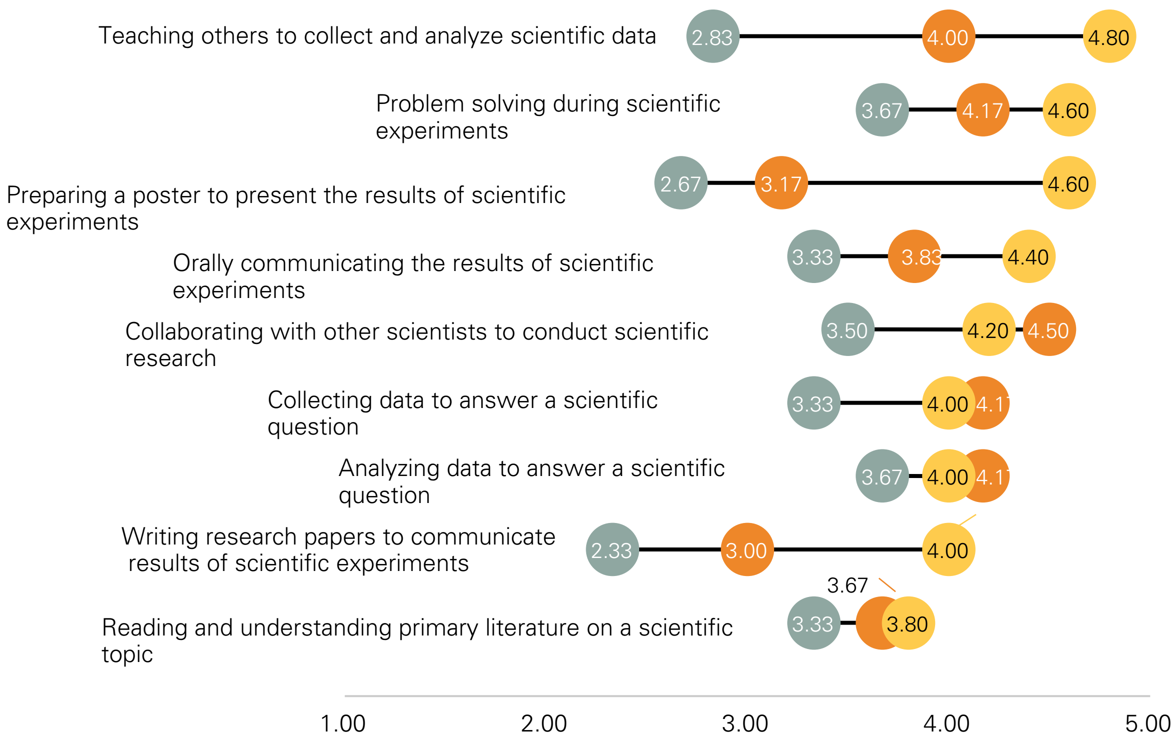

Figure 12. Undergraduate student ratings of impacts of CATE participation on their understanding of research and communication of findings (n=5 for timepoints one and two, n=6 for timepoint three)

On the final survey, students indicated on a five-point scale, ranging from 1=*strongly disagree* to 5=*strongly agree*, their level of agreement with a series of statements about the impacts of participating in Citizen CATE on their skills as researchers (Figure 13). Students agreed that participating in the project made them more confident in their ability to do research and gave them a better understanding of how scientific knowledge is built.

Figure 13. Students' mean level of agreement with statements about the impact of CATE on their research skills and attitudes (n=5)

University mentors discussed the growth of students' skills and abilities as a result of CATE. Several reported seeing a growth in confidence, maturity, and independence in their students over the course of the project. As one stated,

> *I would say [my student] has shown an ability to work independently that he didn't have at the beginning of the project. Now he is much better at participating in developing a plan with a task list. That's a very valuable skill.*

> *"None of the undergrads came in knowing a lot about this research. By the end, they had the ability to do the background research and put in the work. It was also a chance to learn perseverance, because in research there can be more dead ends than not."*
> —CATE co-PI and university mentor

Another stated of a student, "After participating in the eclipses, handling the data, knowing what the data is, and knowing the procedures, it made her more professional in the way she did things." Yet another reported,

> *CATE gave my student the opportunity to have significant hands-on experience in conducting research. He got hands-on applications with software and hardware in normal and stressful conditions in a way that most undergraduates don't get to do. The level of responsibility he was given in the project went a long way in increasing his abilities.*

The project principal investigator noted that students came into the project with varied experiences with research. For the WKU high school students, CATE was their first exposure to research and they gained a better appreciation for it. Others with more research experience learned a great deal with respect to the academic material and content covered in the REU. He commented that the project gave the students the opportunity to "interact with a large variety of people, which was a good thing for them."

"There were points in the process where the students knew more than the state coordinators did. They took ownership of the process."
—CATE co-PI and university mentor

Mentors commented that the greatest strength of a project like CATE in terms of impacts on undergraduate students is giving them real-world research experiences. One commented, "An REU program offers the immersion experience necessary for student to understand what research is." One mentor also spoke about the benefits to students of understanding what a career in research entails. This individual said,

> *When students are just focused on classes and the mechanics of being a student, like time management and all that, it's hard for them to see the connection between their pedagogical training and actually what it's like to be a professor at a university. When they are involved in a research project like this, they get an idea of what we do besides just standing up in front of a class.*

Communicating Science to the Public

Mentors all felt that students increased their communication skills with respect to professional audiences as well as the general public through their participation in CATE. One co-PI who mentored three students for the project commented on seeing students' communication skills progress with each presentation they gave. He commented, "By the third presentation, they were old pros. I watched them present to faculty from around the state more like graduate students than the high school students they were." Another said, "[My student] became very enthusiastic about public presentations. He was able to handle open-ended questions about all kinds of things related to the project. I attribute a lot of that growth to CATE—there's been a real change over time."

"Projects like CATE are a custom fit for undergraduates because it was sufficiently advanced to challenge a student but didn't require the background a graduate student would have. They could step in and learn and grow in this kind of experiment."
—CATE co-PI and university mentor

On the final survey, students indicated a high level of agreement with statements about the impacts of the project on their communication skills (Figure 14). In final interviews, students commented that they had gained a great deal with respect to the communication of research goals and findings and in working with people in their interactions with CATE volunteers. One student noted,

> *My communication skills have definitely been my greatest growth. I've worked with a huge range of people, done trainings in person and by phone, and debugged software with people across the country. This summer I feel like I*

know what I'm talking about. It's a confidence boost—I can answer 95% of [volunteers'] questions.

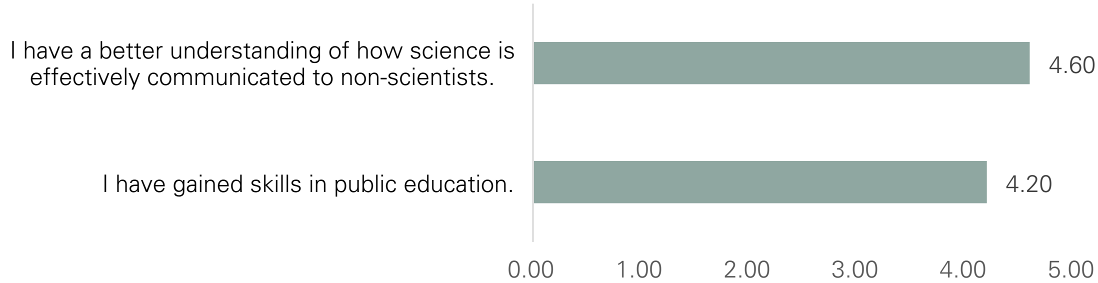

Figure 14. Students' mean level of agreement with statements about their public education skills (n=5)

Impacts on Careers

Students noted in interviews and on surveys that CATE helped to solidify their academic and career plans, although for most, those plans were not in astronomy. With respect to career impacts, on the final survey, students indicated that participation

- Increased their experience and skills in the field (*n*=2)
- Increased their confidence in their educational/career path (*n*=3)
- Gave them exposure to a new field for educational pursuits (e.g., solar physics) (*n*=2)

Mentors noted that even if the project didn't engage all students in astronomy-related careers, it did provide them with an understanding of what it meant to do graduate-level research and helped to solidify their plans. Of the CATE students who participated in at least one year of the summer REU program,

- One has taken a job at the Space Telescope Institute after completing his baccalaureate degree and intends to continue to graduate school at some point;
- One has entered graduate school in solar physics at New Mexico State university;
- One has entered the University of Kentucky as an undergraduate majoring in physics and computer science;
- One is completing his undergraduate degree with the intent to continue to graduate school in some aspect of astronomy; and
- One graduated high school and entered the U.S. Air Force Academy.

Eclipse Day
Madras, OR, CATE Team

The Madras, OR, CATE team set up in the parking lot of the Erickson Aircraft Collection Museum— home to World War II aircraft—next to the Exploratorium crew that would be live streaming the eclipse. Unprecedented crowds were expected for the event, so to protect the equipment and the work of the citizen scientists, the CATE team used caution tape along the perimeter of their space. Volunteers took turns talking with visitors at a designated site, explaining the CATE experiment and providing information about the eclipse. A table with a sun spotter and binoculars was available to allow visitors to observe sun spots. Signs provided information about the CATE project, the team's sponsoring organization (the Boyce Research Initiatives and Education Foundation), and the science of the solar corona. The team distributed informational flyers and CATE solar glasses to the steady stream of visitors who stopped by to view CATE information.

The Citizen CATE team would only get one chance to record the eclipse and nervous excitement was palpable in the moments leading up to totality; volunteers made comments like "I'm going to be shaking." Moments before totality, the team rapidly discussed the final steps to be taken during totality, assigning roles such as who would announce totality, who would remove the telescope lens, and who would jump in front of the lens in the seconds before the sun returned in force.

As the moon made first contact, one citizen scientist began to read the roughly 100-point checklist out loud to the rest of the team, starting with the step number to ensure no steps were missed. One citizen scientist was assigned to the telescope, one sat at the computer, and two more observed and double-checked the work on the computer. It was clear the team had practiced, as each citizen scientist seemed to know his or her role and understand each step. By 9:40 am, the Citizen CATE team had images of the Sun on the computer. Their excitement and well-deserved pride showed as the team congratulated one another and took pictures around the telescope and the computer to capture the moment.

Meanwhile, a second group of CATE volunteers was tasked with measuring the shadow bands and the temperature changes. They had set up nearby with a camera and Go-Pro aimed at a poster board. As totality neared, this team's excitement also grew as they noticed the changes in their shadows; they spent the next few minutes coming up with creative shadows to record.

After months of preparation, the moment came. At 10:20 am, a citizen scientist announced totality. After a short cheer, the Earth got eerily quiet and the sky turned from brilliant purples and oranges to black. Image recording began and the citizen scientists reveled in the much-anticipated moment alongside the rest of the crowd as the Earth took on a serene stillness.

As the sun began to emerge again, the stillness was broken, and the team went back into action. The pressure was on at this point. Had the team succeeded? Had they captured the amazing images? In the moments following totality, the team struggled to find the data on the computer; they wondered if the camera had stopped during totality. At last the data were found, and the team breathed a sigh of relief as they resumed the checklist to back up the data and select images to upload as one of the 68 CATE sites.

Evaluation Findings: Citizen CATE Volunteers

Citizen-science volunteers included state coordinators and volunteer teams; these volunteers were drawn from members of the general public with an interest in astronomy, staff members from observatories and planetariums, education outreach providers, K–12 teachers, and university faculty members. Evaluators collected formative data from citizen-science volunteers on their CATE training through a training feedback survey and through observations of early training opportunities. State coordinators also participated in a survey to determine their training needs. Evaluators provided training feedback to the project principal investigator and state coordinators immediately after the trainings so that they could follow up with additional support in areas where volunteers expressed needs. This section of the report presents highlights from those formative reports. A detailed breakout of volunteer findings is presented in Appendix H.

Volunteer Preparedness for Eclipse Day

90% of volunteers rated CATE training as **good** or **excellent**

In preparation for the eclipse, volunteers attended one of twelve training sessions held in nine states in April and May of 2017. Of the 110 volunteers who received post-training surveys, 79 (72%) completed the feedback surveys. Of those, 90% rated the CATE trainings as *good* or *excellent*. They indicated they gained significant learning about the purpose of the Citizen CATE project, the plan for data collection across sites, safe solar observation procedures, and solar eclipses. Volunteers responded to questions about their level of preparedness for eclipse day on a five-point scale ranging from 1 = *not at all prepared*, to 5 = *very prepared*. As a result of training, CATE volunteers indicated feeling somewhat prepared to prepared in all areas of training (Figure 15). Volunteers felt most prepared with respect to safe solar viewing, telescope assembly, communicating with volunteers, alignment, and camera operation. Volunteers felt only somewhat prepared for working with volunteers, data calibration, data upload, crowd management, and networking with other sites.

When asked what more they needed to be fully prepared for the eclipse, the majority of respondents indicated the need for multiple practice sessions with their team to practice assembling equipment, collecting data, and uploading their files to the shared Google drive. A typical volunteer response was, "After the training, I feel more confident and know what needs to be done and to be set up. Now I mainly need to practice the procedure a lot." When asked about further support they needed prior to the event, respondents indicated the following:

- YouTube videos and written procedures in nontechnical language
- Clarification on the calibration tab in MATLAB
- Written instructions for operating each application in the eclipse folder, including GPS, Arduino, and FlyCapture, along with photos of the equipment and screen shots of the software
- Clarification on when to take drift and calibration data with respect to the eclipse
- Review and explanation of camera orientation and alignment
- Estimates of public numbers and outreach information for eclipse day
- When to make the call that cloud cover is sufficiently heavy to make it "hopeless" to get any useful data

- Detailed description of what data to send on the day of eclipse
- Troubleshooting tips and information about how other teams have overcome challenges

Practice sessions between the training and the event allowed volunteers to practice procedures related to calibration of the equipment and data upload.

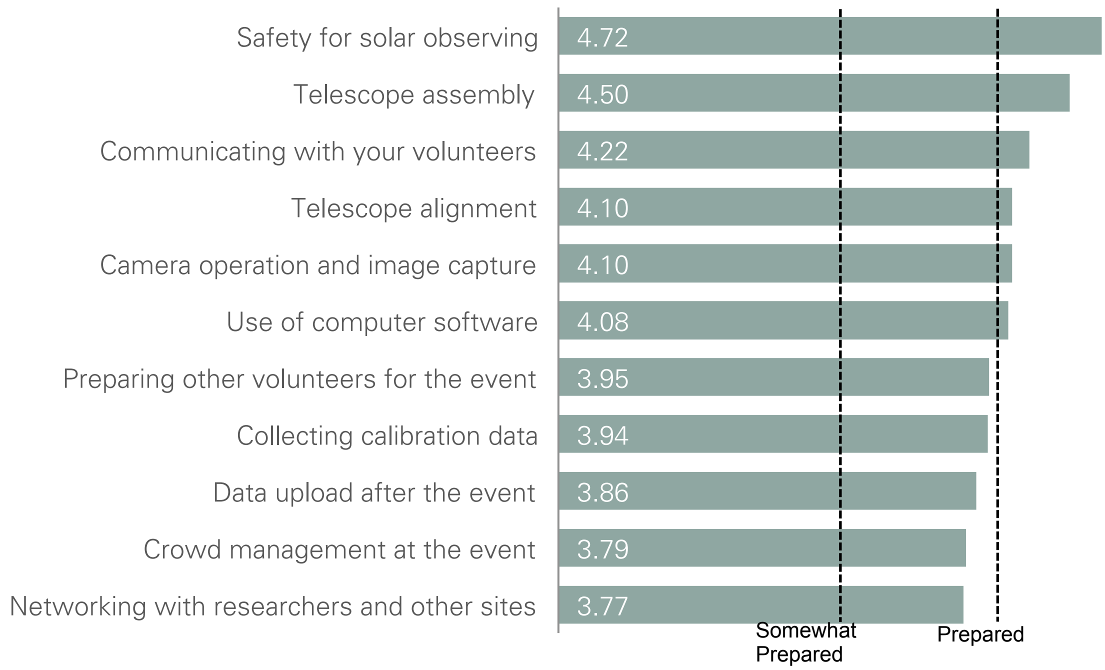

Figure 15. Volunteers' ratings of their level of preparedness for eclipse day after training and before practice sessions (n=76-79).

On the post-eclipse survey:

- **92%** of volunteers indicated feeling **prepared** or **very prepared** for their roles on the day of the eclipse.
- **97%** felt their roles and responsibilities **were clear** prior to the event.
- **98%** were **satisfied** or **very satisfied** with their roles during the eclipse.

Evaluators shared detailed findings from the training feedback survey with the CATE team. In response, the undergraduate team prepared training videos, checklists, and other materials for volunteer teams to use in follow-up practice sessions and on eclipse day. Practice sessions after the initial training also eased volunteer concerns about eclipse day. On the post-eclipse survey, a large majority of volunteers indicated that they felt prepared on the day of the eclipse.

Post-Training Preparation

On the post-eclipse survey, respondents indicated how they had prepared for the eclipse between the formal training sessions and eclipse day. To prepare for collecting data during the eclipse, respondents participated in the following activities:

- 97% participated in practice runs with the equipment (e.g., assembling equipment, observing sun spots, observing full moon) prior to the eclipse;
- 85% participated in a spring 2017 in-person training with a state coordinator or CATE undergraduate student;
- 75% participated in email exchanges with a state coordinator;
- 72% participated in email exchanges with CATE undergraduate students;
- 43% participated in online videos;
- 22% participated in Zoom calls/webinars with CATE team; and
- 25% shared other ways they prepared, including creating blog posts, consultating with astronomers, engaging in email exchanges and in-person meetings with the project principal investigator, practicing with other teams, and making presentations to others on their teams.

When asked if any further training would have better prepared them, 20% indicated they would have liked the following:

- Additional in-person trainings (n=3)
- Practice sessions with the state coordinator
- Being informed about the timing of progress checks
- More documentation on the assembly of the Arduino unit
- Having a practice script earlier in the process
- More opportunity to practice with drift and polar alignment
- More information on the use and reduction of data
- Better understanding of the why and how behind steps in the process

Training Successes and Challenges

In interviews about the project, the project principal investigator and co-investigators noted successes and challenges related to training citizen-scientist teams. One investigator commented that the idea to have state coordinators was a good one; coordinators helped with managing the trainings and practice sessions prior to the event. Using the undergraduate students as trainers was also noted as a highly positive aspect of the project from the perspective of the project team. It not only empowered the participating students, but provided an effective means to manage the large number of sites. One co-principal investigator stated,

> *Retired astronomers were looking to the undergrads to know what was going on. They hadn't done astrophotography before. They didn't come in with misconceptions and learned how to do it right. In a short amount of time, we had 300 people trained to use telescopes well.*

Others noted that face-to-face trainings were critical to the project success and one investigator commented that one more face-to-face visit with teams prior to the event would have been beneficial. He stated, "It would be good to have a regional meeting to bring people back together to finetune things and double check that everyone knows what they are doing."

In interviews, themes emerged with respect to challenges with enlisting and training citizen-science volunteers for the project. Challenges included some sites not having equipment for trainings, varied quality of training, and varied levels of commitment to practicing before the eclipse. Due to challenges with securing funding, some sites did not have their equipment available at the team training events in April and May. This meant that while they could observe the assembly and use of the telescope and the software for observing, attendees at these training sessions did not get hands-on experience with an in-person trainer. These sites did have opportunities for follow-up training and practice when their equipment arrived, but participants reported that not having the equipment at the in-person training made it more challenging to learn how to use it.

Some investigators commented on the challenges involved with gauging the level of commitment among the volunteers. They commented that while some teams practiced regularly with their equipment, others "needed more motivation" and didn't "prioritize trainings as much as they could have." One investigator stated that for another similar project, there might need to be some way of vetting the commitment level of volunteers prior to accepting them for participation. This could involve more clearly laying out the expectations for participation in training and practice events.

Figure 16. CATE undergraduate students practice assembling equipment and taking images

Pre-Eclipse Citizen CATE Outreach

State coordinators, project investigators, and volunteers conducted outreach and dissemination activities about CATE prior to the August 21 eclipse.

17,000 adults were reached directly through conference presentations, public events, information booths, presentations to educators, and science lunches.

7,400 K–12 students were reached through summer camp activities, library presentations, school family science nights, STEM clubs, Junior Ranger Club, and planetarium talks.

90,000+ adults and children were reached indirectly through large public events including booths at music and cultural festivals, Eclipse Expos, and Eclipse Fests.

60+ newspaper, radio, and TV programs featured CATE groups and stories.

Effects of Participation in CATE on Citizen Scientists: NASA SMD Top-Level Objectives 2 and 3

Key Question: NASA Top-Level Objective 2—Improve U.S. STEM Literacy

Did Citizen CATE increase citizen scientists' understanding of scientific processes and Sun-Earth relationships?

Data on the outcomes of program participation included eclipse-day observations and interviews of teams in Madras, OR, and Weiser, ID; a post-eclipse CATE volunteer survey; and undergraduate, mentor, and principal investigator interviews.

A link to a post-eclipse survey was sent to 163 CATE volunteers who had participated in training.[2] Of those, 3 emails bounced; 103 individuals responded to the survey, a 64.7% response rate. Post-eclipse survey respondents represented sites in all of the states where the Citizen CATE experiment was conducted (Figure 17).

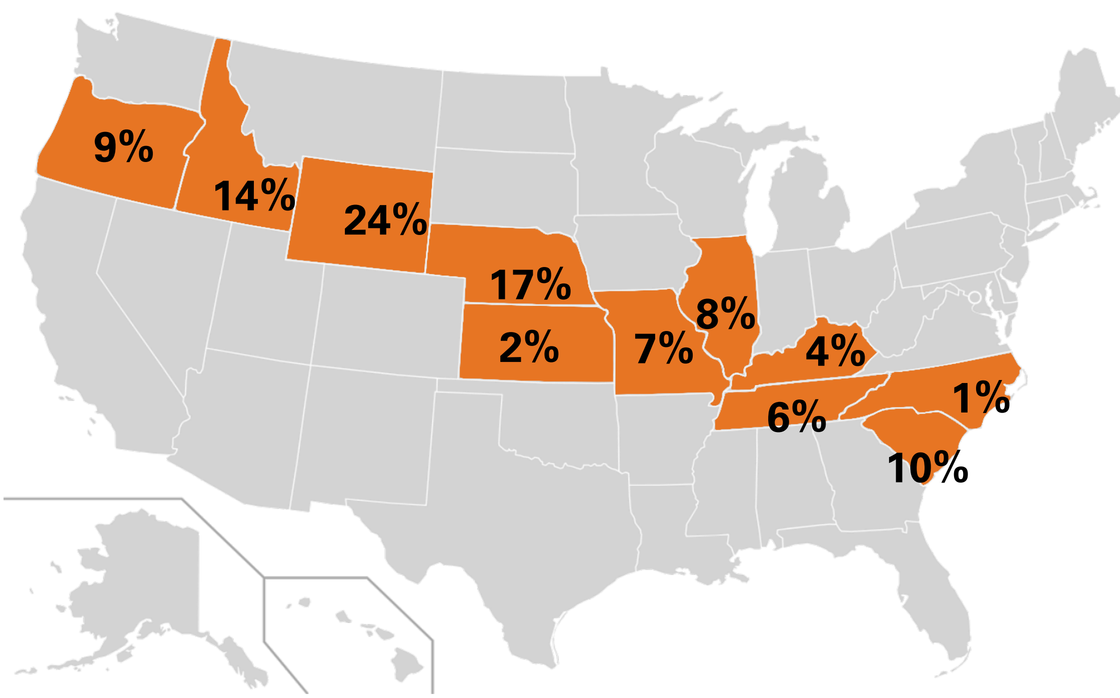

Figure 17. Post-eclipse survey response rates by state (n=103)

Volunteers' Knowledge and Skills (NASA Top-Level Objective 2)

After the eclipse, volunteers rated their skill levels on a 7-point scale ranging from 1 = *no knowledge* to 7 = *expert,* for understanding how solar eclipses happen, characteristics of the solar corona, how scientists observe solar corona and investigate questions about the sun, NASA heliospheric missions, and conducting education and public outreach (Figure 18).

[2] Teams reported a total of 270 volunteers on eclipse day; many team members brought along friends, colleagues, and family members to provide additional help on the day. Evaluators surveyed only those who had been trained as part of the project.

Volunteers indicated growth in all areas of their knowledge and skills related to the project. The greatest growth was in areas related to the science of observing the corona and skills related to collecting solar data to answer scientific questions. Particular attention was given during trainings to safe solar viewing and volunteers indicated growth in this area. Results of paired samples t-tests indicate that volunteers' perceived growth was statistically significant for each of these items (p < .001) (Table 1).

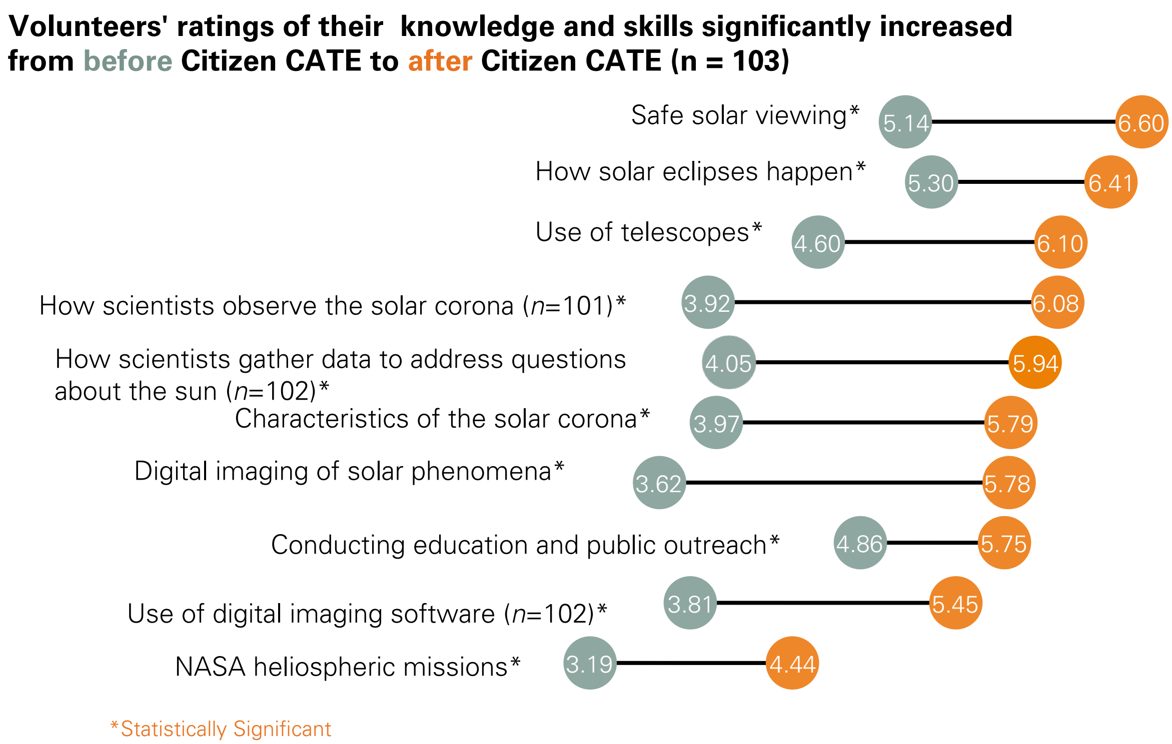

Figure 18. Mean ratings for volunteers' self-reported level of understanding before and after participating in CATE

CATE Volunteers....

...came from **27** home states.

...traveled up to **2,700** miles to reach their observing sites (M=360.4).

Table 1. Results of paired samples t-tests of volunteers' self-reported learning outcomes (n=103)

	Before			After			Paired t-test results		
	N	Mean	SD	N	Mean	SD	Mean Diff	t	p-value
How solar eclipses happen	103	5.30	1.63	103	6.41	0.89	1.11	8.15	<0.001
How solar scientists gather data to address scientific questions about the sun	102	4.05	1.85	102	5.94	0.87	1.89	12.51	<0.001
How scientists observe the solar corona	101	3.92	1.90	101	6.08	0.83	2.16	12.84	<0.001
Characteristics of the solar corona	103	3.97	1.87	103	5.79	1.04	1.82	11.55	<0.001
Digital imaging of solar phenomena	103	3.62	1.99	103	5.78	1.02	2.16	12.98	<0.001
NASA heliospheric missions	103	3.19	1.91	103	4.44	1.61	1.24	9.98	<0.001
Safe solar viewing	103	5.14	1.75	103	6.60	0.60	1.47	9.02	<0.001
Use of telescopes	103	4.60	1.99	103	6.10	0.89	1.50	10.63	<0.001
Use of digital imaging software	102	3.81	2.04	102	5.45	1.19	1.64	10.65	<0.001
Conducting education and public outreach	103	4.86	1.65	103	5.75	1.09	0.88	7.92	<0.001

In open-ended responses, citizen-scientist volunteers noted that they learned about the processes involved in imaging the solar corona, including assembling and operating the telescope, calibrating the equipment, and running the software to record the images. They also commented on their learning about the solar corona and general astronomy and their expanded understanding of what was happening with the sun during a solar eclipse. One volunteer commented, "I really appreciated learning about all the stories that people made up about eclipses and how that showed that mankind has always been fascinated with astronomy."

> *"We learned so much about the solar corona and how scientists will use the data. We also learned a great deal about properly setting up the telescope so that it will track celestial objects."*
> *–Citizen CATE volunteer*

Volunteers' Attitudes Toward Astronomy and Citizen Science (NASA Top-Level Objective 3)

> **Key Question:** NASA SMD Top-Level Objective 3—Advance National Education Goals
>
> *Did participation in Citizen CATE increase citizen scientists' interest and engagement in astronomy?*

Volunteers responded to questions about the impact of participating in the CATE experiment on their interest and engagement in astronomy, their contributions to solar science, and their appreciation for the work of solar scientists by indicating their level of agreement with statements on a five-point scale (Figure 19). The majority of volunteers agreed or strongly agreed that participation in the CATE project made them more interested in astronomy and solar phenomena.

After participating as a volunteer in the Citizen CATE project, participants had positive attitudes toward astronomy, citizen science, and the work of solar scientists.

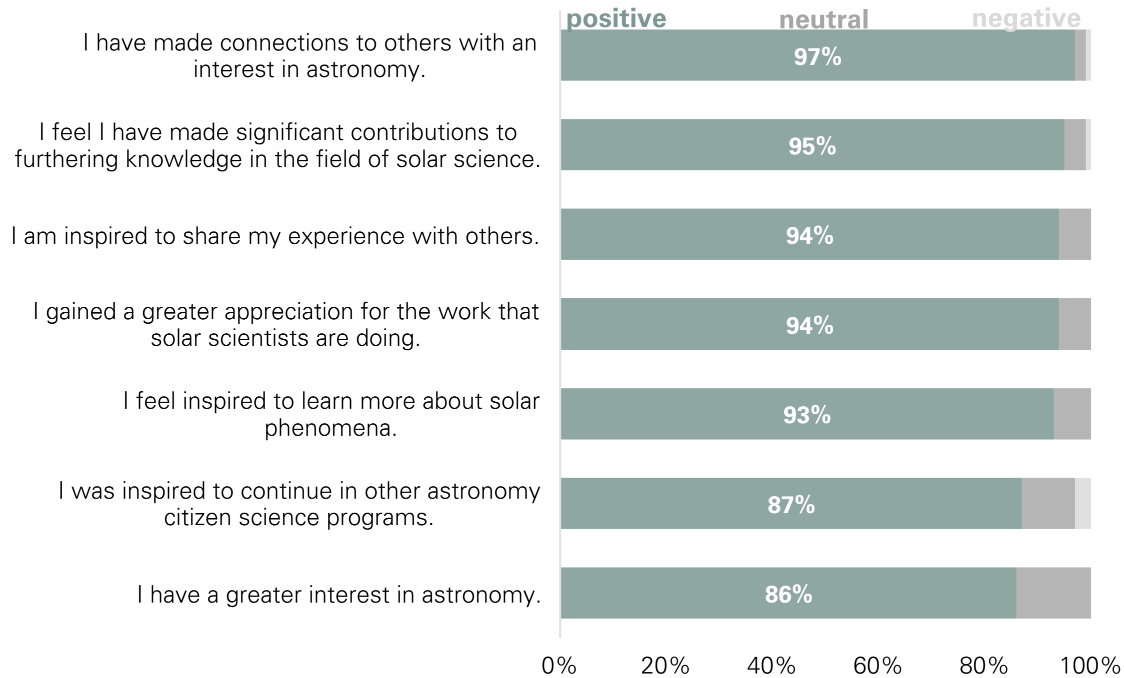

Figure 19. Volunteers' level of agreement with statements regarding the impact of CATE on their interest and engagement in astronomy

Citizen-scientist volunteers overwhelmingly agreed that they had made connections to others with an interest in astronomy and felt inspired to share their experiences. One volunteer stated,

> *The contact with other interested people was very special. After practicing on our own for four months, it was exciting to get to share our experience on eclipse day with three teams of dedicated and experienced scientists. My students and I will never forget our efforts and satisfaction of doing a good job preparing for and producing our image data.*

In open-ended responses, many volunteers wrote of how they enjoyed sharing the excitement of CATE through public outreach during the eclipse. As one noted, "[I enjoyed] communicating with people who were genuinely interested and excited about the event." Another commented, "I enjoyed the enthusiasm of young kids and citizens towards eclipse observations, and being part of a larger group activity."

Engaging Aspects of Participating

CATE volunteers provided a variety of response to an open-ended question about what most excited or interested them about participating in the project. Volunteers most frequently (n=40) wrote about the opportunity to be part of a larger experiment that went beyond their individual sites and gave them the opportunity to contribute to furthering scientific knowledge about the Sun. A typical citizen scientist comment was, "I was able to be part of something that was much larger than myself, and feel like I was making a significant contribution to the field." Another wrote, "[What was exciting was] the fact that the volunteers were totally in charge of the scientific equipment and the observations. This really made you feel integral to the project."

Many volunteers (*n*=18) commented that the most exciting part of CATE was the opportunity to watch a total solar eclipse and experience the beauty of the moment, including the changes in the Sun and Earth during totality. As one volunteer commented, "The most exciting part was getting to see this thing you had been preparing for for months happen right before your eyes."

> *"During totality, the beautiful white ring in the sky was just so amazing and the 360-degree sunset was unbelievable. That was definitely the best part."*
> *—Citizen CATE volunteer*

A number of volunteers (*n*=13) who had brought student groups to the eclipse as part of their CATE experience commented that the best part of CATE was sharing the experience with those students. One volunteer commented, "Seeing students learn and apply knowledge about astronomy and develop relationships with the scientific and astronomical community was exciting."

An evaluator interviewed students on the Weiser, ID, CATE team on site after the eclipse. The students shared their pride in being part of a larger scientific endeavor. One commented, "Being on the telescope, we worked so hard and to have those pictures be our work—we were really a part of making it real for other people." Another said," I always liked space, but with this I could participate and interact with it. And I wanted to be a helping hand with the project." They also commented on all they had learned in training and in their many practice sessions prior to the eclipse. One student shared, "I learned a lot about use of a telescope and a lot about the sun." Another commented that participating in CATE had cemented her interest in astronomy: "I learned that have a real interest in telescopes and space and all the things I didn't know. When I was younger I was into the stars and the universe. This project gave me hands-on experience with it."

Rating Eclipse Day Activities

- **98%** rated interactions among team members as **good** or **excellent**
- **99%** rated interactions with the public as **good** or **excellent**
- **97%** rated operation of CATE equipment as **good** or **excellent**
- **89%** rated upload of data as **good** or **excellent**

And finally, a few volunteers noted that the eclipse was a culmination of many months of effort and practice. As one wrote, "Those few seconds where you could feel all of your hard work finally paying off were just incredible." Another summed that feeling up well:

> *All the preparation really paid off. I was able to collect the data and experience totality. Being a CATE team member enhanced my overall experience. I also understand that it's not over; I've been awed by the short video that has come out*

and can't wait for more science to be teased out of the data that we collected. I am excited to see more videos and to be a part of collecting it was truly a once-in-a-lifetime event.

I Never Realized….

On the post-eclipse survey, volunteers responded to an item asking them to reflect back on their participation in the Citizen CATE project and complete the sentence "I never realized . . ." In response, volunteers commented on several different aspects of participating. The most frequent responses (*n*=29) reflected a new understanding of the extent of scientific knowledge that would come from the project and their own learning from participating. For example, volunteers responded, "I never realized . . .

> *"It was even better than I was expecting. It felt so surreal—the fact we've seen videos and heard what people experienced in past eclipses—but to be here and experience the temperature dropping and the light disappearing …"*
>
> *—Citizen CATE volunteer*

… how complex the solar corona is."
… that scientists couldn't observe the corona very well without an eclipse to block out the Sun."
… how much we still don't know about the Sun."

Many (*n*=17) wrote that they never realized how beautiful and awe inspiring an eclipse could be. Others (*n*=8) hadn't realized the amount of effort involved in a project like CATE, for example, "how much goes into capturing data before and after totality," and "how much work it takes to coordinate experiments." Other responses included not realizing how much public interest there would be in the project (*n*=7), how much citizen scientists could accomplish (*n*=7), and how unique CATE was as a project (*n*=4).

Eclipse-Day Outreach

It is difficult to estimate the number of people reached by the CATE project on the day of the eclipse. Many CATE sites were part of larger eclipse programs or had other organizations and projects observing at the same localities. In an annual report to NASA (Penn, 2017), the project principal investigator noted that sites located at high schools or involving high school students "inspired the schools to host larger eclipse events and engage more student in viewing the eclipse, resulting in an estimated 20,000 students impacted"(p. 9). He also noted that CATE sites on some college campuses impacted a roughly estimated 100,000 people in large-scale events. He went on to say that small towns that hosted CATE sites may have impacted approximately "300,000 people in small towns across the path of totality." While these numbers are best estimates and difficult to verify, it can safely be said that hundreds of thousands of people interacted with the project on some level, either directly or as part of wider eclipse events.

Sustaining the Impacts of CATE

A key intent of the Citizen CATE project was to sustain the excitement and interest in astronomy beyond the total solar eclipse. CATE empowered sites to continue the work by giving the volunteer teams the telescopes and laptops they used to collect data, so they could continue to use the skills learned as part of CATE to take digital images of their observations. On the post-eclipse survey, 85 respondents indicated how they intended to use the equipment after the eclipse (Figure 20). Most teams reported intending to use their telescopes in education programs or as part of public outreach. Groups also reported that they would use their telescopes to study the Sun, variable stars, and comets.

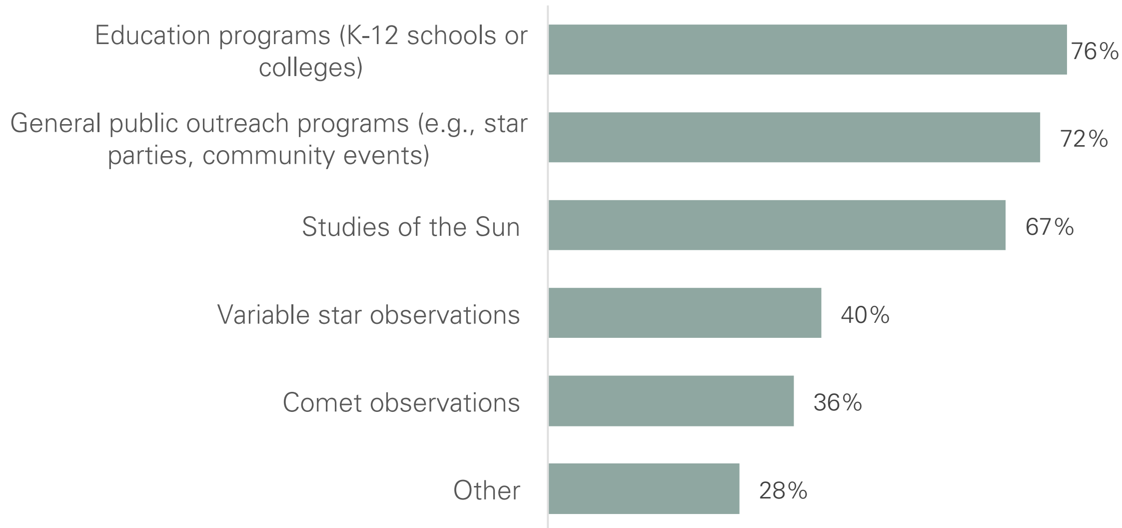

Figure 20. Volunteers' intended uses of CATE equipment after the eclipse (n=85)

Other intended uses reported on the survey included:

- Starting a high school astronomy club (*n*=4)
- Supporting college-level physics and astronomy classes (*n*=3)
- Placing the telescope in an Exploradome observatory and allowing students to control it from the planetarium
- Asteroid occulations (*n*=2)
- Lunar observations (*n*=2)
- Observing total Lunar eclipse on January 31, 2018
- Deep sky and planetary imaging/space photography (*n*=2)
- Any programs possible (*n*=2)
- Anything that NASA would make available
- Donating it to Amateur Telescope Makers of Boston (ATMOB)
- Solar and astrophotography projects with the club
- Training on the operation of telescopes
- More citizen science projects, if possible
- Don't know, would like guidance (*n*=2)

For many sites, the project built the capacity of high schools to start astronomy clubs and get more students involved and interested in astronomy. Volunteers also indicated an interest in obtaining more information, ideas, and resources to continue school and public outreach with the equipment.

Post-Eclipse Outreach

Evaluators reached out to state coordinators two months after the eclipse to see how they had used their equipment since the project ended. With about half of the CATE sites reporting in, respondents noted that the telescopes are largely housed at high schools, colleges, or universities. Several site leads indicated they had given presentations about their CATE experiences to students in their schools, faculty members at universities, professional teachers associations, and local newspapers. Sites indicated that since the eclipse they have used the CATE equipment to conduct public moon- and stargazing events, engage in outreach to schools and Girl Scouts, and start astronomy clubs at their schools. Sites that had not done outreach since the event indicated that they plan to do so in the near future.

In an interview, the project principal investigator cited as one of the key challenges to the project the need for follow-up after the eclipse. He noted, “We really need to capitalize on the excitement from the eclipse and need someone from the project who can be committed to following up with the sites.” He commented that if the team were to do a project like CATE again, it would be essential to build intentional plans for follow-up into the project design. The CATE team will continue to follow up with sites to track use of the equipment and to network about ideas for potential use.

Scientific Impacts of Citizen CATE

Key Question: NASA SMD Top-Level Objective 4—Leveraging Partnerships

Did the Citizen CATE experiment increase the capacity for scientists to collect and analyze solar eclipse data?

Adding to the Body of Knowledge of the Solar Corona

By leveraging partnerships with institutions and organizations across the U.S., the Citizen CATE project collected solar corona images on a scale never before attempted. Of the 68 CATE sites, 66 sent USB drives containing data to the National Solar Observatory, even though some sites were clouded out, reducing the usability of data. During totality, CATE sites captured approximately 45,000 images of the solar corona and teams collected images "during more than 80% of the 93 minutes of totality that were available from coast to coast" (Penn, 2017, p. 7). The project principal investigator notes that early viewing of the images is revealing characteristics of the corona that haven't been seen before. He commented, "We did the research-quality data collection we were looking for. No one has done it before. It's giving us a brand new way to think about eclipses."

Analysis of the 2017 data has begun. The principal investigator noted that initial examination of the movies of spliced images of the corona are showing slow and rapid outflow events, split polar plumes, and a chromospheric surge on the west solar limb, among other findings (Penn, 2017). Next steps on the project are to get support with data analysis and complete the movie of spliced images. The principal investigator commented, "We need to get the movie produced at a level where we can see the changes we know are in the data, like solar wind, and put together a calibrated time sequence of the eclipse."

Final Thoughts on the Overall Project

The project principal investigator and co-investigators offered their final thoughts about the Citizen CATE project in interviews. Investigators noted that the project was particularly successful in mobilizing a large number of volunteers across geographic and organizational boundaries toward a common goal. Investigators commented on the dedication of volunteers and the pride they took in being part of the project. The principal investigator reflected,

> *[The volunteers] were unbelievably committed to the project. It hit an important point—to be involved in the science. Most would have gone to see the eclipse anyway but this empowered them to be involved in eclipse research at this level. I was worried we would give telescopes to people and never hear from them or that they wouldn't travel to locations, but they did.*

A co-investigator commented, "The citizen part of the project was kept alive. I'm very proud of the 'citizen' in Citizen CATE." One investigator noted that the large-scale volunteer network will keep the excitement and engagement alive even as the project ends. He commented, "Now a lot of people can successfully do outreach. We will see payback from that for a long time as they keep doing outreach even after the project is over."

Another aspect that investigators felt worked was having a hierarchy for communication and training, with the project team communicating with state coordinators who, in turn, communicated with volunteers. Also, two investigators commented that involving teachers and students in the project broadened the impacts and had effects at the classroom level. One co-investigator said, "The involvement of teachers was really great because it allowed them to have something tangible in classes as the spring semester wound down toward the eclipse." And finally, all co-investigators voiced their appreciation of the leadership provided by the principal investigator in envisioning, managing, and carrying out the project.

Summary and Discussion

This evaluation study examined the impacts of the Citizen CATE project on participating undergraduate students and volunteers. Through a mixed methods design involving surveys, interviews, observation, and document review, evaluators studied how the project prepared volunteers for solar imaging and how participating affected the knowledge, skills, and attitudes of participants with regard to astronomy and citizen science. Participants in the study included six students who participated in summer research experiences and more than 100 volunteers who participated in training and eclipse-day data collection and upload.

Citizen CATE was an ideal project for citizen involvement. Gommerman and Monroe (2012) note that the projects most suited to citizen-scientist participation are those where:

- Data collection is labor intensive,
- Data are collected from field situations,
- Quantitative measurements or observations are needed,
- Protocols are well designed and easy to learn and execute,
- Spatial or temporal extents are broad,
- Internet-accessible data submission and results acquisition are possible,
- Guide materials or professional assistance are available, and
- Large data sets are needed.

Observation of the solar corona during the Great American Eclipse fit all of these criteria. By creating a diverse network of volunteers at 68 sites across the path of totality, CATE allowed project investigators to capture solar coronal images on a scale never before attempted. Volunteers included teams of high school and university students, teachers, amateur astronomers, professional astronomers, and university professors. The project, which was carried out over the course of two years, involved an intensive amount of planning and training, coordinated by the project principal investigator with the help of undergraduate students, state coordinators, and co-principal investigators. In the end, the project directly engaged more than 200 volunteers and reached thousands more members of the public who were present at CATE sites or who learned about the project through news and social media.

For CATE undergraduates who participated in summer research experiences and who provided training and support to teams of volunteers prior to and during the eclipse, the project provided many opportunities and benefits. Students saw growth in their communication skills through opportunities to write papers for publication and to prepare and present talks and posters at scientific meetings. Students also grew in their abilities to communicate science effectively to the members of the public. Participation in CATE supported students in thinking and feeling like scientists and gave them an increased understanding of how research is conducted. University mentors and the project principal investigator saw students grow in their ability to problem solve and work through challenges through significant hands-on experiences in taking an experiment from its beginning to the end of data collection. CATE also helped students to solidify career plans, whether those plans included the intent to continue in astronomy or to pursue other areas of science in undergraduate or graduate programs.

For Citizen CATE volunteers, the project offered a highly satisfying way to participate in a significant, large-scale scientific endeavor. Volunteers indicated significant growth in their knowledge of how eclipses happen, characteristics of the solar corona and how scientists study it, NASA studies of the Sun, and how to use and operate equipment to study the Sun. Volunteers also noted significant growth in their skills in conducting education and public outreach with visitors to their sites. Volunteers overwhelmingly agreed that CATE helped them to make connections to others with an interest in astronomy and inspired them to share their experiences. The majority indicated that the project sparked their interest in citizen science. Volunteers felt great pride and satisfaction in viewing the beauty of the solar eclipse while making contributions to the field of solar science.

Citizen CATE worked well with respect to recruiting, training, and mobilizing a large network of volunteers across the country. Through the use of a hierarchy of contacts from the project investigators, to the undergraduate students and state coordinators, to the volunteer teams, the project prepared citizen scientists to take on specific roles on eclipse day and trained them to image the corona. Volunteers felt well prepared to safely observe the eclipse, image the corona, and upload their data after totality. Data analysis, including processing the images and studying the features of the solar corona they captured, is ongoing; preliminary examination suggests the images will reveal new knowledge about our Sun and the solar corona.

Project challenges had mainly to do with securing funding for equipment and the compressed timeframe of the project. Due to initial funding shortfalls that were subsequently rectified through National Science Foundation funding, some sites did not have equipment at the in-person trainings, which limited participants' ability to work through the processes with supervision and support. Project investigators also noted varied levels of commitment among teams to practicing before the eclipse.

In an effort to sustain the impacts of CATE, the project equipment was donated to the observation teams in the hope that they would continue to use it for scientific and educational purposes. Having the telescopes and laptops has allowed several of the high school–based teams to start astronomy clubs for their students. Many teams have already begun to use the telescopes to conduct public stargazing events, solar viewing parties and outreach to classrooms in their areas. Allowing the sites to keep the CATE equipment ensures that the impacts of the project go beyond the single day of the eclipse to provide public benefit for years to come. In all, the Citizen CATE project evidenced exemplary characteristics of a successful citizen-science effort.

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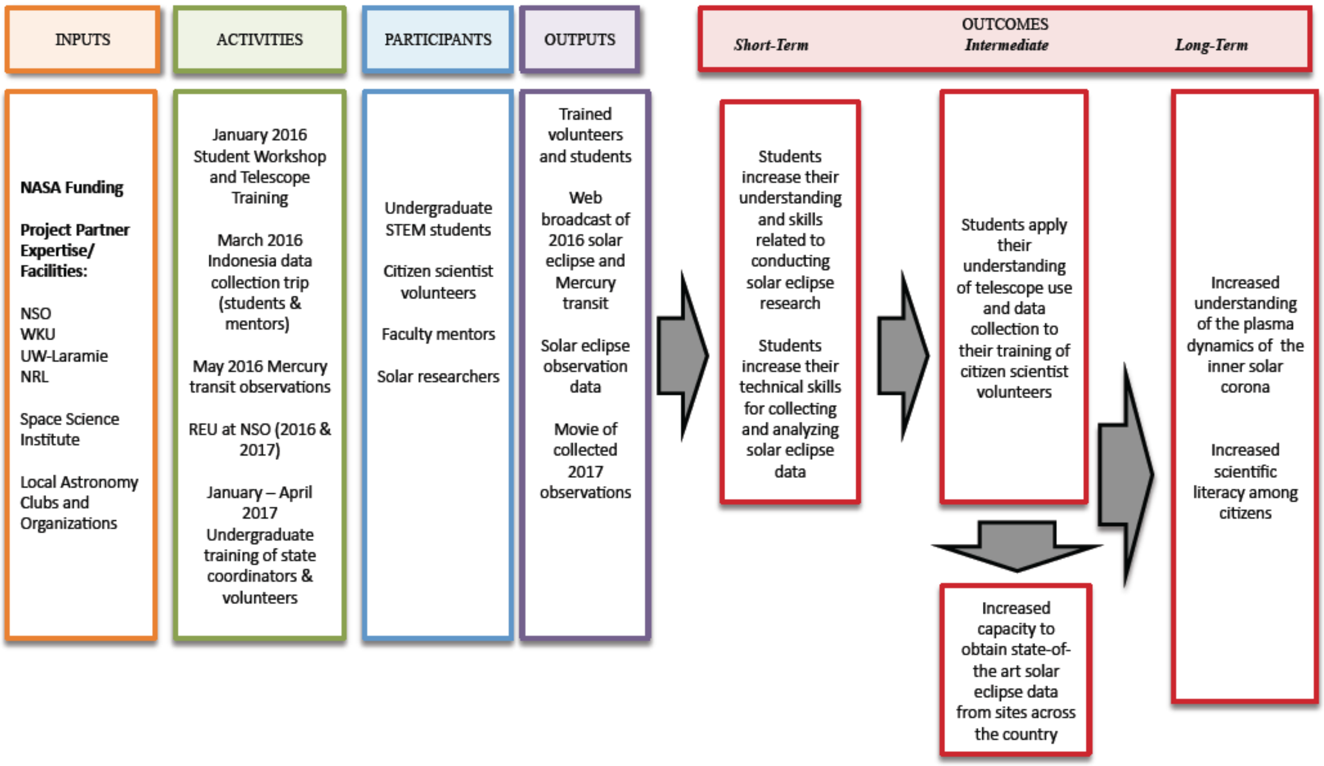
Appendix A: CATE Logic Model



Appendix B: CATE Evaluation Matrix

Evaluation Questions	Formative Evaluation Data Sources & Timeline	Metrics
How well did the Citizen CATE project prepare undergraduate students to collect solar eclipse data? How can training be improved to better meet student needs?	Observations at summer REU (Years 1 & 2); student interviews (Years 1 & 2); skills assessments (Years 1 & 2)	Students feel prepared to collect data. Students exhibit knowledge and skills needed for data collection.
How well did the project prepare undergraduate students to train other students and citizen volunteers for data collection?	Student interviews (Years 1 & 2); Observations and interviews during state trainings (Year 2); State Coordinator Survey (Year 2); State coordinator assessments of trainings (Year 2)	Students successfully train others in data collection. Citizen scientists are prepared for data collection.
How well did state trainings prepare citizen scientists for participation in data collection activities?	Citizen Scientist Training Feedback Survey (Year 2); Citizen Scientist Post-Eclipse Survey (Year 2)	Citizen scientists feel prepared for data collection. Citizen scientists apply the knowledge gained in trainings on eclipse day.

Evaluation Questions	Summative Evaluation Data Sources & Timeline	Metrics
Did participation in the Citizen CATE project increase undergraduate student knowledge and skills related to data collection around solar eclipses? Did students gain an understanding of research processes?	Retrospective Student Pretest (Years 1 & 2); Student interviews (end of project); Mentor interviews (Year 2); Technical skills assessments (Years 1 & 2)	Students perceive an increase in knowledge and skills from participating. Mentors provide evidence of student gains in knowledge and skills.
Did participation in Citizen CATE trainings increase citizen scientists' interest and engagement in astronomy?	Observation of state trainings (Year 2); Citizen Scientist Post-Eclipse Survey (Year 2);	Citizen scientists show increased interest and engagement with astronomy and eclipse data collection.

Appendix C: CATE Evaluation Measures

Evaluators used a variety of evaluation measures to understand impacts of participating in CATE on students and volunteer participants.

Student Measures

Student measures included surveys, interviews, and observations.

Perception Surveys

Participating undergraduate students, including those trained by the four undergraduates from the lead institutions, completed surveys after key events and research opportunities throughout the program. Surveys included a mix of Likert-scale and open-ended responses to understand how students perceived their learning after key events and identify where additional support from the project team was needed, what worked well, and where students were experiencing challenges.

Surveys provided feedback and perceptions of students' learning after the following events:

- Program kick-off and telescope training meeting
- Indonesia travel and data collection trip
- 10-week research experience in 2016
- Training of citizen scientists
- August 2017 eclipse data collection
- Year-end (1 & 2)

Student Interviews

Magnolia evaluators conducted interviews with participating students at three points during project implementation. Interviews addressed evaluation questions related to students' learning and preparedness to conduct training with citizen scientists and the impacts of participation on knowledge and skills related to data collection and analysis of solar eclipse observations. Interview protocols examining project impacts were aligned to research on potential benefits of undergraduate research experiences, including impacts on career decisions, content learning gains, gains in research skills, increased abilities in "thinking like a scientist," enhanced preparation for future studies, and personal gains (Lopatto, 2007; Russell, Hancock & McCullough, 2007; Seymour, Hunter, Laursen, & Deantoni, 2004). Evaluators conducted interviews with students after the March 2017 Indonesia trip and during the REU site visits. Six students participated in interviews during the 2016 REU, and three participated during the 2017 REU.

Student Retrospective Pretest

Evaluators administered a retrospective pretest at the end of Years 1 and 2. Using a combination of Likert-scale and open-ended items, the retrospective pretest asked students to report their level of understanding before and after CATE with respect to data collection and image processing, targeted science content, and the research process. Students also responded to questions about their skills in presentating research findings and in education and public outreach and about their attitudes toward STEM careers. The use of the retrospective pretest avoided the response-shift bias that occurs when a participants' frame of reference changes during an intervention in a traditional pretest/posttest design. This response-shift bias can result because participants have misconceptions about concepts prior to an intervention, or "don't know what they don't know" when starting a program, leading to high self-ratings on knowledge and skills prior to the intervention (Lamb, 2005; Pratt, McGuigan, & Katzev, 2000).

REU Site Visits

Evaluators conducted site visits to the National Solar Observatory in Tucson during the ten-week research experiences in Years 1 and 2. Observations and interviews examined how the research experience was implemented and explored student perceptions of their learning and attitudes.

Mentor Interviews

At the end of the project, evaluators interviewed faculty mentors from the University of Wyoming, South Carolina State University, Southern Illinois University, and Western Kentucky University. Mentors provided feedback on the impacts of participation on the students they mentored with respect to professional growth and to their education and careers. Mentors, who are also co-principal investigators on the project, also offered feedback on the overall CATE project.

Citizen-Scientist Volunteer Measures

Citizen-scientist volunteer measures included surveys, training observations, and eclipse-day observations.

State Coordinators Survey

State coordinators responded to a survey about their experiences working with the undergraduate students in the program and about their training experiences. Coordinators also provided feedback on their need for support between the training and the eclipse. The survey contained a mix of Likert-scale, fixed-response, and open-ended items. The online survey was provided to volunteers via email.

Citizen-Scientist Training Observations

Evaluators attended two citizen-scientist trainings during April and May 2017. Feedback from the January training observations informed modifications to subsequent trainings.

Training Feedback Survey

Volunteers completed a survey immediately after attending CATE training sessions. The survey contained a mix of Likert-scale and open-ended responses. Participants rated their knowledge and skills before and after training and rated the quality and utility of the training in preparing them for eclipse day. They also noted areas where they needed additional support prior to eclipse day.

Eclipse Day Observations

Evaluators observed CATE teams at two sites on the day of the eclipse. Evaluators interviewed CATE teams after the eclipse to understand what worked well and where they had challenges.

Citizen Scientist Post-Eclipse Survey

Evaluators surveyed volunteers immediately after the eclipse on August 21. The post-eclipse survey contained a mix of Likert-scale and open-ended questions. The survey asked about impacts on citizen scientists identified in the literature (e.g., Gommerman & Monroe, 2012), including increased knowledge and understanding of scientific processes, increased understanding of scientific phenomena, and increased awareness of the field of study. Participants retrospectively rated their knowledge and skills prior to and after participation in CATE. The survey also included items related to the project's impacts on attitudes, interest, and engagement in astronomy. Across all sites, 103 volunteers completed the post-eclipse survey.

Outreach Tracking

Evaluators tracked outreach events about CATE at several points before and after the eclipse. State coordinators provided spreadsheets with dates, brief description of events and the number of adults and youth reached through the event.

Appendix D: Study Timeline

STUDY ACTIVITY	Spring 2016	Summer 2016	Fall 2016	Spring 2017	Summer 2017	Fall 2017
Indonesia student eclipse survey	◆					
Summer REU survey		◆			◆	
REU site visits		◆			◆	
Student interviews		◆			◆	
Student retrospective survey			◆			◆
Mentor interviews						◆
State coordinator survey				◆		
Volunteer training feedback surveys				◆		
Training observations				◆		
Eclipse observation					◆	
Outreach data collection			◆	◆	◆	◆
Final reporting						◆

Appendix E: Citizen CATE Volunteer Demographics

Evaluators collected demographic data from volunteers through the post-eclipse survey. These included gender, age, ethnicity, state of residence, primary occupation, level of experience with astronomy, and affiliations.

Table E-1. Respondents' Age (n=103)

	n	%
14–17	18	17.5%
18–24	9	8.7%
25–34	8	7.8%
35–44	18	17.5%
45–54	17	16.5%
55–64	23	22.3%
65 or older	10	9.7%

Table E-2. Respondents' Gender (n=101)

	n	%
Female	30	30%
Male	67	66%
Prefer not to answer	4	4%

Table E-3. Respondents' Primary Ethnicity (n=101)

	n	%
Non-Hispanic/Latino	85	84.2%
Hispanic/Latino	3	3.0%
Prefer not to answer	13	12.9%

Table E-4. Respondents' Race (n=102)

	n	%
White	88	86.3%
Native Hawaiian/Pacific Islander	0	0.0%
Black/African American	3	2.9%
Asian	0	0.0%
American Indian/Alaskan Native	1	1.0%
Two or more races	4	3.9%
Prefer not to answer	6	5.9%

Table E-5. Respondents' Highest Degree Earned (n=102)

	n	%
Currently in high school	18	17.6%
High school diploma or GED	11	10.8%
Bachelor's degree	17	16.7%
Master's degree	26	25.5%
Doctoral degree	25	24.5%
Professional degree (MD, JD)	3	2.9%
Prefer not to answer	2	2.0%

Table E-6. Respondents' Primary Occupation (n=101)

	n	%
Student: High school	18	17.8%
Student: Undergraduate	7	6.9%
Student: Graduate	3	3.0%
Teacher: Elementary	1	1.0%
Teacher: Secondary	20	19.8%
Informal educator	5	5.0%
Scientist or engineer	29	28.7%
Other professional (not teacher, scientist, or engineer)	10	9.9%
Homemaker	0	0.0%
Retired	8	7.9%

Table E-7. Respondents' Level of Experience with Astronomy (n=102)

	n	%
I have little to no previous experience with astronomy.	21	20.6%
I am an amateur astronomer.	49	48.0%
I am an astronomy student.	11	10.8%
I am a university professor who teaches astronomy.	9	8.8%
I am a professional astronomer.	12	11.8%

Table E-8. Respondents' Affiliations (Check all that apply) (n=102)

	n	%
Astronomy club member	48	47.1%
Volunteer with observatory or planetarium	17	16.7%
Staff member with observatory or planetarium	17	16.7%
Astronomy education outreach provider (K–12)	24	23.5%
K–12 school teacher or administrator	19	18.6%
University faculty	22	21.6%
Member of professional astronomy association	21	20.6%

Appendix F: CATE Partners

UNIVERSITIES

- Boise State University, ID
- Montana State University, MT
- Brigham Young University—Idaho, ID
- University of Wyoming, WY
- Chadron State College, NE
- University of Nebraska Kearney, NE
- Benedictine College, KS
- University Central Missouri, MO
- University of Missouri, MO
- Drury University, MO
- Jefferson College, MO
- Southeast Missouri State University, MO
- Southern Illinois University, Carbondale, IL
- Western Kentucky University, KY
- Morehead State University, KY
- Tennessee Tech University, TN
- Tri-County Community College, NC
- Southwest Community College, NC
- Austin Peay State University
- Radford University, VA
- Clemson University, SC
- Lander University, SC
- Coker College, SC
- South Carolina State University, SC
- Orangeburg-Calhoun Tech. Univ., SC
- Westminster College, UT
- University of Michigan, MI

HIGH SCHOOLS

- Mitchell High School, OR
- Dayville School, OR
- Grant City Schools, OR
- Weiser High School, ID
- Bozeman High School, MT
- Teton High School, ID
- Harlem High School, MT
- Teton School District, WY
- Dubois High School, WY
- Arapahoe School District, CO
- Lander High School, WY
- Laramie High School, WY
- Pathways Academy HS, WY
- Goshen HS, WY
- Beatrice High School, NE
- Cienega High School, AZ
- Hiawatha High School, KS
- Unity Point Schools, IL
- Gallatin County Schools, IL
- Christian County Schools, KY
- Spring City High School, TN
- Sequoyah High School, TN

INFORMAL SCI-ED

- Boyce Research Foundation, CA
- National Space Science & Technology Institute, CO
- American Museum of Natural History, NY
- The Exploratorium, CA
- Pawnee City Public Library, NE
- Astronomical Society of Kansas City, MO
- Amateur Astronomy Association of NY, NY
- Amateur Telescope Makers of Boston, MA

NATIONAL LABS

- National Radio Astronomy Observatory
- NASA/MSFC
- LSST/NOAO
- National Solar Observatory

Appendix G: Undergraduate Student Survey Responses

Table G-1. Students' ratings of their skills before, during, and after CATE (n=5–6).

	Before			Fall 2016			Fall 2017		
	N	Mean	SD	N	Mean	SD	N	Mean	SD
Using telescopes and observational equipment	6	2.67	1.63	6	4.17	0.75	5	4.20	0.84
Collecting solar eclipse data	6	1.67	0.82	6	4.33	0.82	5	4.80	0.45
Processing and analyzing solar eclipse data	6	1.33	0.82	6	4.50	0.55	5	4.60	0.55
Interpreting solar eclipse data	6	1.33	0.82	6	4.00	0.89	5	4.20	0.84
NASA heliospheric missions	6	1.67	0.82	6	2.83	1.17	5	3.20	0.84
Digital imaging for astronomy	6	2.33	1.51	6	3.17	0.75	5	4.00	0.71
Characteristics of solar corona	6	2.33	0.82	6	4.17	0.75	5	4.20	0.84
General astronomy knowledge	6	3.33	1.51	6	3.83	0.75	5	3.80	0.84
Integrating theory and practice in science	6	2.67	1.21	6	3.33	0.82	5	4.20	0.45

Table G-2. Students' ratings of their research abilities before, during, and after CATE (n=5–6).

	Before			Fall 2016			Fall 2017		
	N	Mean	SD	N	Mean	SD	N	Mean	SD
Collecting data to answer a scientific question	6	3.33	1.03	6	4.17	0.75	5	4.00	1.00
Analyzing data to answer a scientific question	6	3.67	0.52	6	4.17	0.75	5	4.00	1.00
Collaborating with other scientists to conduct scientific research	6	3.50	0.84	6	4.50	0.55	5	4.20	0.45
Problem solving during scientific experiments	6	3.67	0.82	6	4.17	0.75	5	4.60	0.55
Reading and understanding primary literature on a scientific topic	6	3.33	0.52	6	3.67	0.52	5	3.80	0.84
Orally communicating the results of scientific experiments	6	3.33	0.52	6	3.83	0.41	5	4.40	0.55
Preparing a poster to present the results of scientific experiments	6	2.67	1.03	6	3.17	0.98	5	4.60	0.55
Writing research papers to communicate the results of scientific experiments	6	2.33	0.82	6	3.00	0.63	5	4.00	1.00
Teaching others to collect and analyze scientific data	6	2.83	1.17	6	4.00	1.10	5	4.80	0.45

Table G-3. Students' ratings of their knowledge and skills (n=5–6).

	Fall 2016			Fall 2017		
	N	Mean	SD	N	Mean	SD
I have a greater understanding of how scientists work on real-world problems.	6	4.50	0.55	5	4.60	0.55
I have a greater understanding of how scientists think.	6	4.17	0.41	5	4.40	0.55

	Fall 2016			Fall 2017		
	N	Mean	SD	N	Mean	SD
I have a greater interest in astronomy.	6	3.83	1.17	5	4.20	1.30
I have a better understanding of how scientific knowledge is built.	6	3.67	0.52	5	4.40	0.55
I feel more confident about speaking with my professors or other scientists about their research.	6	4.00	1.10	5	4.60	0.55
I am more confident collaborating with others on a research team.	6	4.50	0.55	5	4.80	0.45
I am more confident in my ability to do research.	6	4.50	0.55	5	4.60	0.55
I have made connections to others in my field.	6	4.50	0.55	5	4.80	0.45
I feel I have made significant contributions to furthering knowledge in the field.	6	3.83	0.98	5	4.40	0.55
I have gained skills in public education.	6	4.17	0.41	5	4.20	0.45
I am more confident in my leadership ability.	6	3.83	1.17	5	4.60	0.55
I have a better understanding of how science is effectively communicated to non-scientists.	6	4.33	0.82	5	4.60	0.55
I am better able to master complex scientific concepts related to solar astronomy.	6	4.17	0.41	5	4.40	0.89
I feel more like a scientist than I did before.	6	3.83	1.17	5	4.60	0.55
I feel ready to advance as a researcher.	6	4.17	0.98	5	4.60	0.55
I have a better understanding of what graduate school might be like.	6	3.50	1.22	5	3.80	0.84

Appendix H: Post-Eclipse Volunteer Survey Responses

Table H-1. Volunteers' ratings of knowledge and skills before and after CATE

	Before			After			Paired t-test results			Gain Scores	
	N	Mean	SD	N	Mean	SD	Mean	t	Sig.	Mean	SD
How solar eclipses happen	103	5.30	1.63	103	6.41	0.89	1.11	–8.15	0.00	1.11	1.38
How solar scientists gather data to address scientific questions about the sun	102	4.05	1.85	102	5.94	0.87	1.89	–12.51	0.00	1.89	1.53
How scientists observe the solar corona	101	3.92	1.90	101	6.08	0.83	2.16	–12.84	0.00	2.16	1.69
Characteristics of the solar corona	103	3.97	1.87	103	5.79	1.04	1.82	–11.55	0.00	1.82	1.60
Digital imaging of solar phenomena	103	3.62	1.99	103	5.78	1.02	2.16	–12.98	0.00	2.16	1.68
NASA heliospheric missions	103	3.19	1.91	103	4.44	1.61	1.24	–9.98	0.00	1.24	1.26
Safe solar viewing	103	5.14	1.75	103	6.60	0.60	1.47	–9.02	0.00	1.47	1.65
Use of telescopes	103	4.60	1.99	103	6.10	0.89	1.50	–10.63	0.00	1.50	1.43
Use of digital imaging software	102	3.81	2.04	102	5.45	1.19	1.64	–10.65	0.00	1.64	1.55
Conducting education and public outreach	103	4.86	1.65	103	5.75	1.09	0.88	–7.92	0.00	0.88	1.13

Table H-2. Volunteers' level of agreement with statements about participating

	Strongly Disagree		Disagree		Neither Agree nor Disagree		Agree		Strongly Agree		
	n	%	N	%	n	%	n	%	n	%	Mean
I have a greater interest in astronomy.	0	0%	0	0%	14	14%	36	35%	53	51%	4.38
I have made connections to others with an interest in astronomy.	0	0%	1	1%	2	2%	39	38%	61	59%	4.55
I feel inspired to learn more about solar phenomena.	0	0%	0	0%	7	7%	39	38%	57	55%	4.49
I feel I have made significant contributions to furthering knowledge in the field of solar science.	0	0%	1	1%	4	4%	39	38%	59	57%	4.51
I gained a greater appreciation for the work that solar scientists are doing.	0	0%	0	0%	6	6%	28	27%	69	67%	4.61
I was inspired to continue in other astronomy citizen science programs.	1	1%	2	2%	10	10%	35	34%	55	53%	4.37
I am inspired to share my experience with others.	0	0%	0	0%	6	6%	27	26%	70	68%	4.62

Table H-3. Volunteers' ratings of aspects of eclipse day

	Poor		Fair		Average		Good		Excellent				
	n	%	n	%	n	%	n	%	n	%	N	Mean	SD
Interactions among CATE team members (*n*=102)	0	0%	1	1%	1	1%	21	21%	79	77%	102	4.75	0.52
Operation of CATE equipment (laptop, camera, etc.)	1	1%	0	0%	2	2%	29	28%	70	69%	102	4.64	0.63
Interaction with the public	1	1%	1	1%	9	9%	22	22%	68	67%	101	4.53	0.78
Interaction with the media	4	4%	1	1%	9	10%	21	23%	58	62%	93	4.38	1.01
Uploading/sharing data after the event (*n*=100)	1	1%	3	3%	7	7%	26	26%	63	63%	100	4.47	0.83

Table H-4. Volunteers' roles on eclipse day (n=103)

	n	%
Operating the telescope and collecting data	86	83%
Education and public outreach on site	62	60%
Uploading data after the eclipse	59	57%
Communicating/interacting with media personnel/reporters	53	51%
Communicating with the public via social media (Facebook, Twitter, Instagram, etc.)	22	21%
Other	19	18%