ExMASS: Implementation and evaluation of an authentic, inquiry-based research experience for secondary students

Andrew J. Shaner\(^1,\)*, Sanlyn Buxner\(^2\) and David A. Kring\(^1\)

\(^1\)Lunar and Planetary Institute, USRA, Houston, TX, USA; \(^2\)Planetary Science Institute, Tucson, AZ, USA

*shaner@lpi.usra.edu

Abstract

The Exploration of the Moon and Asteroids by Secondary Students (ExMASS) program provides pre-college students the opportunity to conduct authentic, inquiry-based research with assistance from their teacher and a professional scientist. This paper presents an overview of the ExMASS program and results of ongoing program evaluation. The goals of the ExMASS program are to 1) provide an opportunity for secondary students to engage in multiple practices of science, 2) foster positive student attitudes toward science, and 3) enhance student lunar and asteroid science content knowledge. Evaluation data affirms the program is meeting these stated goals. In particular, assessment of student attitudes toward science show statistically significant increases in positive attitudes post program. The validity of the survey has been shown previously through factor analysis (Shaner et al., 2018). This paper includes a discussion of the continued assessment of student attitudes toward science (n = 125 students), showing statistically significant changes in both personal connections to science and the importance of science in society.

Keywords: Secondary students; Authentic research; Inquiry-based research; Attitudes toward science

1 Introduction

The Exploration of the Moon and Asteroids by Secondary Students (ExMASS) is an academic-year-long, lunar/asteroid research program that envelops U.S. secondary (high school) students in multiple processes of science. Working alongside their teachers and scientist advisors, 10 student teams from across the U.S undertake authentic, open-inquiry research projects each year. In its first 10 years, 600 students from 30 states participated in the program (Figure 1). Over 40 planetary scientists participated as student team advisors and/or student research judges. The program is managed by the Lunar and Planetary Institute (LPI) and was originally funded by the NASA Lunar Science Institute (NLSI) as an education and public outreach component to the LPI– and NASA Johnson Space Center (JSC)–led Center for Lunar Science and Exploration (CLSE). Since 2014, ExMASS has been funded by NASA’s Solar System Exploration Research Virtual Institute (SSERVI).

The goals of the ExMASS program are to 1) provide an opportunity for secondary students to engage in multiple practices of science, 2) foster positive student attitudes toward science, and 3) enhance student lunar and asteroid science content knowledge. Using these goals as a framework, ExMASS introduces students to the process of science and critical analysis.
1.1 Defining authentic and inquiry-based research

Within the context of the ExMASS program, authentic student research occurs when they undertake the same processes as professional scientists during an investigation, such as creating questions (Hsu et al., 2010; Chinn and Malhotra, 2002), analyzing data, and presenting findings. Participation in authentic science activities improves learners' perspectives of and involvement with science (AAAS, 1989), promotes understanding of scientific processes (Bencze and Hodson, 1999), and contributes to the development of a science identity (Chapman and Feldman, 2017).

Inquiry-based student research occurs when students pursue a research question/topic that is of interest to them and draw upon their knowledge to ask scientifically oriented questions, collect and analyze evidence, develop explanations, and communicate those explanations with their peers (Furtak et al., 2012) as well as with professional researchers. There are several stages built into ExMASS to address this, including an introduction to lunar and asteroid science (section 2.3) and a research phase (section 2.4) in which students identify a suitable research problem, investigate the problem, and prepare results for presentation.

1.2 Student ownership of the research process

The ExMASS program encourages students to do the “heavy lifting” when it comes to teams identifying a research question or addressing a problem, designing a research plan, and completing other tasks. Teachers and advisors are encouraged to let students independently grapple with the process, but also to step in and guide the students when necessary. Placing students in a position where they form their own research questions and research plans makes their experience more authentic than if they are simply told what to do.

Naturally, one might wonder to what extent student teams “own” their research. To what extent are students responsible for independently completing the various phases of their research? An answer to this question can be partially answered by data collected from program exit surveys (section 3.4).

1.3 Attitudes toward science

The number of U.S. students choosing to pursue STEM careers has been declining and attitude is key to choices individuals make (Hillman et al., 2016). Research has shown that increasing positive attitudes toward science (STEM) increases student interest in pursuing such careers, enrollment in science and mathematics courses, or participation in STEM activities (Ebenezer and Zoller, 1993). As will be presented later, evaluation of ExMASS demonstrates the program’s positive impact on participating students’ attitudes toward science.
2 Implementing ExMASS

2.1 Recruiting teams and advisors

Students are not directly recruited to participate in ExMASS. The program reaches out to high school teachers across the U.S. to apply for the program. The application is completed online via SurveyMonkey®. Teachers are recruited through multiple educator listservs including lists curated by the LPI and other planetary research institutions. If selected, teachers invite students from within their school to participate. Participating teachers from previous years are allowed to apply for a second year, but the program has placed a two-year cap on participation. In addition, if teachers return for a second year, they must select a new group of students to participate. These rules allow more schools and students to participate.

Like teachers, advisors (planetary scientists, particularly lunar scientists) are recruited to participate through various listservs and newsletters used by planetary scientists. Past advisors often return to work with new teams of students. As noted previously, 10 teams are selected to participate in ExMASS each year. This upper limit was set early in the program due in part to the program’s experience in fielding the necessary pool of advisors. It should also be noted that advisors are not compensated for their time. Consequently, most, if not all, advisors participate due to a sense of responsibility for training the next generation.

Once teachers are selected and advisors have been confirmed, advisors are paired with teachers (student teams) based on geographic proximity. However, advisors are rarely located within reasonable travel distance to their teams. As a result, communications between advisors and students primarily take place via videoconferencing platforms such as Zoom or via email. Virtual communication between student teams and advisors has been the norm from the inception of the program.

2.2 Teacher and advisor roles

Teachers and advisors participating in ExMASS are the program’s strongest and most important assets. The ability of these two roles to work in concert and individually is paramount to student success. Advisors provide content knowledge and research process expertise. They have little to no experience working with secondary students. Conversely, teachers may or may not have much content knowledge and/or research experience. However, teachers know their students. Teachers are aware of resources readily available to their students, as well as those that are not. Most importantly, teachers work closely with students and know how to help them manage their time.

There would appear to be a clear delineation of teacher and advisor roles simply based on the backgrounds and experiences of the two. However, conversations with teachers and advisors early in the program made it clear that it was necessary to explicitly define advisor and teacher roles, within the context of ExMASS, for guiding student teams in their research. Figure 2 illustrates where these roles diverge and intersect. Table 1 further elaborates on each role. Both the figure and table were developed by teachers and advisors who participated in ExMASS. Both are reviewed at the end of each program year by advisors and teachers and updated if necessary.

2.3 Laying a foundation of content knowledge

Based on learning expectations outlined within the Next Generation Science Standards (NGSS Lead States, 2013b), it is fair to assume that, apart from lunar phases and tides, most secondary students are likely to have little knowledge of lunar science concepts and even less knowledge of asteroid science. However, students may have obtained some knowledge of the Moon or asteroids from other sources including museums and social media. Hence, students are likely to enter the ExMASS program with fundamental knowledge gaps and/or misconceptions that can inhibit their ability to conduct lunar or asteroid research.

During the first six weeks of each program year, students complete two activities — “Moon 101” and “Asteroid 101” — consisting of readings on various lunar and asteroid science topics (e.g., impact cratering, volcanism, tectonism, meteorites) to fill likely knowledge gaps and/or address misconceptions. Upon completion of the readings, students present geologic characterizations of lunar and asteroid surface features visible in pre-selected images. Student teams are prompted to address questions including, but not limited to: What geologic features are present? How did they form? How old are they relative to each other, and how do you know? Students present these characterizations to the ExMASS program manager via Zoom. Pre- and post-101 evaluation data (section 3.3) reveal these activities increase students’ content knowledge of lunar and asteroid science.

2.4 Research Phase

After completing the “101” activities students dive into their research. With assistance from their teacher and advisor, students identify a lunar or asteroid research topic to investigate and create a research plan. Research topics vary but most teams decide on a lunar-related topic (Fig. 3). Following approximately six months of research, teams write abstracts and create conference-style posters to communicate their research. These posters are scored by a panel of judges from the planetary science community. The top four scoring teams present their research via webinar to the panel, and from these presentations, one team is selected and funded to present in person during NASA’s annual Exploration Science Forum (ESF, 2014–2021 program years) and meet with scientists. Prior to the ESF, selected student teams presented during the annual NASA Lunar Science Forum (2009–2012 program years). Table 2 lists the title of each program year’s winning project. Although one team is funded to return to work with new teams of students. As noted previously, 10 teams are selected to participate in ExMASS each year. This upper limit was set early in the program due in part to the program’s experience in fielding the necessary pool of advisors. It should also be noted that advisors are not compensated for their time. Consequently, most, if not all, advisors participate due to a sense of responsibility for training the next generation.

Once teachers are selected and advisors have been confirmed, advisors are paired with teachers (student teams) based on geographic proximity. However, advisors are rarely located within reasonable travel distance to their teams. As a result, communications between advisors and students primarily take place via videoconferencing platforms such as Zoom or via email. Virtual communication between student teams and advisors has been the norm from the inception of the program.

2.2 Teacher and advisor roles

Teachers and advisors participating in ExMASS are the program’s strongest and most important assets. The ability of these two roles to work in concert and individually is paramount to student success. Advisors provide content knowledge and research process expertise. They have little to no experience working with secondary students. Conversely, teachers may or may not have much content knowledge and/or research experience. However, teachers know their students. Teachers are aware of resources readily available to their students, as well as those that are not. Most importantly, teachers work closely with students and know how to help them manage their time.

There would appear to be a clear delineation of teacher and advisor roles simply based on the backgrounds and experiences of the two. However, conversations with teachers and advisors early in the program made it clear that it was necessary to explicitly define advisor and teacher roles, within the context of ExMASS, for guiding student teams in their research. Figure 2 illustrates where these roles diverge and intersect. Table 1 further elaborates on each role. Both the figure and table were developed by teachers and advisors who participated in ExMASS. Both are reviewed at the end of each program year by advisors and teachers and updated if necessary.

2.3 Laying a foundation of content knowledge

Based on learning expectations outlined within the Next Generation Science Standards (NGSS Lead States, 2013b), it is fair to assume that, apart from lunar phases and tides, most secondary students are likely to have little knowledge of lunar science concepts and even less knowledge of asteroid science. However, students may have obtained some knowledge of the Moon or asteroids from other sources including museums and social media. Hence, students are likely to enter the ExMASS program with fundamental knowledge gaps and/or misconceptions that can inhibit their ability to conduct lunar or asteroid research.

During the first six weeks of each program year, students complete two activities — “Moon 101” and “Asteroid 101” — consisting of readings on various lunar and asteroid science topics (e.g., impact cratering, volcanism, tectonism, meteorites) to fill likely knowledge gaps and/or address misconceptions. Upon completion of the readings, students present geologic characterizations of lunar and asteroid surface features visible in pre-selected images. Student teams are prompted to address questions including, but not limited to: What geologic features are present? How did they form? How old are they relative to each other, and how do you know? Students present these characterizations to the ExMASS program manager via Zoom. Pre- and post-101 evaluation data (section 3.3) reveal these activities increase students’ content knowledge of lunar and asteroid science.

2.4 Research Phase

After completing the “101” activities students dive into their research. With assistance from their teacher and advisor, students identify a lunar or asteroid research topic to investigate and create a research plan. Research topics vary but most teams decide on a lunar-related topic (Fig. 3). Following approximately six months of research, teams write abstracts and create conference-style posters to communicate their research. These posters are scored by a panel of judges from the planetary science community. The top four scoring teams present their research via webinar to the panel, and from these presentations, one team is selected and funded to present in person during NASA’s annual Exploration Science Forum (ESF, 2014–2021 program years) and meet with scientists. Prior to the ESF, selected student teams presented during the annual NASA Lunar Science Forum (2009–2012 program years). Table 2 lists the title of each program year’s winning project. Although one team is funded to
participate in the ESF, all four “finalist” teams’ posters are displayed at the meeting alongside professional research posters.

3 Impact evaluation: Investigating the ExMASS program’s impact on students

The goals of the ExMASS program are to 1) provide an opportunity for secondary students to engage in multiple practices of science, 2) foster positive student attitudes toward science, and 3) enhance student lunar and asteroid science content knowledge. Evaluation instruments (surveys) have been used to collect data over the course of the program to determine the extent to which the program is meeting these stated goals. All surveys are completed online via Survey Monkey®. Results and findings of the evaluation effort are reported here. It is important to note that the requisite Internal Review Board (IRB) exemption was not obtained for data collected during the 2009–2012 program years. IRB exemption was obtained for the 2014 program and all subsequent years. Consequently, the data presented here is from the 2014 and later programs.

3.1 Goal 1: Participate in multiple processes of science

A survey was created to determine how many, and which, science processes students engage in while participating in ExMASS. The instrument is a multiple-response survey in which students select indicators of the process(es) of science they engaged in while conducting their research. The stem of each survey item prompts respondents to consider their engagement in a process of science. Respondents select from a list following the stem of possible indicators of engagement in each process. The processes and indicators in the survey are borrowed from the practice of science standards and indicators found in the Next Generation Science Standards (NGSS Lead States, 2013a). Table 3 summarizes the results to date of this survey. The data indicates that most students recognize their participation in at least one indicator under each practice of science. When asked in the exit survey about the value of the program to them, students commonly identify engaging in practices of science as being valuable:

3.2 Goal 2: Foster positive attitudes toward science

Shaner et al. (2018) reported results of validity and reliability tests on a survey specifically designed to measure ExMASS students’ attitudes toward science. This study found the survey both valid and reliable in measuring student attitudes across two factors: 1) personal importance of science and 2) importance of science in society. The study also found statistically significant increases in positive student attitudes toward science when measured pre- and post-ExMASS participation. Data reported in the 2018 study was collected during the 2014, 2015, 2016, and 2017 ExMASS program years. Following the conclusion of the 2021 program, survey data about student attitudes were analyzed again using paired t-tests to determine if the changes in students’ scores were statistically different. This new analysis combined data from the 2020 and 2021 programs and data from the 2018 study. Paired t-tests revealed statistically significant differences in students’ attitudes before and after participation in ExMASS for both factors. For students’ attitudes about their personal connection to science, their reflected pre-ExMASS scores (mean = 3.48, s.d. = 0.48) were significantly lower than their post-ExMASS scores (mean = 3.55, s.d. = 0.43), t(125) = 3.21, p < 0.001. The effect size for these means was small (d = 0.29). For students’ attitudes toward the importance of science in society, their reflected pre-ExMASS scores (mean = 3.35, s.d. = 0.42) were significantly lower than their post-ExMASS scores (mean = 3.47, s.d. = 0.39), t(125) = 5.43, p < 0.001 with a small to medium effect size (d = 0.49). For both factors, this updated statistical analysis shows the ExMASS program’s continuing positive impact on student attitudes toward science. When asked in the student exit survey if they are considering a career in science as a result of their experience in ExMASS, student replies of “Yes”
or “No” are approximately split 50/50. However, they generally elaborate by saying they could see themselves pursuing science as a career (if they weren’t already) and that science is something in which anyone can participate:

(Participating in ExMASS) helped me realize that a career in science would fit me / is attractive and that research opportunities are a priority when considering college options. I not only learned more about space but about science in general and that anyone can do scientific research, not just science majors.

3.3 Goal 3: Enhance lunar and asteroid science content

Students come into the ExMASS program with lunar and asteroid science knowledge gaps. The Moon 101 and Asteroid 101 activities provide a foundation of basic knowledge in lunar and asteroid science that is beneficial to students as they move into the research phase of the program. Students complete both a lunar content (see Appendix) and an asteroid content survey before undertaking the “101s.” Students then complete the same surveys following the Moon and Asteroid 101 experience, but before they begin the research phase. These surveys consist of a mix of multiple choice, multiple response, matching, and open-ended items. Results of the pre- and post-lunar and asteroid content surveys are shown in Tables 4 and 5, respectively. Both tables show the average percentage of students who correctly responded to each survey item, pre- and post-101. In general, the percentage of students scoring better on each item increases in the post-lunar content survey compared to the pre-survey. The low correct response rates for Item 1 in the lunar content survey is likely due to a single word used in response option “C” causing confusion. The asteroid content survey sees vast improvement between pre- and post-scores on most items. Those few items that don’t see as significant an improvement are items addressing complex topics or are items with more than one correct response. In the latter case, students may not trust their own understanding and only select one of the correct responses.

An item in the student exit survey asks them if they think of the Moon or asteroids in a different way than before their participation in ExMASS. Most respond “Yes.” Those who choose to elaborate further say:

I always thought of the Moon as having served its scientific purpose, but now I see a lot of potential in continued research. I know so much more about the moon than I did before that I can’t help but change the way I see it in the night sky. Sometimes a fact or identifier that seems common knowledge to me now (highlands vs mare) slips out when talking with other people, and it’s fun to get to explain all these things to them that I’ve learned.
### Table 2. Titles of student research selected to present in-person during NASA’s Lunar Science Forum/Exploration Science Forum.

<table>
<thead>
<tr>
<th>Program year</th>
<th>Student research title</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009-2010</td>
<td>An Examination of Mare Age Based on Cratering Density</td>
</tr>
<tr>
<td>2010-2011</td>
<td>Using Boulder Diameter-Crater Diameter Ratios to Differentiate Primary from Secondary Craters on the Lunar Surface</td>
</tr>
<tr>
<td>2011-2012</td>
<td>Stratified Ejecta Boulders as Indicators of Layered Plutons on the Lunar Nearside</td>
</tr>
<tr>
<td>2012-2013</td>
<td>A Comparison of the Relative Age of a Selected Area of Mare and Highland Using Crater Frequency and Degradation State</td>
</tr>
<tr>
<td>2015-2016</td>
<td>Basalt Thickness of Mare Tranquilitatis using Two Methods</td>
</tr>
<tr>
<td>2016-2017</td>
<td>Mapping Possible Locations for Lunar Ice Mining Based on Topographic, Economic, and Elemental Data</td>
</tr>
<tr>
<td>2017-2018</td>
<td>Volcanic Contribution of Water at Lunar Silicic Domes</td>
</tr>
<tr>
<td>2020-2021</td>
<td>Evidence for Water on Vesta: Comparing the Geomorphology of Debris Flows in Craters on Earth, Mars, the Moon, and Vesta</td>
</tr>
<tr>
<td>2021-2022</td>
<td>Possible Causes of Hydration of Vesta’s Oppia Crater</td>
</tr>
</tbody>
</table>

### Table 3. Results of the student Process of Science Survey, 2014–2021. Most students identify participating in one or more practices of science.

<table>
<thead>
<tr>
<th>Next Generation Science Standards Practice of Science</th>
<th>Number of Indicators</th>
<th>Percentage utilizing one or more indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asking questions</td>
<td>6</td>
<td>96%</td>
</tr>
<tr>
<td>Developing and using models</td>
<td>6</td>
<td>80%</td>
</tr>
<tr>
<td>Planning and carrying out investigations</td>
<td>6</td>
<td>97%</td>
</tr>
<tr>
<td>Analyzing and interpreting data</td>
<td>6</td>
<td>96%</td>
</tr>
<tr>
<td>Using mathematics and computational thinking</td>
<td>6</td>
<td>83%</td>
</tr>
<tr>
<td>Constructing explanations and designing solutions</td>
<td>5</td>
<td>95%</td>
</tr>
<tr>
<td>Engagement in argument from evidence</td>
<td>6</td>
<td>79%</td>
</tr>
<tr>
<td>Obtaining, evaluating, and communicating information</td>
<td>5</td>
<td>99%</td>
</tr>
</tbody>
</table>

### Table 4. Pre- and post-Moon 101 lunar science content survey results. Item 9, an open-ended item, is not included.

<table>
<thead>
<tr>
<th>Item</th>
<th>Pre-101 correct responses (%)</th>
<th>Post-101 correct responses (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>2a</td>
<td>47</td>
<td>65</td>
</tr>
<tr>
<td>2b</td>
<td>37</td>
<td>66</td>
</tr>
<tr>
<td>2c</td>
<td>49</td>
<td>67</td>
</tr>
<tr>
<td>3</td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>4</td>
<td>45</td>
<td>60</td>
</tr>
<tr>
<td>5</td>
<td>28</td>
<td>46</td>
</tr>
<tr>
<td>6</td>
<td>72</td>
<td>73</td>
</tr>
<tr>
<td>7</td>
<td>87</td>
<td>93</td>
</tr>
<tr>
<td>8</td>
<td>38</td>
<td>38</td>
</tr>
</tbody>
</table>

### Table 5. Pre- and post-Asteroid 101 asteroid science content survey results.

<table>
<thead>
<tr>
<th>Item</th>
<th>Pre-101 correct responses (%)</th>
<th>Post-101 correct responses (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>73</td>
<td>95</td>
</tr>
<tr>
<td>1b</td>
<td>71</td>
<td>91</td>
</tr>
<tr>
<td>1c</td>
<td>71</td>
<td>90</td>
</tr>
<tr>
<td>1d</td>
<td>73</td>
<td>95</td>
</tr>
<tr>
<td>2</td>
<td>75</td>
<td>82</td>
</tr>
<tr>
<td>3a</td>
<td>58</td>
<td>86</td>
</tr>
<tr>
<td>3b</td>
<td>25</td>
<td>37</td>
</tr>
<tr>
<td>3c</td>
<td>23</td>
<td>43</td>
</tr>
<tr>
<td>4</td>
<td>61</td>
<td>67</td>
</tr>
<tr>
<td>5</td>
<td>49</td>
<td>73</td>
</tr>
<tr>
<td>6</td>
<td>33</td>
<td>67</td>
</tr>
<tr>
<td>7</td>
<td>58</td>
<td>87</td>
</tr>
<tr>
<td>8</td>
<td>60</td>
<td>92</td>
</tr>
<tr>
<td>9b</td>
<td>91</td>
<td>100</td>
</tr>
<tr>
<td>9c</td>
<td>21</td>
<td>32</td>
</tr>
<tr>
<td>9d</td>
<td>32</td>
<td>49</td>
</tr>
</tbody>
</table>

### 3.4 Student ownership of the research process

At the end of each program year students, teachers, and advisors complete an exit survey. One item found on each survey asks respondents to rate the extent to which students were responsible for completing various phases of their research. Ratings fall on a Likert-scale — from one (1), indicating the advisor was mostly responsible, to five (5), indicating the students were mostly responsible. The phases of research rated were selection of research topic, development of research question, developing research plan, analyzing and interpreting data, constructing an explanation, determining layout/content for poster, and writing the abstract. Data collected following the 2016, 2017, 2020, and 2021 program years are summarized in Figure 4. The clustered column chart indicates on average the percentage (y-axis) of students (black columns), teachers (yellow columns), and advisors (gray columns), providing a rating of 4 or 5 for each research phase (x-axis).

These data suggest students take strong ownership of their research. With one exception (Writing abstract; advisors), no one group (students, teachers, or advisors) agreed 100% that student teams took full ownership of any phase of the research process. This is not surprising. For most ExMASS participants, this is their first experience conducting student-driven research. This data is positive but limited as it is self-reported. In the future, this data could be complemented with interviews of students, teachers, and advisors to better understand why members of each group chose the ratings they did. Though preliminary, this data also provides a first step to examining the relationships between students, advisors, and/or teachers. Taking a deeper dive, Williams-Duncan and Watson (2022) analyzed email communications between ExMASS teachers, advisors, and students during the 2020-2021 program. Their reported findings outline the positive characteristics of advisor-student relationships as well as best practices for advisor-student relationships.

### 3.5 Other examples of program success

Annual evaluation data show the program consistently meets its stated goals:

- Students utilize multiple processes of science during their investigations
- Positive student attitudes toward science increase significantly due to participation in ExMASS
Data show, based on self-reporting from students, teachers, and advisors, students take a great deal of ownership of the various phases of their ExMASS research experience. In addition to evaluation data, the products of student research and student participation in scientific activities after ExMASS are reflections of the program’s success. Table 6 outlines some of these products and activities.

### 4 ExMASS compared with other authentic research programs

The ExMASS program was created to provide secondary students an opportunity to conduct authentic, open-inquiry research. The program was designed to envelop students in the processes of science, from formulating a question or identifying a problem, to designing and carrying out research, to presenting results to the scientific community. Pairing participating teams with a professional scientist to guide them throughout the process is essential within the ExMASS model of authentic research. The student-defined, open-inquiry nature of the program makes this model stand out. Indeed, similar student research programs that pair students with scientists to perform authentic science research exist (Osborne and Collins, 2000). However, these programs tend to place students in a position where they are assisting in the researcher’s investigation, rather than the researcher supporting student-defined research (Scogin and Stuessy, 2015). Consequently, students are generally not provided an opportunity to engage in multiple science practices, including communicating their research, in a collaborative setting. Despite the Next Generation Science Standards (NGSS Lead States, 2013b) call for developing authentic scientific communities of practice for students (Scogin and Stuessy, 2015), opportunities to do so remain sporadic.

### 5 Conclusion

The ExMASS program was built with the guidance of research literature findings on the impact on students participating in authentic, inquiry-based experiences. This ExMASS model produces positive, cognitive change in pre-college students sought by the education and science communities. The program’s confirmation of research findings, along with the dearth of such
experiences, supports a need for similar programs. Such programs do not need to be limited to planetary science. The ExMASS model can be used to create authentic, inquiry-based student research experiences in any scientific discipline. While it is hopeful students may be inspired to pursue a STEM career with NASA or academia, it is understood that a small subset of program participants will ultimately dedicate themselves to that path. Developing an appreciation for, and remaining excited about, science is a great outcome for most participants. Indeed, learning to distinguish between a priori beliefs, speculation, and evidence-based findings will benefit students throughout their lives, regardless of the occupational path they choose. Likewise, the program can broaden the students’ perspectives, which may make them better community members. All resources provided by the program are available online free of charge. This access provides teachers with a vetted, pre-packaged research program to replicate at little to no cost. The one difficulty teachers may encounter in replicating the program is identifying scientists as potential advisors for students. In such situations, the ExMASS program manager is available to assist in contacting potential advisors. For more information on the ExMASS program, please visit https://www.lpi.usra.edu/exploration/education/hResearch.

6 Acknowledgements

The ExMASS program is funded through cooperative agreement #80NSSC20M0016 with NASA’s Solar System Exploration Research Virtual Institute (SSERVI).

References


Hsu, P.-L., van Eijck, M., and Roth, W.-M. (2010). Students’ representations of scientific practice during a science intern-
7 Appendix: Lunar and Asteroid Content Surveys

7.1 Lunar Content Survey

1) The most accepted, scientific explanation for how the Earth’s Moon formed is known as the Giant Impact Hypothesis (GIH). Which of the following observations support the GIH?

(A) Compared to Earth’s iron core, the Moon has a relatively small iron core.
(B) The volume of the Pacific Ocean is approximately equal to the Moon’s volume.
(C) The chemical compositions of the Earth’s mantle and the Moon’s mantle are similar.
(D) Both A & C.

2) When looking at the Moon without the aid of binoculars or telescopes (with only your eyes), three main geological features stand out: impact craters, the lunar highlands, and the lunar mare. Look at the image below and identify which feature is labelled A, B, and C.

3) Three students are discussing the origin of the lunar highlands. Read each student’s explanation of how the highlands formed and choose the student (and explanation) with whom you most agree.

Nina: When the Moon first formed, it was a ball of hot magma. The rocks making up the lunar highlands solidified near the core of the Moon and floated to the surface as the Moon cooled.

Dale: The Moon was completely molten when it first formed, but the rocks making up the lunar highlands formed at the top of the magma, at the surface, because they were the hottest.

Sarah: Rocks making up the lunar highlands formed at the top because their minerals are less dense which caused them to float to the top of the magma ocean.

4) Three students are discussing the formation of the lunar maria. Read each student’s explanation of how the lunar maria formed and choose the student (and explanation) with whom you most agree.

Kim: Very early in the Moon’s history, large asteroids hit the Moon, making cracks in the surface. Hot, buoyant magma underneath the surface then seeped through the cracks and spread out onto the surface.

Matt: The lunar maria formed at the same time as the highlands. The minerals that make up the lunar maria rocks are the same density as the highlands so they also floated to the top of the molten Moon.

Parker: The lunar maria formed after the lunar highlands and after the large asteroids hit the surface. The magma seeped up through weak places in the crust, including areas where large impacts occurred.

5) With some exceptions, most impact craters are round in shape when they form. Which statement below best explains why impact craters are round?

(A) Most impactors (asteroids, for example) are round and impact craters take the shape of the impactor.
(B) Most impactors are spherical so when an impactor hits a planetary surface, surface material is pushed down and compacted together in the subsurface leaving a spherical cavity.
(C) Impactors bury themselves upon impact with a surface and explode under the surface, throwing out material equally in all directions.
(D) Impactors explode just before hitting a surface and a spherical blast pushes material down and out onto the surface equally in all directions.

6) Some scientists in the lunar science community think the entire Moon experienced a period of intense impact cratering about 3.9 billion years ago. This idea is known as the Lunar Cataclysm Hypothesis. Which of the following observations support the idea of a “lunar cataclysm”?

(A) Lunar meteorites have less potassium and phosphorus than the lunar samples collected by the Apollo astronauts.
(B) Impact rocks collected by Apollo astronauts are much younger than the oldest surfaces on the Moon.
(C) Lunar meteorites that have been affected by impact events are much younger than the oldest surfaces on the Moon.
(D) All of the above.

7) Examine the image of the lunar surface below. Rank the labelled craters in order from oldest to youngest.

(A) C, B, A
(B) B, C, A
(C) C, A, B
(D) A, C, B
8) Three students are discussing the image below showing two different tectonic features criss-crossing each other. Sunlight illuminates the surface from the right; north is up. Read each student’s explanation for how each feature formed and which one formed first. Choose the student (and explanation) with whom you most agree.

Lindsay: The linear feature running northwest to southeast is a depression formed when the Moon's surface stretched, maybe from magma pushing up from underneath. The feature running northeast to southwest formed when the Moon's surface contracted. The right side went up compared to the left side. The feature running northeast to southwest may have formed second. It looks like debris fell during the uplift and now sits in the trough. I need to see more of the area not seen here to make a better guess at which formed first.

Rob: The linear feature running northwest to southeast formed when lava flowed across the Moon's surface. The feature running northeast to southwest formed after the first feature when the Moon's surface shrunk. This caused the right side to thrust upwards. This is why you see a shadow on the left side of the feature.

Matthew: The mostly straight, but kind of curvy feature running northeast to southwest formed before the straight feature running northwest to southeast. The curvy feature is an empty lava channel. It formed as lava flowed underground. After the lava drained, there was an underground tube left behind that looks like it does now when the surface overhead collapsed. The straight feature formed when the Moon's surface stretched and caused the crust to split apart.

9) Image A below is a wide-angle view of the lunar surface. Image B is a narrow angle view (close-up) of the area bounded by the white box in Image A. Why do you think both of these images are useful for understanding the geology of this region?

7.2 Asteroid Content Survey

1) Below are four hypothetical asteroids of varying albedos. Rank the asteroids in order of increasing albedo (1 = lowest, 4 = highest).

2) With the exception of the small fraction of meteorites that come from Mars and the Moon, meteorites originated from small parent bodies, or asteroids. Which of the following statements is true about the importance of establishing asteroid-meteorite links?

(A) Establishing asteroid-meteorite links reveal what conditions were like in the very early solar system.
(B) Establishing asteroid-meteorite links can identify potential resources available on asteroids.
(C) Establishing asteroid-meteorite links can identify possible impact threats to the Earth.
(D) All of the above.
3) Three types of meteorites (pallasite, achondrite, and iron meteorite) are pictured below. Match the layer of a differentiated asteroid that each meteorite type most likely represents.

![Pallasite](image1) ![Achondrite](image2) ![Iron](image3)

4) Which of the following properties of an asteroid is best determined from ground-based telescopes?

(A) Dimensions (diameter, length, etc.)
(B) Composition
(C) Density
(D) None of the above

5) Which of the following properties of an asteroid is best determined by spectroscopy?

(A) Dimensions (diameter, length, etc.)
(B) Composition
(C) Density
(D) None of the above

6) Based on the above data, what can you infer about the shape of asteroid 9 Metis?

(A) Asteroid 9 Metis has a spherical shape.
(B) Asteroid 9 Metis is shaped like a potato.
(C) It is not possible to infer its shape from this data.
(D) None of the above.

7) Based on the above data, which of the following scenarios is most likely?

(A) The two asteroids have similar albedos and likely have the same composition.
(B) Asteroid 40921 is probably larger than asteroid 43032.
(C) These two asteroids are most likely located in different parts of the asteroid belt.
(D) None of the above.

8) Examine the reflectance spectra below from two different asteroids. Use these spectra to answer question 7.

8) Which of these statements best describes the shape of this asteroid?

(A) The asteroid was probably spherical when it formed but is now oddly shaped due to impacts from other asteroids.
(B) The asteroid may be made up of two asteroids weakly held together by gravity.
(C) The asteroid is made up of hundreds of smaller asteroids that have come together to form its present shape.
(D) None of the above.

9) Examine the image below of the surface of an asteroid.
What geologic process(es) is/are responsible for the features seen on this surface?

(A) Volcanism
(B) Impact Cratering
(C) Tectonics
(D) Weathering/Erosion