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Full Title: **Astronomy Modeling Instruction with Exoplanets: Motivating Science Teaching and Learning in the 21st Century**

Shortened Version Title for *Running Head*:
A new approach to teaching high school *astronomy*

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Abstract: This study utilized a mixed method design to investigate the effects of an inquiry-based and data-driven astronomy course on high school teacher and student pedagogy, confidence, motivation, competence, and engagement. Participants were composed of two groups: 1) teachers in a workshop, and 2) the students of one of those teachers. Quantitative data revealed significant increases in both teachers' and students' astronomy concept knowledge, as well as improved teacher self-efficacy. Qualitative data further illustrated these results and added context about how teachers transformed their pedagogy by including Modeling Instruction (MI) and the use of astrophysical data and analysis techniques. Data-driven experiences resulted in improved student engagement and students reported enjoying working with real astrophysical data over "learning from a book". After completing a 15-week Astronomy Modeling with Exoplanets workshop, teachers with little or no prior background in astronomy or astrophysics were able to conduct astronomical observations, perform photometry on astronomical data sets, and include more astrophysics in their high school level courses than many college-level introductory astronomy courses.

Keywords: astronomy; astrophysics; astronomy education; exoplanets; Modeling instruction

Introduction

Astronomy has some of the greatest powers of any scientific field to both educate and induce awe and inspiration in our students (National Academies of Sciences, 2021). The 1960s space race, although driven by the cold war, built on human curiosity about the cosmos and helped galvanize the world's interest in STEM (science technology, engineering, and mathematics) driving STEM education to new heights (Wissehr et al., 2011). Today, it is projected that the US will lead the space industry (e.g. NASA, Space Force, Virgin Galactic, Blue Origin, SpaceX, etc.) and that jobs in this sector are growing fast and are already higher (55%) than a decade ago (Foundation, 2021). However, future US jobs in STEM, especially within the more specialized space industry sectors may go unfilled due to an insufficient supply of skilled US STEM professionals (Butow et al., 2020; Foundation, 2021; National Academy of Sciences, 2007). With students in developed countries, such as the US, scoring below average on standardized assessments in STEM disciplines (Schleicher, 2019) and studies reporting low student interest in science courses (Osborne & Collins, 2001; Schreiner & Sjøberg, 2004; Steidtmann et al., 2023) there is an obvious need for STEM education reform. Adding astronomy to the high school curriculum could help, since astronomy and space-related concepts function as a "Gateway Science" to motivate and excite student STEM interest (Bartlett et al., 2018; Oliveira, 2019; Salimpour et al., 2021).

While astronomy has the potential to be a catalyst to increase student interest in STEM and space careers and prepare a US workforce for its future economy, current opportunities in K-12 schools to exploit this appeal and invoke its intrinsic awe-inspiring nature in our students are scarce.

The Astronomy Modeling with Exoplanets (AME) Pilot Study

This paper describes results of a small mixed methods astronomy education pilot study involving both teachers and students. Our research is informed by the potential student excitement about advances in space science and astronomy and astrophysics and the current state of high school astronomy education.

Most high school astronomy teachers are out-of-field. We wanted to explore the extent to which teachers could master skills and techniques used by professional astronomers, i.e., working with research quality telescopes, self-collected or publicly available astronomical data and images, and conduct their own analyses. We measured their confidence in their ability to help students learn and use these skills in the context of a more engaging and rigorous astronomy or astrophysics course. We also wanted to learn what impact such a course would have on high school students.

Research Questions

(1) In what ways and to what extent does astronomy professional development for secondary science **teachers** grounded in Modeling Instruction (MI) pedagogy and utilizing the collection and analysis of astronomical image data:
    (a) transform their approach to teaching astronomy?
    (b) improve teacher confidence and competence in teaching astronomy?
    (c) affect student engagement?

(2) In what ways and to what extent do **students** in an astronomy course taught by one of these teachers:
    (a) increase understanding of astronomy concepts, skills, and knowledge?
    (b) affect interest, motivation, and engagement?

The Current State of K-12 Astronomy Education

Worldwide, only 17% of K-12 schools offer an astronomy course (Salimpour et al., 2021). The Committee of Ten, a group of educators convened by the National Education Association in 1892, decided that astronomy need not be a part of college admission requirements and therefore should not be a required element of the high school curriculum (Studies, 1894). Previously, it was a required course for virtually all secondary school students (Bishop, 1990; Bishop, 2003; Krumenaker, 2009; Sheppard & Robbins, 2002). This committee opted for the now familiar sequence of biology, chemistry, and then physics (B-C-P) for US high schools (Sheppard & Robbins, 2002). B-C-P resulted in not only the near disappearance of astronomy at the high school level, but also a decline in physics enrolment, since in many cases it became an elective option for students (Sheppard & Robbins, 2002). Despite the space race that began over 60 years ago, this trend has continued. In 2019, 40% of US high school graduates completed a physics course, while 97% completed biology, and 76% completed chemistry (Statistics, 2022). Regarding astronomy, there is little data about its current availability, but as of 2007 just 12% of US high schools reported offering an astronomy course and the number of sections offered was declining (Krumenaker, 2009).

Although astronomy is touched upon occasionally in other K-12 science classes, misconceptions (e.g., gravity in space, cause of seasons, lunar phases, scale, cosmic spatial reasoning and knowledge, and others) abound in teachers at all grade levels (Brunsell & Marcks, 2005) and are the most prevalent in elementary and middle school teachers (Brunsell & Marcks, 2005; Trumper, 2003). While high school physics classes have potential for including some astronomy, a recent national US survey of 506 physics teachers indicated that only about 14% of them teach any astronomy (Personal Communication, Megowan-Romanowicz, March 28, 2023). A 2007 study indicated that most high school astronomy teachers are not highly qualified to teach it (Krumenaker, 2009). While more recent studies about teachers' qualifications to teach high school astronomy are lacking, there is little reason to suppose that this has changed significantly. A recent study reports 84% of middle school and 68% of high school physical science teachers are teaching out-of-field (no major or minor in the field), while 91% of middle school and 80% of high school earth and space science teachers are teaching out-of-field (Taylor et al., 2020). Moreover, most community college astronomy teachers do not have a degree in astronomy and over 88% of students are taking astronomy from a teacher with no formal training in it (French, 2019).

The language of astronomy is mathematics, and the degree to which it is utilized in an astronomy course is considered a metric for its academic rigor level (Brogt, 2009; Brogt & Draeger, 2015). Little is known about the rigor of high school astronomy courses, however, in college level introductory astronomy courses for non-majors, the level of rigor is generally considered low for most offerings, (Brogt & Draeger, 2015; MacLeod et al., 2015).

Modeling Instruction Pedagogy for Astronomy Education

Modeling Instruction (MI), developed in the late 1980s by physicist David Hestenes and his graduate student Malcolm Wells, restructured the teaching of physics by systematically building, refining and applying the fundamental conceptual models that form the content core of the discipline (Hestenes, 1997; Wells et al., 1995). The development and dissemination of MI via Modeling Workshops for high school teachers, and its eventual replication for chemistry, biology, and physical science in middle school was supported for over 20 years by National Science Foundation (NSF) funding. When funding expired in 2005 the American Modeling Teachers Association (AMTA) made it their mission to support the Modeling teacher community (which now numbers over 15,000), offer Modeling Workshops, and develop and curate Modeling curriculum resources. Research has validated the effectiveness of Modeling Instruction pedagogy in middle and high school science education (Haag & Megowan-Romanowicz, 2021; Hestenes, 1997, 2006; Jackson et al., 2008), and has also demonstrated that it improves out-of-field teacher confidence and competence (Haag & Megowan, 2012, 2015; Hestenes et al., 2011; Jackson et al., 2008).

In 2018, AMTA joined with astronomy education researchers from the Global Hands-on Universe (GHOU) project to create an Astronomy Modeling Workshop (Carpenter et al., 2018). The expectation that students learn to "do science as scientists do," is the norm in MI classrooms, and is a fundamental part of science education reform (Council, 2012, 2013, 2015) This served as a guiding principle in the development of this workshop as it does in all Modeling Workshops.

Teacher Self-Efficacy

A teacher's belief in one's self, or self-efficacy, relates directly to their confidence level in their abilities to advance student learning (Bandura & Wessels, 1994). Teachers with low self-efficacy tend to give up more easily with struggling students, are less tolerable of student misconceptions (Nurlu, 2015), and their students will learn less as compared to teachers with a higher self-efficacy (Akbari & Allvar, 2010; Çakiroglu et al., 2005). These teachers are also more likely to have higher stress and poor job satisfaction (Klassen & Chiu, 2010).

In contrast, improving teacher self-efficacy can positively effect teacher motivation, confidence, and job satisfaction (Perera & John, 2020), as well as positively transform how they teach within the classroom (Bray-Clark & Bates, 2003; De Neve et al., 2015; Nurlu, 2015). A strong self-efficacy can also help a teacher overcome challenges and develop resilience (Lent et al., 2000), such as with a science teacher with poor skills in their teaching subject area (e.g., astronomy). However, even though some studies find it to be independent of one's skills in a discipline (Bandura, 1986), others find that self-efficacy can be negatively affected when a science teacher lacks adequate conceptual knowledge in the field in which they teach, and this can then affect their teaching approach and motivation (Riggs & Enochs, 1990). For intervention, the implementation of teacher professional development workshops (e.g., MI) have been shown to increase teacher motivation, self-efficacy, and confidence in effectively embracing new teaching strategies (Bray-Clark & Bates, 2003; Gray et al., 2017; Haag & Megowan, 2015; Haag & Megowan-Romanowicz, 2021).

Student Motivation

Students will engage in a learning experience if they have intrinsic motivation from perceiving the activity to being “fun” and giving them both arousal and control (Middleton, 1995; Middleton et al., 2003; Middleton et al., 1992). The potentiality of space and astronomy being a “Gateway Science” (Bartlett et al., 2018; Oliveira, 2019; Salimpour et al., 2021) may inspire such intrinsic motivations from students. Additionally, the MI learning environment allows for more goal driven activities in line with goal theory (Ames, 1992) and has a more conceptual nature (Thompson et al., 1994), which can lead to a higher-level of adoption of intrinsic student engagement.

Methods

We combined quantitative and qualitative data for a mixed methods study to capitalize on the ability to add greater detail and context to our research investigation (Creswell & Clark, 2017; Johnson et al., 2007; Tolan & Deutsch, 2015). The intervention used was an AME Workshop for high school teachers. Our original intent was to study only teachers, however, during the workshop, one teacher expressed interest in having his high school astronomy students participate in our research during the following semester. We seized on the opportunity to expand our research to include students. To collect relevant data for this work, the investigator used surveys and semi-structured interviews to help to answer our research questions.

The Intervention: AME Teacher Workshop

AME is a 15-week, 45-hour, distance learning Modeling Workshop offered through AMTA, with optional enrolment available at a regional university for 3 graduate credits. Teachers, all but one in the US, were invited to AME through AMTA, SETI Institute, and associated researcher contacts. AME was conducted via Zoom from January – May 2022. Prior to the COVID-19 pandemic, the majority of Modeling Workshops were in-person 3-week summer workshops. However, the pandemic caused a sharp rise in distance-learning Modeling workshops. Distance-learning was a silver lining for AME as it better fit teachers' budgets, schedules, and allowed more time for participants to plan and schedule astronomical observations—a challenge for the shorter 3-week format. Additionally, although many teacher workshops in science require teachers to be present in person to conduct laboratory investigations, AME is unique in that investigations can be completed on a laptop computer with internet browser.

One college and 23 high school teachers enrolled in the AME Workshop. None were astronomers and most were out-of-field teachers who had completed at least one other Modeling Workshop (mostly physics). AME met weekly over Zoom for 3 hours.

As is the norm in Modeling Workshops, classroom discourse was in both "student" and "teacher" mode. In student mode, teachers participated as their students would, working through activities in collaborative groups of 3 or 4. Once workshop leaders had set the stage for an activity, "student" groups were placed into Zoom breakout rooms where they used digital whiteboards (i.e., Google Jamboards) to represent their data, analysis and consensus model. After each activity, teachers removed their "student hats" to have teacher-to-teacher discussions of classroom management and the design of the learning environment. Fundamental conceptual models for the course were embodied in four units as outlined in ***Table 1***.

Table 1. Names and descriptions of the fundamental models into which the AME learning experience was divided.

Unit	Name	Fundamental Models
1	How Do We Map & Measure Space from Earth's Perspective?	The celestial sphere, coordinate systems (e.g. right ascension and declination), cosmic distances and measurements.
2	How Do Objects Interact in Space?	Motion, forces, gravity, and Kepler's Laws.

3	How Do We Know About Objects and Events in Space?	Light: gathering, measuring, and its analysis.
4	How Do We Know the Evolution and Fate of the Universe and SETI?	Stellar evolution, cosmology, and SETI.

To infuse the original MI/GHOU resources with exoplanet science and associated data, we used exoplanet citizen science resources and platforms accessible to K-12 teachers and students. Identifying exoplanets via the transit method was our primary approach with AME. This method works by measuring changes in flux in images of an exoplanet's host star during a transit event, which results in a transit light curve that shows this change as a dip in brightness over time.

We utilized the NASA Universe of Learning and Harvard-Smithsonian Center for Astrophysics MicroObservatory DIY Planet Search, which allows students to request images remotely from robotic telescopes, and hosts a browser-based photometry tools package (Gomez & Fitzgerald, 2017; Gould et al., 2012). Teachers were also able to request images from the Las Cumbres Observatory (LCO) Global Telescope Network (Brown et al., 2013), which facilitates exoplanet observations for students (Sarva et al., 2020). A Unistellar and SETI Institute citizen science network was also made available to AME teachers through a prototype education image and data request program called Unistellar Observation Requests for Education (UOR for Ed.). The citizen scientists who belong to this network use portable Unistellar eVscopes, which can acquire images of deep space objects and image data from exoplanets (Marchis et al., 2020; Peluso et al., 2023). UOR for Ed. allowed teachers to submit a request for an image or scientific observation (e.g., exoplanets) for their class. Requests were filtered and shared with Unistellar citizen scientists, then images or data captured were shared with the teacher who made the request. In addition, we facilitated the donation of an eVscope to the AME Workshop teacher whose students we studied.

In addition to the DIY Planet Search photometry tool, teachers learned to use SalsaJ, an astronomical image software developed for GHOU (Doran et al., 2012; Mora, 2022; Rollinde, 2019), as well as a GHOU edited version of JS9 (Cominsky et al., 2021; Matilsky, 2020; Noel et al., 2020), a browser-based, but more limited version of SalsaJ. Most teachers opted to use JS9 since SalsaJ required users to download and install it onto their local machine, an issue for many teachers as there are bureaucratic barriers to installing software on student computers.

Teacher & Student Participants

Of the 24 teachers who took the AME Workshop, 14 consented to participate in the research: 9 males and 5 females. One taught college and high school level physical science in Canada; the other 13 taught high school science in the US. Their primary teaching assignments were in physics (79%), chemistry (7%), earth and space science (7%), and astronomy (7%). Teachers' educational attainment consisted mostly of master's degrees (one PhD) with majors in physics or physics education (50%), astronomy or astrophysics (22%), chemistry education (14%), and plant pathology or environmental science (14%). Twenty-one percent of participating teachers had 16 or more years teaching experience while the remaining (79%) were evenly spread over a range from 1 to 15 years' experience. More teachers (57%) taught in public schools than in private schools (43%). Twenty-nine percent of teachers taught in schools with over half (50%) of students receiving free or reduced lunch.

Nineteen high school students who attended a public high school in the Northeastern US consented to participate in the study: 9 male, 9 female, 1 non-binary. Over half (50%) of students at this school received free or reduced lunch.

Teacher & Student Surveys

All teachers and students were given pre- and post-course surveys. We examined this data for statistically significant differences in pre- and post-test results using a dependent samples t-test to identify the direction of this difference, with $\alpha = 0.05$. For Likert scale data to measure qualities such as self-efficacy, motivation, confidence, etc., we found median differences between pre and post results.

Teacher Surveys

Teacher Survey Measures & Procedure

A pre- and a post-course survey and one delayed post-course survey were administered to teachers who participated in the AME Workshop to measure the effects of the course on teacher motivation, content knowledge, confidence, changes in pedagogy, and teacher self-efficacy.

To measure changes in astronomy content knowledge, we used the Test of Astronomy STandards (TOAST) (Slater, 2014), which has proven to be a reliable and valid instrument by Cronbach alpha and classical test theory analyses (Slater, 2014). In addition, to assess teacher competence in areas of specific relevance to the AME Workshop, such as exoplanets and observational astronomy, we designed a short assessment titled the Observational Astronomy Test Standards (OATS) (see ***Appendix***).

To measure changes in teacher motivation, confidence, pedagogy, and general self-efficacy we adapted the Science Teaching Efficacy Belief Instrument (STEBI) (Riggs & Enochs, 1990) by replacing the word “science” with the word “astronomy” wherever it occurred, and renamed it STEBI for Astronomy (STEBI-AST, see ***Appendix***). Additionally, we converted the STEBI-AST Likert scale to a scale ranging from 1 (strongly disagree) to 5 (strongly agree). The original STEBI was in reverse order. In analysing STEBI-AST data, questions that were phrased in the negative (questions 3, 6, 8, 10, 13, 17, 19-22, 24-25) were recoded so that pre and post results would give a consistent picture of teachers’ self-efficacy.

To gauge the persistence of effects post-course, we administered a short 6 question Likert scale follow up survey 10 months after the AME Workshop for teachers ended. The response scales for this follow-up survey ranged from 1 (*strongly disagree*) to 4 (*strongly agree*). The follow-up survey questions focused on changes in astronomy teaching confidence and motivation following their 2022 AME Workshop experience.

All participants in the workshop were invited to complete the surveys, however, only results of those who chose to participate in the research study and completed both the pre- and post-surveys are reported here. Surveys were administered online using AMTA's Secure Online Assessment Repository, except the follow up survey, which was given via a secure password protected Google form. All results were anonymous.

Student Surveys

Student Survey Measures & Procedure

For students, 1 pre- and post-course survey was used to measure changes in astronomy concept knowledge. We utilized the same TOAST (Slater, 2014) assessment as with the teachers. We did not administer OATS to students.

Students were invited to participate in the study by their astronomy teacher, Percy Munoz (pseudonym) during their AME inspired astronomy course (Aug. 2022 – Jan. 2022). Munoz had all students from his two sections of high school astronomy complete both surveys, but we only report results from those who returned consent and assent forms and who completed both the pre- and post-course surveys. Surveys were given by Mr. Munoz during his two classes. He replaced student names with anonymous identifiers before forwarding the data to the research team.

Nineteen students ($N = 19$) completed the consent and assent process.

Methodology & Analysis for Teacher & Student Interviews

Qualitative data from teachers and students were collected using semi-structured interviews. Semi-structured interviews are advantageous by allowing reciprocity with both the interviewer and participant (Galletta, 2013) and improvisation from the interviewer (Rubin & Rubin, 2005) for a more organic and stimulating conversation to help provide context for the interview subject. Separate interview protocols were created for both teachers and students to help focus discussions.

Teacher interviews focused on confidence, motivation, competence, various challenges associated with AME and its implementation, suggestions regarding future AME Workshops, and changes in pedagogy. The semi-structured format allowed for the emergence of other topics, such as past, current, or future students, and other topics in science or astronomy education.

In student interviews, participants were initially asked to summarize what they were learning in their astronomy course. Then, students' astronomy concept knowledge was probed as well as their motivation and interest in astronomy and other STEM disciplines and careers.

All 21 interviews were conducted by the same investigator via Zoom and recorded for later analysis. Audio recordings from the interviews were digitally transcribed to text format by video and audio editing software, Descript (*Descript*), which produced 276 pages of interview transcripts. Interviews were then read and coded to identify utterances related to categories suggested by research questions. Teacher and student names were replaced with pseudonyms to preserve anonymity. A rubric was designed to assign a point value to each coded utterance (***Table 2***). Total scores were then tallied for each category (***Table 4*** – Teachers, ***Table 6*** – Students).

Table 2. Scoring rubric for teacher and student interview analysis.

Description	Approximate Length of Utterance	Point Value Assigned Per Utterance
Simple and short answer with little context or value.	words to full sentence	1
Moderately complex answer with moderate context or value.	full to few sentence(s)	2
Significantly complex answer with significant context or value.	several sentences or longer	3

Teacher & Student Interview Samples

A total of 5 teachers participated in three rounds of interviews. Interviews were conducted during the AME Workshop ($N = 5$), shortly after it ended ($N = 4$), and concluded with a final interview ~10 months after the AME workshop ($N = 3$). A total of 5 students participated in 2 rounds of semi-structured interviews. Student interviews occurred in the middle ($N = 5$) and conclusion ($N = 4$) of their astronomy/AME course.

Results

Teacher Survey Results

For TOAST & OATS ($N = 12$), STEBI-AST ($N = 10$). The results from the teachers' combined TOAST & OATS pre-test ($M = 31.3$, $SD = 4.62$) and post-test ($M = 32.5$, $SD = 3.12$) indicated that content and conceptual knowledge improved significantly, $t(12) = 2.20$, $p < 0.05$.

Comparing the results from the teachers' separated TOAST and OATS results also produced significant results. Teacher TOAST pre-test ($M = 23.08$, $SD = 3.06$) and post-test ($M = 23.75$, $SD = 2.56$) revealed that content and conceptual knowledge improved significantly, $t(12) = 2.20$, $p < 0.001$ and results from the teacher's OATS pre-test ($M = 8.25$, $SD = 1.86$) and post-test ($M = 8.75$, $SD = 0.87$) likewise revealed that content and conceptual knowledge improved significantly, $t(12) = 2.20$, $p < 0.01$.

Teacher Survey Results: STEBI-AST

STEBI-AST results (***Figure 1***) showed little change from pre to post from an already fairly confident group of teachers. Questions 11, 20, and 25 showed a slight decrease, while questions 3, 5, 8, 10, 13, 16 ,17, and 19 had large positive shifts. Question 5 (teacher confidence in astronomy pedagogy and competence) showed the greatest increase. Only question 11 (teaching philosophy) from post-course responses scored below a 3 and overall there were more items of increase (10) in self-efficacy than a decrease (3).

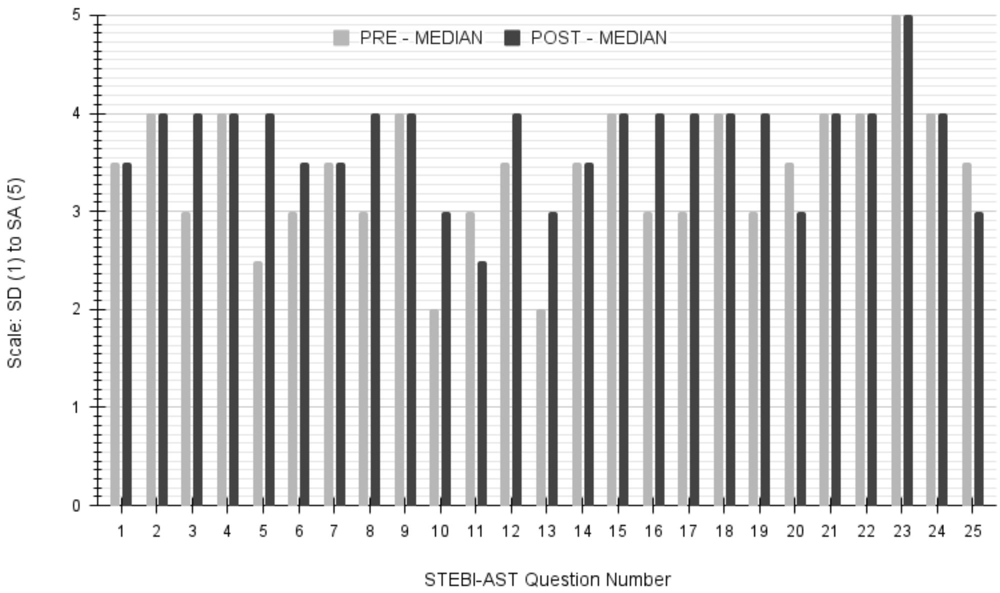

Figure 1 Caption: Bar chart comparing pre and post median results from teacher responses of the STEBI-AST. SD = strongly disagree and SA = strongly agree.

Teacher Survey Results: Follow Up Survey

Eleven teachers completed the follow-up survey (***Table 3***). Results from statements 1-4 show that most teachers report an increase in confidence and motivation to teach astronomy using Modeling pedagogy. The response for statement 3 from one participant for “strongly disagree” was clarified by the participant’s free response comment that he “was already strongly motivated” before the workshop, and by the same participant for statement 6 that his administration was making it challenging for him to do so. Statements 5 and 6 also show increased motivation, but towards including more astronomy in other classes and attempts to expand astronomy offerings.

Table 3. Results from the extended follow up survey ~10 months after the conclusion of the teacher AME workshop.

Statement	Percentage of Respondents			
	Strongly Disagree (1)	Disagree (2)	Agree (3)	Strongly Agree (4)
1. I am more confident in using Modeling Instruction in my science classes since taking the 2022 Astronomy Modeling with Exoplanets course.	0.0%	0.0%	27.3%	72.7%

2. I am more confident in my ability to teach astronomy.	0.0%	0.0%	27.3%	72.7%
3. I am more motivated to teach astronomy than I was prior to attending Astronomy Modeling with Exoplanets.	9.1%	0.0%	18.2%	72.7%
4. I am more motivated to teach astronomy using Modeling curriculum resources that include astrophysical data in student learning activities.	0.0%	0.0%	18.2%	81.8%
5. I am trying to include more astronomy concepts in my non-astronomy classes (e.g., physics, chemistry, earth and space science, etc.).	9.1%	18.2%	45.5%	27.3%
6. I am advocating for a new astronomy class at my school where none exists or trying to expand upon my school's current astronomy course(s) (e.g., more offerings, yearlong versus semester, etc.).	9.1%	18.2%	27.3%	45.5%

Student Survey Results: TOAST

Results from the students' TOAST pre-test ($M = 8.68$, $SD = 3.23$) and post-test ($M = 11.1$, $SD = 4.09$) revealed that content and conceptual knowledge improved significantly, $t(19) = 2.10$, $p < 0.001$. These greater gains in comparison with teacher results on TOAST are not unexpected as teachers had greater content knowledge at the start of the AME workshop than did students at the beginning of their astronomy course.

UOR for Ed. Use

The availability of UOR for Ed. resulted in 14 AME teachers requesting images of asteroids, stars, star clusters, nebulae, and galaxies. This yielded 115 images from nine participating Unistellar citizen scientists. We also polled 21 citizen scientists on their interest in undertaking an exoplanet observation for middle or high school teachers and 90% had interest. From 4 teacher requests, 2 exoplanet transit observations were attempted, which resulted in 1 successful transit light curve for exoplanet, Qatar-1b.

Teacher Interview Results

While analyzing the interview data qualitative coding yielded categories directly and indirectly related to our research questions. Utterance scores from interviews from each coded category are provided in ***Table 4.*** Below we also quote from interviews transcripts that exemplify passages coded for these categories. Some interview excerpts were placed in multiple categories but are titled for their primary theme.

*Table 4. Teacher utterance scores by category. Each utterance found within the interviews was assigned a point value according to the rubric from Table 2. These points were then summated for each category. "Telescope use" consisted of utterances related to LCO, DIY Planet Search/MicroObservatory, or Unistellar eVscopes. "Image analysis" consisted of utterances related to JS9 or SalsaJ. Categories with a * indicate those directly related to research questions.*

Teacher Categories	Utterance Score
*Changes in pedagogy	86
Motivation	66
Using data with students	51
*Increased student engagement	50
*Confidence/self-efficacy	49
Telescope use or image analysis	43
Competence, knowledge, or skills	30
Challenges in using Modeling Astronomy curriculum	29
Concept of exoplanets used in learning	25

Changes in pedagogy

All teachers interviewed described marked changes in how they approached teaching astronomy. For example:

> "This class really showed me, like, maybe the data's not coming in a package with my textbook, but a lot of it's out there and I need to really, you know, seek out those data sets and find ways to bring that into each unit within astronomy." (Camelia Preston, teacher)
>
> "I would say the new part was doing more of this data processing with the lens of teaching and learning versus just pure research . . . that was pretty important." (Melissa Fennimore, teacher)

Even so, teachers also expressed concerns with their students' ability to adjust to a more data-intensive course and 4 of the 5 (80%) interviewed expressed concern on some level with their ability to cover everything they learned in AME. These concerns could limit teacher ability to achieve their stated desire for making pedagogical changes.

> "[With] data analysis there's always some sort of . . . procedure that you have to do with the data that might be a little bit of a steep learning [curve]." (Melissa Fennimore, teacher)
>
> "I'm trying to frame it from a half year course . . . the average student probably isn't gonna be able to do things quickly or super in-depth . . . I would definitely have to pick and choose what's done . . . definitely wouldn't get to all the units."

(Bradley Watson, teacher)

Additionally, there was also concern among two teachers about their ability to even offer an astronomy course. For example:

> "[The new administration] shelved all new electives unless there was a certification that they could point to that students could like obtain."
>
> (Bradley Watson, teacher)

Self-Efficacy & Confidence

Teachers reported their self-efficacy was improved as a result of feeling they were a part of a group of other teachers in similar situations and skill levels. Additionally, getting exposure to astronomical tools (e.g., JS9), learning image analysis, and working with provided and collected datasets in the workshop increased their confidence.

> "It was just a real confidence boost because I kind of felt like I was like in my own little astronomy bubble in my school . . . Nice to just be with a group of other educators and . . . just to kind of be like, oh okay, I am doing the right things and now here's ways that I can do it better."
>
> (Melissa Fennimore, teacher)
>
> "I [was] intimidated by the tools . . . data taking tools . . . being forced to use them and learn how they work . . . that was really helpful and now I'm not as intimidated by them."
>
> (Bradley Watson, teacher)
>
> "I feel a lot more comfortable . . . [before] in astronomy, I didn't have data sets, I didn't have an idea of how to do that . . . felt like I had to just teach all the textbook and with videos . . . I didn't . . . have . . . data sets . . . I felt frustrated . . . and I feel like it was so much richer this year . . . we got kids really thinking like scientists about data . . . I really feel like we can do some original research . . . take some telescope data and you know get some photometry data and do something with it. I feel like I have capacity to do that now . . . this [workshop] gave me the foundation to at least teach in a way that's a lot more engaging, that gets kids curious and really developing habits of mind and not just memorizing facts."
>
> (Camelia Preston, teacher)

Regardless of the increased confidence in working with astronomical data and analyzing images, teachers still felt they needed more practice with photometry skills and programs such as JS9, as follows:

> "More photometry skills . . . I feel like we just didn't get enough time on the ground practice."
>
> (Camelia Preston, teacher)

Student Engagement

Bradley Watson's comment below comes from students in his physics class as he was not able to teach a dedicated astronomy course at the time of interviews. Watson, however, did include AME activities within his traditional physics course, which he explained was engaging for his students. The excerpt below, also highlights general student interest in astronomy, which offers evidence that it is a "gateway science":

> "Definitely promoted the idea that I want to use Modeling as much as possible . . . mostly for student engagement . . . I think that they actually learn better this way… I put out a survey asking the students if they'd be interested in an astronomy elective just to see what they'd say. I gave it to every physics student I have . . . about a hundred . . . I think we had 49 or something that said that they would be interested in taking it, which is pretty good."
>
> (Bradley Watson, teacher)

The following interview excerpt gives interesting details about one teacher's experience with increased student engagement in his astronomy course:

> "We're not just building bridges with popsicle sticks, you know . . . [we're] using photometry and images and [exoplanet] transit data . . . that's STEM, you know . . . [and it] doesn't have to [only] be in an astronomy course…I was integrating exoplanet[s] into my class . . . [exoplanet] transit data . . . [we] talked about the Trappist [exoplanet] system . . . talked about exoplanets quite a bit . . . then we went and saw [a] movie [at] the planetarium . . . [students] were like, 'oh, well, they need to update their movie. We [students] know a lot more than that movie because [it] was a few years old' . . . So yeah . . . I thought that was pretty neat! . . . I've actually doubled you know, almost doubled the number of kids taking astronomy."
>
> (Percy Munoz, teacher)

There was no evidence from teacher interviews that indicated any decrease in or difficulty with student engagement.

The Percy Munoz Case Study

Percy Munoz is a 60-year-old Caucasian male who became a credentialed teacher after working as an engineer. He has primarily taught physics for the past 12 years and only recently began teaching astronomy. His post-secondary education was in physics, and he had no formal education in astronomy before AME. To complement his participation in this study, Mr. Munoz received a Unistellar eVscope for use with his students. He communicated more often with the researchers than other teacher participants, particularly with respect to training in how to operate his Unistellar eVscope and integrate its use into his astronomy course. Munoz also participated in the same semi-structured teacher interviews as other teacher participants. ***Table 5*** summarizes important changes for Munoz from pre and post intervention.

Table 5. Summary of interesting results related to changes in pedagogy, self-efficacy, and identity from before and after the AME Workshop with Percy Munoz.

Percy Munoz Case Study Summary	
Pre AME Workshop	Post AME Workshop
No involvement in local astronomy clubs.	Very active member of a local astronomy club.
Had a telescope, but hadn't used it in years.	Uses eVscope regularly (~5 times/month) and attributes better understanding of astronomy and motivation for teaching to it, as well as student excitement/engagement around his use and sharing with class.
Used "Starry Night" astronomy curriculum and student complained about "oh another worksheet".	Students are more engaged in a more active (Modeling) class using whiteboards, real data, and Google Jamboards.
Never involved students in his own observation of an exoplanet.	Included students in an attempted observation of a real exoplanet and students were engaged/excited about this.
Taught only a 1 semester-long section of astronomy for the academic year.	Went from 1 section of astronomy (2020-2021) when teaching with "Starry Night" curriculum to 1 section for each semester when first starting astronomy Modeling (2021-2022) to 3 sections in the current academic year (2022-2023).
Self-assessed himself 3/10 on confidence in teaching astronomy.	Self-assessed himself 8/10 on confidence in teaching astronomy.

Munoz details increased motivation for offering astronomy as a year-long elective to stand alongside other rigorous courses offered at his school and an increase in his enthusiasm for teaching it:

> "Some of [Astronomy Modeling] is more difficult than my school has typically put into an elective . . . we [do] have electives [that] are sort of serious electives . . . rigorous . . . like human anatomy and physiology . . . or AP environmental . . . then we have other electives that are like marine science and wildlife and astronomy and those are all sort of been in the more general easier survey level electives . . . [with] the material [I'm using now] it's become more serious in content, which is why I'm trying to push for [astronomy] to become a yearlong course."
> (Percy Munoz, teacher)

> "Every time I show [students] something, I'm like, God, this is, this is real. We're not just reading about a planet in a textbook. This is, this is real stuff that real astronomers are doing right now . . . I will say very clearly that [the workshop] has increased my enthusiasm to teach astronomy."
>
> (Percy Munoz, teacher)

Munoz increased his use of telescopes both personally and within his class, which also showed changes in how he taught and increased self-efficacy:

> "I've never really looked through a telescope that much. I've done it more in the past six months than I have ever."
>
> (Percy Munoz, teacher)
>
> "The eVscope for me is a game change . . . [I'm] more confident . . . When I talk [to students] about that [eVscope exoplanet] observation . . . present [the data] to the kids . . . the mistakes I made [observing] . . . that's like what it's all about to be a teacher . . . I was able to talk about my [exoplanet observation] . . . we're bringing real data into the classroom. We're not just [doing] the same old experiment . . . when you show that to the kids . . . you're showing them something that's actually happening right now . . . working with real data . . . that's gonna hook kids . . . it's not a textbook."
>
> (Percy Munoz, teacher)

Although Munoz brought in a unique experience to his students with the eVscope, use of it to collect original data for his classes was limited because of a lack of experience observing exoplanets, weather, and time to commit to long exoplanet observations which take 3-5 hours on average to capture. Munoz did attempt the exoplanet observation of HAT-P-32b in December 2022, which his students helped him to plan as part of their learning experience. However, this was the only attempt, and it did not result in a detection because of poor focusing and collimation of the instrument, which resulted in unusable data. Even so, Munoz shared students had some of the highest levels of engagement and excitement during this exercise and learned fundamental observational astronomy techniques not typical in a high school course. Additionally, Munoz shared that learning from the challenges encountered in conducting an exoplanet observation was also a valuable learning experience for his students to understand how real science can be messy and not always successful, but that it does give investigators important lessons to learn from.

Student Interview Results

As with teacher interview data, qualitative coding yielded categories directly and indirectly related to our research questions. Utterance scores from interviews from each coded category for students are provided in ***Table 6.*** Excerpts are reported in similar fashion as teachers excerpts.

*Table 6. Student interview utterance scores by category. The same utterance scoring methodology and definitions for "Telescope use" and "image analysis" as used in Table 4 were followed here. Categories with a * indicate those related to research questions.*

Student Categories	Utterance Score
*Competence, knowledge, or skills	43
*Increased student interest and engagement	41
Concept of exoplanets used in learning	27
Motivation to learn about astronomy and STEM	26
Using data in class learning	14
Challenges in learning in the Modeling Astronomy course	12
Noticing a different way of teaching/learning, i.e., Modeling Instruction	11
Telescope use or image analysis	9
Motivation in pursuing astronomy or STEM career	7
Science identity	5

Competence, Knowledge, or Skills

The following excerpts illustrate increases in student competence related to spatial reasoning, celestial mechanics, observational astronomy, and exoplanets:

> "It makes sense now . . . I can look up in the sky and understand when things are gonna happen and why."
>
> (Loren, high school student)
>
> "[I learned] how they map out the planets and like the stars and all that stuff . . . around the . . . Earth . . . you gotta have a way to tell other people where things are . . . pretty interesting learning how they do that. And then, yeah the exoplanets."
>
> (Bobby, high school student)

All students reported increases in competence, however, two students also detailed specific concepts that were especially challenging:

> "Sometimes it's hard to understand like the measurement or like how far away things are to like process it cause it's just so big or measurements are so big."
>
> (Courtney, high school student)
>
> "Coordinates and how to locate something in the sky . . . that was pretty difficult . . . I wish I got a bit more experience in actually working with the night sky instead of on the computer."
>
> (Loren, high school student)

And one student shared concern about the amount of material in his astronomy course:

> "You can't cover all of astronomy in half a semester."

(Emmett, high school student)

Student Engagement

Students expressed interest and enthusiasm for the more explorative and research-based nature of their astronomy Modeling course, such as:

> "In most [other] science classes, it's a bit more strict . . . [This] astronomy class is more explorative . . . [Interesting] knowing that there's other stuff out there that we barely even hear of, and we recently just did the Drake equation and stuff and calculating chances of [extraterrestrial intelligence]. I thought that was interesting."
>
> (Courtney, high school student)
>
> "This [astronomy course is] more research based and you're trying to figure it out on your own by doing your own research . . . rather than the other thing, which is basically they lead you along the entire way . . . it's like more independent . . . not that much lecturing . . . other ways of teaching."
>
> (Bobby, high school student)

Only one student shared a specific aspect of the course (lecturing) related to these categories that was not engaging for him:

> "The [parts] I don't really care for . . . maybe just the sitting there and listening portions."
>
> (Emmett, high school student)

Unistellar Telescopes & Student Engagement

Several students sounded excited about the prospect of using the telescope:

> "[The telescope] seems pretty cool. It seems fancy and like we could see some pretty cool things with it."
>
> (Courtney, high school student)
>
> "I do know we're gonna do some more stuff with telescopes . . . I'm excited."
>
> (Loren, high school student)
>
> "[Our teacher] said that he has like this telescope thing. It's the fancy telescope and you tell it where you wanted to look at, you know, like swivel around and look at that . . . he was planning to take some photos and some stuff and then bring them in and then teach us about that . . . that's gonna be pretty cool because, you know it's like more hands-on stuff . . . the stars and all that stuff . .. it gives us a way to actually see stuff."
>
> (Bobby, high school student)

In contrast, one student shared she wished there was more time and practice with the eVscope and was disappointed that her class did not get the data they attempted:

"... more familiarity with the tools we're using. Like it was a great opportunity to have that telescope and everything, but it was brand new, so we didn't have enough practice with it, and we weren't able to get like great data I guess."

(Courtney, high school student)

Motivation, Using Data, Competence, & Student Engagement

The following excerpt illustrates the convergence of several coded categories in a single statement and the excitement around the topic of exoplanets:

"Oh this [exoplanet data] is real. Data that's happening right now, and not just like something that was discovered 50 years ago . . . learning about more current events and being able to understand that data was really exciting . . . I found [it] wasn't too complicated . . . I want to know a bit more about exoplanets . . . finding planets . . . comparing it to Earth or other planets we know . . . I find very interesting. Cause we live on a planet. So what's so different about all of them?"

(Loren, high school student)

It is worthy of note that student interviews were much shorter and not as in-depth as teacher interviews. Students had limited time to speak with the investigator and seemed hesitant to express more critical feedback related to the categories shared here.

Discussion

Even with a small sample size, we saw significant increases in teacher (TOAST and OATS) and student scores (TOAST) that indicate increases in astronomy content knowledge and skills. STEBI-AST results suggest that teachers experienced shifts in their confidence and self-efficacy. The three questions reporting a slight decrease in median from the STEBI-AST were statements having more to do with a general philosophy of student learning than teachers' self-efficacy for astronomy teaching. Moreover, the interviews gave context for what teachers and students were thinking and helped us to draw tentative conclusions when comparing qualitative and quantitative results. As such, teacher interviews provided context for the increases we saw in self-efficacy, such as teachers feeling a part of a group and getting exposure to previously intimidating skills such as photometry and image analysis.

On the basis of the highest interview utterance scores from teachers (i.e., changes in pedagogy) and students (i.e., increase in competence and engagement), it appears that teachers noticed a change in how they taught and this resulted in students having positive classroom outcomes. Teachers were motivated to use astronomical data with their students, and both teachers and students agreed that engagement was improved in the classroom. Another theme that was consistent across teacher and student responses was the excitement about active student-driven learning using real astronomical data from exoplanets using telescopes that students controlled rather than just learning things from lectures or a textbook.

One student shared difficulty in understanding astronomical distance scales. However, this student also expressed the most excitement about working with and analysing real astronomical data. This supports the notion that rigor, in the right context, can be a motivating factor for students. Another student shared problems with finding things in the sky from a lack of practice doing so away from a computer, which suggests more attention should be paid to providing student activities with such experiences.

With Percy Munoz, we saw changes in confidence, motivation, competence, pedagogy, and even teacher identity. Munoz considers himself an active citizen astronomer now, whereas before he had only a mild interest in astronomy and no formal training in it. Additionally, his excitement about teaching and doing astronomy and his motivation and confidence from his growing astronomy skills seems to have rubbed off on his students, as evident in their increased interest and engagement in class. Munoz is the only AME teacher who received and used an eVscope with his students. The availability of this in situ telescope (versus the remotely operated DIY or LCO) clearly brought additional excitement, learning, and motivation to him and his students.

For a broad implementation of AME, challenges still exist. All the teachers we spoke to who taught a dedicated astronomy class only taught a one-semester course. This points to a need for further work, since the current AME curriculum is presently too extensive to fit into a one-semester high school level astronomy course. The AME course will need to be slimmed down for this use case, however, as exemplified by Mr. Munoz’s efforts this also may motivate the creation of year-long astronomy courses.

Implications for Further Research

Future MI astronomy research will explore a more robust study with a larger and more diverse sample size of both teachers and students. An extended study would allow us to follow both teachers and students to assess long-term effects on teaching, learning, identity, and career interest.

We are seeking additional opportunities for teachers and their students to have more unhindered access to telescopes capable of collecting data in real time for teaching and student learning projects. One possible avenue is funding the placement of eVscopes with AME teachers and students and devoting more time and resources to a widespread UOR for Ed. program. These efforts could afford research foci on student engagement, learning, and science identity, as it is impacted by access to in situ eVscopes. Past research show increases in student engagement and learning when students acquire their own images from remote telescopes (Gould et al., 2006; Marshall et al., 2015). However, apart from results from our case study, less is known if this may be affected by, instead, using in situ telescopes capable of data collection (e.g., eVscopes). Even though our eVscope intervention showed some promise, it was not without challenges. Future work should include more teacher eVscope training, practice with collimation and focus, and additional exoplanet observations facilitated by investigators. These changes may increase data acquisition successes (e.g., exoplanet detections) to measure the success and value of such an intervention more adequately.

We also plan to add computer programming to a future MI astronomy workshop so students can use and write coding scripts with either Google Colaboratory or Jupyter Notebooks to automate and streamline the analysis of large numbers of images generated by an exoplanet transit observation. Programming and data science are ubiquitous in modern astronomy and are important skills needed for our modern economy (Kong & Abelson, 2019). In an unrelated mid-course survey, most AME teachers agreed it is essential for students to learn how to write or interpret code for data analysis, however, most also indicated discomfort or lack of training and confidence in their ability to teach these skills.

Implications for Instruction

The Percy Munoz case study has illustrated the power and potential for improving science education through the development of teacher skills and confidence to fashion a student-driven learning environment. When teachers implement more student-centered data-driven learning experiences student engagement and learning increase. Physical science and physics teachers should be encouraged to fold astrophysics into their courses to capitalize on student interest in astronomy concepts (e.g., Bradley Watson mentioned during one interview that his physics students became more excited when they discussed astronomy related topics).

It may be time to rethink the status quo B-C-P sequence. Initiatives such as Physics First (physics as a required high school freshman course) have been shown to be a promising alternative (Glasser, 2012; Lederman, 2005; Scannell, 2019). Outdated education models that do not adapt to modern education research, create opportunities to prime our STEM and space workforce pipeline, and capitalize on student interests (e.g., space and astronomy) are ripe for re-examination and reform. A data science-rich astronomy course should qualify as a college entry science requirement. Mr. Watson's account that his administration was dropping electives that did not award a certification could be an opportunity for schools to offer astronomy for college credit in dual enrolment settings. With astronomy's intrinsic motivational power and the fact that students were highly motivated by working with real astronomical data, a year-long astrophysics course should be recognized as an equivalent learning experience to high school physics as suggested by both teacher and student interviews.

Conclusions

Of the 8.8 million professional scientists worldwide (Lewis et al., 2021), only 0.114% (~10,000) are professional astronomers (Forbes, 2008). Our future economy is moving outward into space (Butow et al., 2020; Foundation, 2021) and excitement about astronomy is widespread, as evident by student interest in life beyond Earth (Morgan, 2017), public interest in the latest JWST images and the next earth-like exoplanets, and space themes in television and movies (National Academies of Sciences, 2021). Astronomy does not have to remain on the side-lines of our outdated B-C-P status quo. It can stand on its own as a rigorous science course that has the potential to engage and motivate both teachers and students and prepare our STEM and space workforce pipeline for our future economic and social success and security.

In this study, despite a modest sample size, we saw significant improvements in content knowledge in both teachers and students. Teachers reported changes in their pedagogy, motivation, and using astronomical data with students. Students reported being more engaged by working with real exoplanet data and overall excitement and interest in the course content. Students also said that they preferred exploring the cosmos and working with data they collected to search for planets around distant stars over learning from a textbook or lecture.

This work shows that a data-driven astrophysics course for regular education students is feasible at a public high school. Further, this study revealed that even if most teachers do not have post-secondary preparation in astronomy, AME and the wonders of the universe can equip them with the requisite confidence and competence to deliver a rigorous and engaging astronomy learning experience for their students.

Limitations

The primary limitation of this study was a small sample size. A larger sample would allow the study to incorporate more diverse demographics from both teacher and student populations to yield more broadly applicable conclusions and provide a more detailed picture of the effects of AME on various demographics.

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Ethics Approval

Human research approval by the University of California Berkeley, Committee for Protection of Human Subjects (CPHS) under the CPHS Protocol Number: 2022-08-15536.

Appendices

Appendix Document 1

Observation Astronomy Test Standards (OATS)

1. What is a light-year?
    a. A measure of time
    b. A measure of distance
    c. A measure of time and distance
    d. How we assign ages to cosmological objects
2. Kepler's 3rd law combined with Newton's law of gravity allows us to determine what about an object orbiting another object?
    a. It's mass
    b. It's orbital period
    c. It's distance to the body it orbits
    d. All of the above depending on what quantities are already known
3. What is the most common and successful way to detect a planet around another star?
    a. There is no way to detect planets around other stars
    b. There are no known planets around other stars

c. Gravitational lensing
d. The transit method
e. Direct imaging

4. Based upon scientific data, is there life outside of planet Earth in our universe?
   a. Yes
   b. No
   c. We do not know, but it is possible
   d. We do not know, but it is extremely unlikely
   e. Other:
5. What is the standard and most common coordinate system astronomers use for locating an object on the night sky?
   a. Latitude and longitude
   b. North, south, east, and west
   c. Right ascension and declination
   d. u, v, w space velocities
6. The apparent magnitude of a star . . .
   a. indicates the brightness of the star as seen from Earth, with the brighter stars having higher magnitudes and fainter stars having lower magnitudes
   b. indicates the brightness of the star as seen from Earth, with the brighter stars having lower magnitudes and fainter stars having higher magnitudes
   c. is the ratio of the star's luminosity to the Sun's luminosity
   d. indicates the brightness of the star as if it were placed at a distance of 10 parsecs from Earth, with the brighter stars having lower magnitudes and fainter stars having higher magnitudes
7. Why is knowing the apparent magnitude of a stellar object important to know for planning your observation?
   a. It can help determine the size of the telescope you will need for your observation
   b. Your telescope camera's sensor may only be able to successfully detect stars in certain magnitude ranges
   c. It tells you how large of a field of view you need to detect the object
   d. Both a and b
   e. Both b and c
8. Which of these time standards would be most useful by an astronomer in planning an astronomical observation?
   a. International Earth rotation time (IERT)
   b. Eastern standard time (EST)
   c. Coordinated universal time (UTC)
   d. Local apparent solar time (LAST)
9. One common measurement that astronomers perform on their images is photometry. In photometry, astronomers are doing what?
   a. Measuring the number of neutrinos captured in the image

b. Measuring the temperature of photons that entered an image pixel
c. Measuring the amount of light from astrophysical sources in an image
d. Measuring the positions of astrophysical sources in an image

10. An observer is located in Boulder, Colorado at a latitude of 40° N. They plan to observe a star with a Declination of +40°. Assuming the observer can see the star continuously from the time it rises until it sets, what is the *maximum* altitude on the sky the star reaches during the night?
    a. 0°
    b. 40°
    c. 50°
    d. 90°

Appendix Document 2
Science Teaching Efficacy Belief Instrument for Astronomy (STEBI-AST)*

Please indicate the degree to which you agree or disagree with each statement below by circling the appropriate letters to the right of each statement.

SA = Strongly Agree
A = Agree
UN = Uncertain
D = Disagree
SD = Strongly Disagree

1. When a student does better than usual in astronomy, it is often because the teacher exerted a little extra effort.	SA A UN D SD
2. I am continually finding better ways to teach astronomy.	SA A UN D SD
3. Even when I try very hard, I don't teach astronomy as well as I do most subjects.	SA A UN D SD
4. When the astronomy grades of students improve, it is most often due to their teacher having found a more effective teaching approach.	SA A UN D SD
5. I know the steps necessary to teach astronomy concepts effectively.	SA A UN D SD
6. I am not very effective in monitoring astronomy experiments.	SA A UN D SD
7. If students are underachieving in astronomy, it is most likely due to ineffective astronomy teaching.	SA A UN D SD
8. I generally teach astronomy ineffectively.	SA A UN D SD
9. The inadequacy of a student's astronomy background can be overcome by good teaching.	SA A UN D SD
10. The low astronomy achievement of some students cannot generally be blamed on their teachers.	SA A UN D SD
11. When a low achieving child progresses in astronomy, it is usually due to extra attention given by the teacher.	SA A UN D SD
12. I understand astronomy concepts well enough to be effective in teaching elementary astronomy.	SA A UN D SD

13. Increased effort in astronomy teaching produces little change in some students' astronomy achievement.	SA A UN D SD
14. The teacher is generally responsible for the achievement of students in astronomy.	SA A UN D SD
15. Students' achievement in astronomy is directly related to their teacher's effectiveness in astronomy teaching.	SA A UN D SD
16. If parents comment that their child is showing more interest in astronomy at school, it is probably due to the performance of the child's teacher.	SA A UN D SD
17. I find it difficult to explain to students why astronomy experiments work.	SA A UN D SD
18. I am typically able to answer students' astronomy questions.	SA A UN D SD
19. I wonder if I have the necessary skills to teach astronomy.	SA A UN D SD
20. Effectiveness in astronomy teaching has little influence on the achievement of students with low motivation.	SA A UN D SD
21. Given a choice, I would not invite the principal to evaluate my astronomy teaching.	SA A UN D SD
22. When a student has difficulty understanding an astronomy concept, I am usually at a loss as to how to help the student understand it better.	SA A UN D SD
23. When teaching astronomy, I usually welcome student questions.	SA A UN D SD
24. I don't know what to do to turn students on to astronomy.	SA A UN D SD
25. Even teachers with good astronomy teaching abilities cannot help some kids learn astronomy.	SA A UN D SD

*Adapted from Riggs, I., & Knochs, L. (1990). Towards the development of an elementary teacher's science teaching efficacy belief instrument. *Science Education, 74*, 625-637.