PHYSICAL REVIEW PHYSICS EDUCATION RESEARCH **19,** 020156 (2023)

Development and assessment of a course-based undergraduate research experience for online astronomy majors

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(Received 7 July 2023; accepted 5 October 2023; published 7 November 2023)

Course-Based Undergraduate Research Experiences (CUREs) have been shown to provide students with a variety of learning benefits including better conceptual understanding, improved critical thinking and data literacy skills, and increased interest in pursuing scientific careers. Additionally, CUREs provide students with opportunities to participate in authentic research experiences that have a broader impact outside of the classroom. Despite the numerous benefits, the field of astronomy has lagged behind disciplines like biology and chemistry when it comes to including CUREs in the curriculum. Not limited to astronomy, however, is the lack of research opportunities and courses offered to students enrolled in undergraduate degree programs online. In the Fall of 2020, Arizona State University (ASU) introduced the nation's first online bachelor's degree program in astronomy and planetary sciences (APS). To make research accessible to a more diverse population of learners, it is imperative that students in this program have access to the same opportunities to participate in authentic research as those in the parallel in-person program. In this work, we describe the development, implementation, and assessment of a fully online CURE for astronomy majors as part of the APS program. We conducted a mixed methods analysis consisting of a Likert style survey administered pre- and postcourse as well as student interviews at the conclusion of the semester. Survey results from the course's first two offerings ($N = 24$) indicated that students' research self-efficacy and science identity both improved. An exoplanet-specific multiple-choice assessment ($N = 26$) showed statistically significant improvements in conceptual understanding postcourse. Additionally, student interview ($N = 11$) responses relayed that students felt a stronger sense of belonging to both ASU and the larger astronomy community after participation in the course. The results from this study are encouraging and suggest that student participation in this online CURE led to similar improvements across a variety of outcomes previously identified in studies of in-person CUREs spanning multiple disciplines.

DOI: 10.1103/PhysRevPhysEducRes.19.020156

I. INTRODUCTION

There has been a tremendous shift toward online learning in the past two decades [1–3]. One particularly important benefit that online learning offers is accessibility to higher education for a more diverse population of learners who may not be able to accommodate the standard model of full-time education. Due to personal or professional obligations, they may be located somewhere that does not offer them suitable or optimal options for higher education. In the last decade, online enrollment has continued to increase to the point that roughly two-thirds of higher education institutions have introduced online instruction and one-third of students in higher education are enrolled in at least one online course [4]. Arizona State University (ASU) has embraced this transformation. Currently, ASU enrolls over 54 000 students in over 300 unique fully online graduate and undergraduate programs [5].

Course-Based Undergraduate Research Experiences (hereafter, CUREs) present students with opportunities to participate in authentic undergraduate research experiences. Participating in research experiences as an undergraduate has been demonstrated to positively impact the educational experience by providing access to mentoring [6], improving data analysis skills and teaching students the scientific process and scientific thinking [7], an increase in

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perceived confidence and competence [8], an increase in self-efficacy [9], and generally higher retention rates for degree programs [10]. The importance of research experiences has been highlighted by the American Association of the Advancement of Science [11] and the National Academies [12]. It has also been shown that research experience is very important when applying to advanced degree programs [13]. CUREs present a unique and accessible way to offer research experiences, especially in online degree programs. Although strides have been made in online degree programs, they are still less likely to offer access to research experiences.

CUREs are courses that involve participation from an entire class in a research project that is of interest to the broader scientific community [6,14]. In 2014, the Course-Based Undergraduate Experiences Network (CUREnet) formalized a definition for CUREs, proposing that they differ from traditional laboratory-type courses in that they involve the students in five components [6]:

1. *Multiple scientific practices* are used in the research process,
2. *Discovery* or the process by which new results and findings are generated. Students address novel scientific questions, of which, the outcome is unknown to both the students and the instructors.
3. Research that has a *broader impact* on and is *relevant* to the scientific community and has meaning beyond the context of the classroom.
4. *Collaboration* among other students and instructors in the course, allowing them to improve their teamwork and communication skills.
5. *Iteration*, an inherent part of the scientific process.

Although some of these components are often seen in laboratory courses, it is the combination of all five of these components that differentiates CUREs. CUREs have been shown to provide students with numerous benefits including (but not limited to): improved scientific literacy [14], improved student confidence in participating in science [8], and increased discipline-specific content knowledge [15]. Student affective outcomes that result from these CURE components are described in the "large CURE model" from Corwin *et al.* [16]. The outcomes that are involved in six or more connections are the "hubs" and include self-efficacy, science identity, and sense of belonging [16].

CUREs can provide students with numerous benefits beyond those offered by traditional internship-style research experiences like formal research experiences for undergraduates (REUs), typically offered at a host university during the summer, or traditional undergraduate research experiences (UREs). Unlike UREs or REUs which only serve self-selecting students who seek out these opportunities, CUREs engage an entire class of students in a research project and provide a lower barrier to entry, broadening access to authentic research experiences and, therefore, the impact of the experience. Students have reported similar gains after participating in a CURE as those who participated in research internships such as learning to think like a scientist, finding research exciting, and clarification of one's career path [6,17]. Easier access is important, especially for online students who do not have as many opportunities to network to find potential research mentors. The nature of CUREs allows for benefits beyond those that students obtain from participation in UREs or REUs. For example, students in CUREs learn to express constructive criticism of their peers' analyses in a way that is thoughtful and helpful. Because students are less likely to view their peers as authority figures, they may feel more comfortable developing and expressing criticism. In doing so, they collaborate to build their own shared understanding rather than relying solely on an authority figure [6].

CUREs have gained traction in fields like biology and chemistry [14,18], and more recently, in astronomy. One previous study investigated the benefits of astronomy CUREs and QCUREs ('Quasi' CUREs), which include astronomical research projects that are components of larger astronomy courses but are not the sole focus and often do not include scientific discovery or broader relevance [8]. It was shown that both QCUREs and CUREs can improve students' perceived confidence, motivation, understanding of the scientific process, and attitudes toward doing science. However, CUREs are more likely than QCUREs to improve students' understanding of analysis and the importance of the role of collaboration in discovery [8]. These findings highlight the importance of implementing additional CUREs in astronomy courses, both in-person and online.

To help ensure that online students are better represented in the astronomy research community, we developed one of the world's first online CUREs in astronomy. There is a precedent for the successful creation of online CUREs in other disciplines. One example of such a CURE in physics is an online course at the University of Colorado, Boulder, a redesign of their large, introductory laboratory course that took place during the COVID-19 pandemic [19,20]. As part of this CURE, students worked with a researcher at the Laboratory for Atmospheric and Space Physics, investigating why the corona of the sun is much hotter than the photosphere. The researchers found that after participating in the CURE, the participants gained relevant skills, experienced teamwork in a productive and enjoyable way, and found the course and the research topic interesting and valuable [19]. This CURE provides a blueprint for the continued development and implementation of innovative, online research courses across physics and astronomy.

Students in the online astronomy CURE discussed throughout the remainder of this paper (hereafter referred to as the ERE, exoplanet research experience) contribute to a research project on the topic of exoplanets. Students in the ERE work to update the orbital parameters of a single, transiting, hot Jupiter. It is an entry-level astrophysics research course with a large impact on the scientific community, as astrophysicists applying for telescope time on space-based telescopes, like the James Webb Space Telescope (JWST) and the European Space Agency's ARIEL mission, need the most precise orbital parameters possible for the planetary targets they wish to observe. Although not one of the five components listed in the formalized CURE definition, data collection has been previously listed as an important aspect of a CURE [8], and therefore, the ERE differs from traditional CUREs in that students do not collect their own data.

In the ERE, students learn the importance of reproducible results, and the impact of the replication crisis on the natural sciences more broadly [21,22]. Through participation in the ERE, students learn how to reproduce, confirm, and update previous results, all while simultaneously advancing current scientific knowledge. The goals of this paper are as follows:

1. Explain in detail the design and structure of the ERE and,
2. To provide an initial analysis of this course's potential impact on a variety of student affective outcomes using the first two semesters of data.

The remainder of this paper is organized as follows: first, we provide details about Arizona State University's (ASU) online degree in astronomical and planetary science (APS), including the goals of the degree program and the demographics of students enrolled in the program. We then unpack the structure and motivation for the ERE, detailing how the course was broken down into 4 units: understanding transit photometry, reducing practice transit light curves, performing light curve reduction for a new target, and writing up the results. Next, we describe the methodology used to evaluate student outcomes as a result of the ERE. We then provide results from surveys and student interviews. Finally, we interpret our results and provide implications for future work and instruction.

II. ASU'S ONLINE DEGREE IN ASTRONOMICAL AND PLANETARY SCIENCE (APS)

In the fall of 2020, ASU introduced the nation's first online bachelor's degree program in astronomy and planetary sciences (APS). Students in the APS program take a variety of courses in communication, mathematics, physical sciences, planetary science, engineering, and astronomy. In addition to core scientific understanding, the APS program aims to provide students with skills in science communication, problem solving, computational techniques, and statistical data analysis. Students in the program are prepared for careers in K-12 STEM education, writing and journalism, science policy, and computer programming [23].

The APS degree program caters to a large variety of diverse learners. As of Spring 2023, there were 304 students enrolled in the APS program, making it the School of Earth and Space Exploration's (SESE) largest degree program by more than double. The APS program has an ethnicity breakdown of 64% White, 14% Hispanic, and 3% African American. The average age of an APS student is 29 with 47% identifying as women and 53% identifying as men. As of the Fall of 2022, one-third of the students are Pell eligible, indicating that they displayed exceptional financial need. Students come from a variety of educational backgrounds with 27% of students being first-time freshmen, 54% being transfer students, and 12% of students are first-generation college students. About 23% of students have a military affiliation.

While the current degree offers a general overview of astronomy, physics, computer programming, and mathematics, it is not currently optimized for students who wish to attend graduate school in astrophysics or a closely related field. Currently, students in the APS degree who have expressed interest in graduate school are advised to double major in physics or pursue a minor in physics at minimum. In a survey sent out to undergraduates enrolled in the APS degree program, 45% (38/84) of survey respondents expressed an interest in going on to graduate school after completing the APS degree, but even if they double major in physics, the lack of research opportunities for these online students makes this goal exceedingly difficult. Students enrolled in SESE's in-person astrophysics degree program have much easier access to faculty, potential research advisors, and REU programs. This creates a glaring inequity in the APS students' ability to participate in authentic research. The development of online CUREs, such as the ERE discussed in this paper, is necessary to address this inequity between the in-person and online degree programs.

III. ERE OVERVIEW

The ERE is a 300-level elective course offered as part of ASU's APS online degree program. In the ERE, students contribute to a citizen science project called Exoplanet Watch, an effort led by NASA/Jet Propulsion Laboratory (JPL) that uses ground-based, robotic telescopes to constrain the orbital parameters of large, transiting, exoplanets. The uncertainty of the celestial positions of these transiting exoplanets increases with time [24]. To keep a more precise record of transiting exoplanets' orbital parameters for eventual observation by space telescopes like JWST and ARIEL, additional follow-up observations must be taken in the interim.

We aimed to make our research course accessible to students who were still in the early stages of the APS program. Therefore, to enroll in the ERE, students needed only to complete a single introductory astronomy course. To make the research process less daunting, the ERE is broken down into 4 smaller units over 15 weeks:

1. Understanding transit photometry.
2. Reducing practice transit light curves.
3. Performing light curve reduction for a new target.
4. Writing up (synthesizing) the results.

TABLE I. An overview of the ERE schedule.

Module	Description	Duration	Section
1	Exoplanet transit virtual lab	1 week	III. B
2	Background literature review	1 week	III. B
3	Creating practice light curves	1 week	III. C
4	Introduction to the light curve reduction code	1 week	III. D
5	Light curve reduction for the target hot Jupiter	2 weeks	III. D
6	Reading other observation papers	1 week	III. D
7	Analyzing the light curves	1 week	III. D
8	Re-running significant detections	1 week	III. D
9	Creating plots to be included in the paper	1 week	III. D
10	Writing the data and methods sections	1 week	III. E
11	Writing the introduction	1 week	III. E
12	Writing the results section	1 week	III. E
13	Writing the abstract and conclusion	1 week	III. E
14	Synthesizing the sections into a single paper draft	1 week	III. E

The ERE is a synchronous online course. The first offering of the ERE occurred during the Fall 2022 semester and the second offering occurred during the Spring 2023 semester. Each offering of the ERE so far has capped at 15 student enrollees. Students were required to attend weekly, synchronous, 90-min meetings via Zoom. During the meetings, the co-instructors would lead a conversation about the previous week's assignment and encourage questions from the class. Especially during the data analysis portion of the course, the meetings were also an opportunity for students to present problems that they had and request feedback from the instructors and their peers. After Unit 3 of the course (reducing practice transit light curves), students worked in groups of 2–3 to synthesize their findings into a draft manuscript. An overview of the ERE schedule and the section containing additional information is provided in Table I.

A. ERE research topic and motivation

Since the first discovery of an exoplanet in 1995 [25], the field of exoplanetary astronomy has grown significantly, with over 5000 confirmed exoplanets discovered to date [26]. Astronomers use a variety of detection methods when searching for extrasolar planets, but the transit method remains the most robust, accounting for nearly 75% of the exoplanets listed on the NASA Exoplanet Archive.

Planetary transits occur when a planet passes in front of its host star, producing a small, periodic decrease in the observed brightness of the star. Astronomers analyze transit light curves, which show a star's change in brightness over time, to identify potential exoplanet candidates. Space telescopes like Kepler (launched in 2009) and the Transiting Exoplanet Survey Satellite (TESS, launched in 2018) [27] have provided hundreds of thousands of light curves to be analyzed in the search for exoplanets. Before the TESS mission comes to an end, it is expected to identify more than 10 000 transiting exoplanets [28], potentially providing thousands of stellar targets for future spectroscopic characterization by space telescopes such as Hubble, JWST, and the Atmospheric Remote-sensing Infrared Exoplanet Large-survey (ARIEL).

Space telescopes like TESS, however, can only observe stellar targets for a limited amount of time, and as a result, there are appreciable uncertainties of important exoplanetary properties such as the planet's midtransit time (when the exoplanet is directly between the observer and its host star) and orbital period. Furthermore, the uncertainty on the celestial positions of these transiting exoplanets increases with time [24,29]. Considering that TESS cannot continuously sample the night sky and that future space-based missions will launch after TESS' tenure is complete, it is critically important to the success of these future missions that the transiting exoplanets' orbital parameters are regularly updated.

To keep a more precise record of transiting exoplanets' orbital periods and midtransit times for eventual observation by space telescopes like JWST and ARIEL, additional follow-up observations must be taken to supplement and confirm TESS light curves. For many large exoplanets, these interim follow-up observations can be taken by small, ground-based telescopes. The planets that these telescopes can observe are typically warm, predominantly made of gas (gas giants), and on relatively short orbital periods. Constraining the ephemerides, or orbital positions in time, of these planets plays a significant role in advancing astronomers' understanding of planet formation. Follow-up characterization of these close-in, giant planets (conducted by missions like ARIEL) will provide significant insight into the relationship between atmospheric composition and planet mass [30,31], which is crucial to better understand both terrestrial and giant planet formation [32]. Providing future space-based missions with the most up-to-date celestial positions of these giant planets will also free

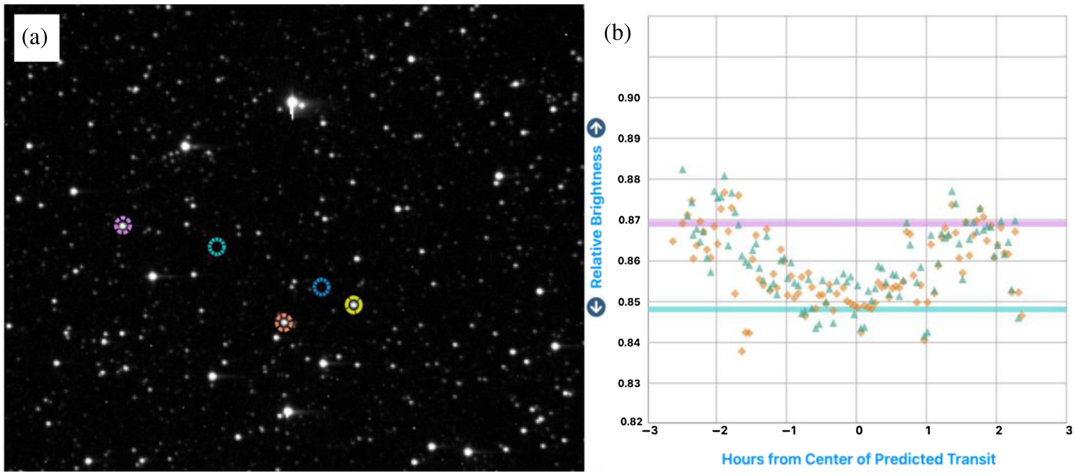

FIG. 1. Panel (a) displays the tool that students use on DIY planet search to identify the target star (yellow circle), comparison stars (orange and purple circles), and sky background points (teal and blue circles) to create a light curve like that shown in panel (b). The different color data points in panel (b) indicate which student performed the analysis.

up more time for future space-based and large ground-based observations of small, rocky planets on longer orbital periods that could be potentially suitable for life.

This research topic is well matched to our particular audience because it does not require prior research experience or advanced prior astronomical knowledge. Students need only to have taken an introductory astronomy course, so they are familiar with the concept of exoplanets. Additionally, using previously collected data enables the students to focus more directly on the analysis and paper writing components of the course. While entry level in nature, the project is still relevant and impactful to the observational astronomy community more broadly.

B. Understanding transit photometry

Students begin the ERE by completing an online lesson taken directly from an online astrobiology course developed at ASU. The course uses an intelligent tutoring system that provides students with individualized feedback as they progress through lessons [33]. Specifically, ERE students complete the lesson on exoplanet transits. The lesson teaches students what a transit is, how to observe a transiting exoplanet, how a transit light curve is generated, and how conditions can affect the appearance of a light curve. After completing the transits lesson, students move on to a background literature review on the topics of transit photometry [24,28,29,34] and the importance of reproducibility in scientific research [21,22]. After reading the suggested articles, the students complete a discussion board post summarizing, listing any questions they have, and engaging with at least one post made by their peers. During the weekly synchronous meeting, the course instructors and a visiting exoplanet researcher answer the student's questions and discuss the topics addressed in the articles in detail.

C. Reducing a transit light curve

After learning about transit photometry, students segue into light curve reduction using a variety of practice tools. First, students learn about multiobject photometry, the process of observing light from multiple astronomical sources, by generating practice light curves using MicroObservatory's DIY Planet Search platform.[1] DIY Planet Search uses the Harvard & Smithsonian MicroObservatory online telescope network (a collection of 6-inch, ground-based, robotic telescopes) to take images of hot Jupiter exoplanets. Users on DIY Planet Search can collect their own data, measure the brightness of their target, produce a light curve, and share their findings with the community. Throughout this process, students in the ERE learn the importance of image calibration. This phase of the ERE is important to ensure that students understand all the steps required to reduce a light curve and, therefore, how the code that they use later in the course works. Each target has around 100 images for the students to work through and calibrate. After calibrating their images, each image becomes a data point on the students' light curve. Examples of tools and data products from DIY Planet Search are shown in Fig. 1.

In addition to learning the steps of light curve reduction, students also learn how to interact with real data. Each group of students is assigned a night of "clean data" and a night of "messy data." This way, students learn how to deal with clouds, haze, bad tracking of the telescope, and other factors that interfere with the brightness measurements of the target star. Following the completion of their light curves, students complete an assignment where they are asked to think critically about the process of light curve reduction.

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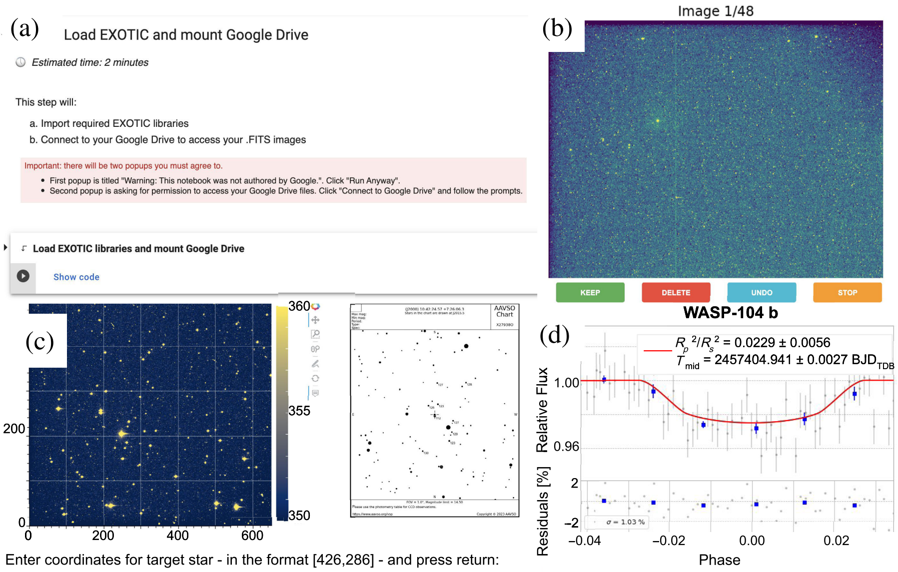
[1] https://waps.cfa.harvard.edu/microobservatory/diy/index.php.


Load EXOTIC and mount Google Drive

Estimated time: 2 minutes

This step will:

a. Import required EXOTIC libraries
b. Connect to your Google Drive to access your .FITS images

Important: there will be two popups you must agree to.

- First popup is titled "Warning: This notebook was not authored by Google.". Click "Run Anyway".
- Second popup is asking for permission to access your Google Drive files. Click "Connect to Google Drive" and follow the prompts.

Load EXOTIC libraries and mount Google Drive

Enter coordinates for target star - in the format [426,286] - and press return:

FIG. 2. Panel (a) displays the Google Colaboratory Notebook with EXOTIC that students use to reduce their light curves. Panel (b) displays a built-in function of EXOTIC that allows students to analyze the quality of each image. Panel (c) presents an example of a star chart that students use to identify the location of their target and comparison stars. Finally, panel (d) displays an example of a light curve output of WASP-104 b from EXOTIC.

D. Performing light curve reduction for a new target

The primary research goal of the ERE is for students to update the orbital parameters of an exoplanet that can be observed using the MicroObservatory network of telescopes. Each semester, we receive approximately 50 nights of data for an individual planetary target from the MicroObservatory team. Students are tasked with cleaning the data, performing the reduction, and analyzing the results. Students use the EXOplanet Transit Interpretation Code (EXOTIC) written by the Exoplanet Watch team to analyze their photometric data [24]. EXOTIC is a Python 3 pipeline that can be run locally or on Google Colaboratory. For our purposes, we chose to use the Google Colaboratory Cloud because (i) it supports the sharing of data and results among team members and (ii) it is user-friendly, especially for those students who have little to no programming experience. As the students reduce their light curves, they submit them to the American Association of Variable Star Observers[2] (AAVSO) repository. If their data are used in a publication, the student will be offered co-authorship. Illustrations of the student view when working with EXOTIC are presented in Fig. 2.

After reducing the light curves, the students work to determine which light curves represent significant detections and can be included in potentially publishable results. These potentially publishable nights of data are then reassigned to different students to rerun to standardize the cleaning and analysis processes. Finally, the students work together to determine and compile the final significant detections, with which they make a direct comparison to previously published values for the target's orbital parameters.

E. Writing the results

The last 5 weeks of the ERE are dedicated to compiling the results from the semester and collectively writing a complete paper suitable for submission to a peer-reviewed, academic journal. Throughout the writing process, students work in groups of three and are assigned a new section of the paper to write each week. They begin with the data and methods sections, then move on to the introduction, results, and finally the abstract and conclusion sections. Each week, the instructor grades each group's assignments and provides in-depth feedback. In the last week of the course, each group combines their work and incorporates instructor and peer feedback to create a complete draft of a paper. One of the instructors of the course then works to combine final drafts into a single paper. During the first iteration of the ERE in the Fall of 2022, the students produced a paper, updating the midtransit time and orbital period of WASP-104 b that was published in the Journal of the American Association of Variable Star Observers [35]. In this paper, students were able to decrease the uncertainty of the midtransit time of WASP-104 b by 97.4% since its discovery [36], rivaling results obtained using the space-based telescope, TESS [37]. During the second iteration of the ERE in Spring 2023, students worked to produce 13 significant light curves of HAT-P-54 b, decreasing the uncertainty on the midtransit time by over 10% since the

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[2] https://www.aavso.org/.

most recent publication [37]. For the results produced in the Fall 2022 semester of WASP-104 b, please see Hewitt *et al.* [35].

IV. METHODS

To best assess student outcomes, we chose an explanatory mixed methods approach, wherein qualitative data were used to further expand upon and explain trends in the quantitative results [38]. Quantitative data on student outcomes were obtained using content knowledge and affective surveys administered to the students at the beginning and end of the course. The surveys are discussed in detail in Sec. IV. A. The qualitative data take the form of interviews administered to a subsection of the students at the end of each semester; this process is described in Sec. IV. C. All work was performed under a research protocol approved by the ASU Institutional Review Board (protocol No. 13950). Students were required to complete both surveys for participation credit, but they were not required to consent to their responses being used for research purposes. Interviews were done on a volunteer basis; participation was incentivized as each interviewee received a $25 gift card. The interviews were conducted via Zoom with cameras off and the transcripts were written to remove any identifying information.

A. Survey development

To begin to evaluate the effectiveness of our CURE, we assessed the impacts of the course on multiple affective outcomes, namely student self-efficacy, science identity, sense of belonging, and project ownership. We chose to prioritize these outcomes based on the “large CURE model” from Corwin *et al.* [16]. Specifically, these affective outcomes were designated as hubs, meaning that they are involved in at least six connections with other outcomes, except for project ownership, which only has five connections [16]. We also measured changes in students’ understanding of the transit method of exoplanet detection. Finally, we evaluated perceived benefits from student participation in the ERE and three out of five of the CURE components listed in Sec. I (discovery, collaboration, and iteration). We evaluated these outcomes with two assessments (one which we will refer to as the “affective survey” and the other which we will refer to as the “content knowledge assessment”). The affective survey included an amalgamation of published, validated assessments (described in detail in Sec. IV. A. 1). We chose to use each validated assessment as written (even if 1–2 survey items did not fully align with our research goals) to avoid revalidation. The content knowledge assessment, however, was of our own design (described in Sec. IV. A. 2). The full text of the affective survey and content knowledge assessment items used may be found in Appendixes A and B, respectively.

1. Affective outcomes: self-efficacy, science identity, sense of belonging, and project ownership

Two different forms of self-efficacy were assessed as part of this study: course performance self-efficacy, and research self-efficacy. The first, course performance self-efficacy, is defined as students’ belief in their ability to perform well in the course. Course performance self-efficacy was assessed at the start of the semester (pretest only) using the 8-item self-efficacy subscale from the Motivated Strategies for Learning Questionnaire [39]. This subscale included statements such as “*I am confident I can do an excellent job on the assignments and tests in this course*” and asked the participants to rank the statements on a five-point Likert scale from strongly disagree to strongly agree. Research self-efficacy is defined as students’ perceptions of their ability to perform various research-related tasks. Research self-efficacy was assessed both at the beginning and end of the semester (pre- and post-test) using the survey from Estrada *et al.* [40], originally modified from Chemers [41]. It included questions that asked students to rank their confidence surrounding research question formulation, use of technical skills, data collection, understanding of scientific literature, and data analysis on a five-point Likert scale from not confident at all to completely confident. Although the ERE did not include a data collection component, we chose to keep the items pertaining to data collection in an effort to administer the previously validated survey from Estrada *et al.* [40] in its entirety.

Science identity was assessed pre- and post-test using the single-item STEM Professional Overlap Identity Measure (STEM-POI-1) [42]. This item presented students with Venn diagrams with varying degrees of overlap between the participant, “Me,” and a “STEM Professional.” Participants were asked to “*Select the picture that best describes the current overlap of the image you have of yourself and your image of what a STEM professional is*.” For the second iteration of the course (Spring 2023), we replaced the term “STEM professional” with the term “scientist.” This is discussed in more detail in Sec. VI.

Student sense of belonging was evaluated pre- and post-test with respect to two different communities: within the astronomy community more broadly and more specifically within ASU. Sense of belonging within the astronomy community was measured using a modified version of the survey from Stout *et al.* [43] with the word “physics” replaced with “astronomy.” The three survey items (*“I feel like I belong in astronomy,” “People in astronomy accept me,”* and *“I feel like an outsider in astronomy”*) were ranked on a five-point Likert scale from strongly disagree to strongly agree. Students’ sense of belonging within the ASU community was measured using survey items from Smith *et al.* [44], modified from Walton and Cohen [45], and the College Satisfaction and Persistence Scale [46]. These four items (“*I feel like I belong in my department,”*

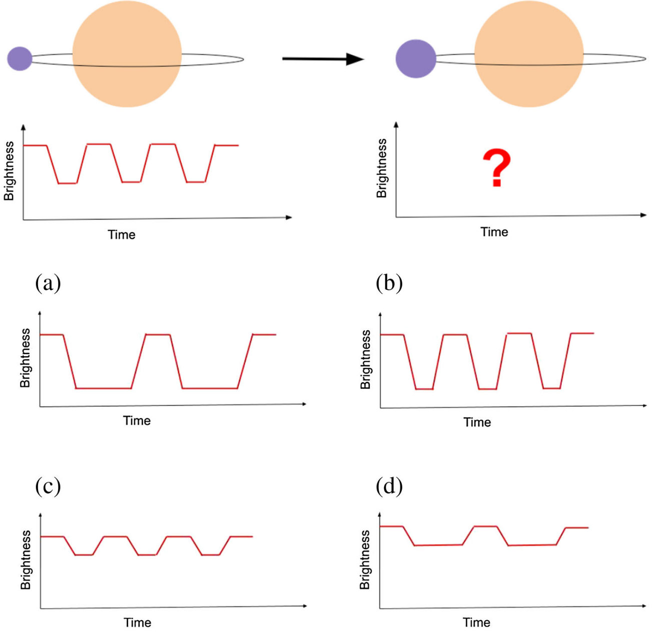

FIG. 3. One of the questions on the content quiz , "How would the light curve change if only the radius of the planet were increased (i.e., distance from the star and radius of the star remain the same)? A simplified light curve for a hypothetical planet-star system is given below. Choose the appropriate light curve for the new system." Panels (a), (b), (c), and (d) are the multiple choice options that the students choose from.

"I am satisfied with my academic experience", "I feel comfortable at Arizona State University," and "*People at Arizona State University accept me*") were also ranked on the same five-point Likert scale.

Project ownership was evaluated postcourse only and only during the Spring 2023 ERE offering. Project Ownership was assessed using a subset of the 15-item Project Ownership Survey (POS) [47]. This survey includes items such as "*My research project was exciting*," "*My findings were important to the scientific community*," and "*The findings of my research project gave me a sense of personal achievement*." The items were ranked on a five-point Likert scale from strongly disagree to strongly agree.

2. Conceptual outcomes and perceived benefits

Students' understanding of the transit method for exoplanet detection was assessed using a seven-item pre- and post-test developed by the authors (referred to as the content knowledge assessment). The content knowledge assessment consisted predominantly of simplified light curves and diagrams of planet-star systems. Students were asked to predict how transit light curves would change as certain parameters of the planet-star system varied. Figure 3 depicts an example of a question from the content knowledge assessment where students were asked, "How would the light curve change if only the radius of the planet were increased (i.e., distance from the star and radius of the star remain the same)? A simplified light curve for a hypothetical planet-star system is given below. Choose the appropriate light curve for the new system." Students were given four multiple-choice options to choose from. The multiple-choice answers include options that represent common conceptual difficulties. For example, for the question shown in Fig. 3, if the student did not consider that the mass of the planet was negligible compared to that of the star, they might assume that increasing the radius of the planet would increase the period (option A). The content knowledge assessment also contains two short-answer questions about more advanced topics highlighted in the ERE.

To evaluate perceived benefits from student participation in the ERE, we used the items from the benefits section of the widely adopted CURE Survey [48,49]. Our decision to use this survey was intentional in that it will enable us to directly compare our students' responses to students who took the identical survey in other CUREs across a variety of disciplines as a direction of future analysis. This will better position us to analyze the effectiveness of the ERE in the context of prior CUREs and will provide additional insight into the efficacy of our CURE model. The benefits section of the CURE Survey was administered post-test only and included 21 items that asked students to rank their perceived level of gain on a five-point scale from no gain to very large gain for several known benefits of CUREs (e.g., skills in interpretation of results, understanding of how scientists think, and skills in science writing).

Finally, to help us understand students' perceptions of their engagement in three out of five of the CURE components listed in Sec. I (discovery, collaboration, and iteration), we asked students (post-test only) to rate their level of agreement (on a five-point Likert scale from strongly disagree to strongly agree) with how well the ERE delivered on expected CURE outcomes. We used the entire 17-item Laboratory Course Assessment Survey (LCAS) [50]. We chose to only assess the three of five CURE components mentioned because these were the components included in the LCAS. Sample survey items include, "in this course I was expected to": explain how my work has resulted in new scientific knowledge, generate my own research question or hypothesis to guide an investigation, and develop new arguments based on data.

B. Quantitative data collection

Survey items assessing science identity, course performance self-efficacy, research self-efficacy, sense of belonging, project ownership, CURE benefits, and the LCAS were all combined into one survey (referred to as the 'affective survey'). All these constructs were measured both at the beginning and end of the semester except for course performance self-efficacy (pre-test only), project ownership (post-test, Spring 2023 only), and CURE benefits and

TABLE II. Summary of affective measurements and timing.

Pre only	Pre and post	Post only
Course performance self-efficacy	Science identity	Project ownership
	Research self-efficacy	CURE benefits
	Sense of belonging (ASU)	CURE components
	Sense of belonging (astronomy)	Interviews

LCAS (post-test only). A summary of the measurements and timing is provided in Table II. The affective survey pretest was administered in the second week of the course and the post-test was administered in the final week of the course. The affective survey was administered online via QuestionPro.[3] The content knowledge assessment was administered via Canvas quiz for participation credit during the first and penultimate weeks of the course.

C. Student interviews

The qualitative component of this research effort took the form of interviews with a subset of the students (20%–50%) enrolled in the ERE at the end of the Fall 2022 and Spring 2023 semesters. The interviews were roughly 45 min long and conducted by a graduate student who had no prior interactions with the students. The graduate student who conducted the interviews received three training sessions prior to interviewing, including two practice interviews and readings on qualitative analysis best practices. The interview questions were designed to cover the same affective and conceptual outcomes as the quantitative assessments, although there were some additional questions aimed at probing topics not fully covered in the aforementioned assessments. These topics included students' connections with their classmates, the course instructors, and ASU, as well as the course's treatment of diverse students, and overall feedback on the course structure. The resulting semistructured interviews were 26 questions long, with four main sections: social aspect, course environment, the process of doing the research, and general questions about their experience as a whole. It is worth noting that not all the interview questions relate directly to the key outcomes addressed in the surveys. Some questions are designed to elicit feedback about the course for use in improving future iterations, while others ask more general questions that could potentially provide explanatory support for the main outcomes. The interview questions are presented in Appendix C. Students were also asked follow-up questions that differed for each interviewee depending on their initial responses. While the interviews were being conducted, we also developed a codebook based on the interview questions and quantitative assessment aims.

The codebook was sorted into the following topics: sense of belonging, confidence, persistence in research, science identity, interpersonal relationships, diversity, course design, agency, benefits of CUREs, overall course gains, and connection with ASU. The specific codes within each section were written based on potential responses and were also modified and added to as the preliminary coding process progressed. In its final version, there were a total of 77 codes in the codebook. Examples of codes include "increased sense of belonging," "want to continue doing research," and "work felt meaningful."

To determine interrater reliability, we chose a simple proportion agreement:

$$\frac{N_{\text{agreements}}}{N_{\text{agreements}} + N_{\text{disagreements}}}. \tag{1}$$

This is a less robust statistic than others commonly used such as Cohen's Kappa [51], as it did not take into account the possibility of an agreement by chance. However, we felt comfortable using this statistic due largely to the size of our codebook, as the large number of codes decreased the possibility of a chance agreement significantly. There is also a precedent of using this statistic in the literature with large codebooks [52,53].

The process of determining interrater reliability was conducted after the Fall 2022 semester using the initial seven interviews. We had two coders, one graduate student who conducted the interviews and developed the codebook and another graduate student who had no familiarity with the research project. Both coders used the codebook to code three out of the seven interviews. This resulted in a total agreement across all codes of 55.3%. At this stage, we took on a negotiated agreement approach, after which 20 of the 77 code names and/or definitions were altered to the mutual satisfaction of both coders. These changes were small, such as changing a code name regarding characteristics of the instructors from "understanding" to "understanding of external factors." Definitions were altered to be more precise. For example, the last sentence was removed from the following code definition: "Students felt appreciative towards ASU for providing the course. They felt that the course was a beneficial addition to their academic journey. They could also express interest in future courses of a similar nature in the future." After this process, both coders recoded two of the previously coded interviews, as well as a third interview that had not been discussed while reformulating the codebook. In this sense, we could get some

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[3] https://www.questionpro.com/.

understanding of independent interrater reliability with the third interview, as well as a confirmation that the reformulated codebook led to higher agreements. With the reformulated codebook, a total agreement of 83.6% across all codes was met. As the combined agreement overall was now above our predetermined limit of 80% ([53]), the graduate student interviewer reviewed and coded the rest of the interviews from the fall semester with the updated codebook. The same graduate student used the codebook to code the Spring 2023 semester interview responses.

V. RESULTS

After the first and second iterations of the ERE, we began an investigation into potential changes across outcomes assessed on both the pre and post-tests (research self-efficacy, science identity, sense of belonging, and content knowledge). Prior research suggests that we would expect to see a statistically significant increase across all four outcomes [16,54–57]. Additionally, we began to evaluate students' responses to the pre-test-only (course performance self-efficacy) and post-test-only (project ownership, CURE benefits, and the LCAS) questions. Finally, we coded all twelve interviews, looked for similar trends with the quantitative data, and gathered further information that could help explain why those trends exist.

A. Setting and participants

We administered both assessments as required components of the ERE's pilot offering. Twenty-nine students total were enrolled in the first and second iterations of the ERE during the Fall 2022 and Spring 2023 semesters (15 students in the Fall and 14 students in the Spring).

Twelve of the students from the Fall and 12 students from the Spring completed both the pre- and post-tests for the affective survey and consented to their data being used for research ($N = 24$), and 14 students from the Fall and 12 students from the Spring completed both the pre- and post-tests for the content knowledge assessment ($N = 26$). All 29 students in the course were enrolled in the online APS program, several of whom were double majoring in physics. Most of the students were more advanced in their degree (or transfer students). Of the 24 students who completed the affective survey's demographic questions, 4 students had earned less than 30 credits, 2 students had earned 30–60 credits, 4 students had earned 61–90 credits, and 14 students had earned more than 90 credits by the end of the semester in which they were enrolled in the ERE. Of the 14 students who responded to the demographic question about their gender, 6 students identified as women, 7 identified as men, and 1 identified as nongender binary. In the Fall 2022 semester, 6 students were recruited from another online CURE offered at ASU and therefore had previous research experience. In the Spring 2023 semester, we added a question asking students: "Is this course your first time conducting scientific research?" Out of the 12 respondents, 2 students indicated that they had previously conducted scientific research and 10 students indicated that they had not. The demographic information collected on the affective survey can be found in Appendix D.

We conducted a total of 12 interviews with participating ERE students in the first year, 7 students from the fall semester and 5 from the Spring. Nine of the interviewed students identified as men and three identified as women.

B. Matched quantitative data

To measure changes across the aforementioned pre- and post-test outcomes, we combined student responses from the Fall 2022 and Spring 2023 semesters, when appropriate. We then determined if the distribution of responses for each outcome was normal or not, indicating which statistical tests we should use. To determine normality, we performed a Shapiro-Wilk test due to our small sample size ($N < 50$) and determined that science identity in both Fall 2022 and Spring 2023 ($p = 0.275$, $p = 0.126$), sense of belonging in astronomy ($p = 0.681$), and content knowledge ($p = 0.122$) were all distributed normally. The responses for the sense of belonging at ASU ($p = 0.019$) and research self-efficacy ($p = 0.025$) were not normally distributed. We analyzed the pre- to post-course changes using paired t tests for the outcomes that met the requirement of normally distributed data and used a Wilcoxon signed rank test for those that were not normally distributed. A summary of the results from this analysis can be found in Table III.

In the analysis of the pre- and post-affective survey, we saw a significant increase in students' reported research self-efficacy, science identity (Spring 2023 only), and content knowledge pertaining to exoplanet transits. However, there were no significant increases in the students' reported sense of belonging (both in astronomy and at ASU) or in students' science identity for the Fall 2022 dataset. Science identity is reported separately for the fall and spring semesters because the survey was modified between semesters to address issues that students had with the wording of the question; this is described in detail in Sec. VI.

C. Unmatched quantitative data

Course performance self-efficacy was assessed on the affective survey only at the start of the Fall 2022 and Spring 2023 semesters ($N = 24$). About 92% of students indicated that they agreed or strongly agreed that they would be able to achieve an excellent grade in the course. In addition, 100% of the students felt they would be able to understand the most basic concepts taught in the course and 75% of the students indicated that they were confident in their ability to understand the more complex topics. Overall, students entered the ERE with high course performance self-efficacy ($M = 4.255$, $\mathrm{SD} = 0.515$).

TABLE III. Results of the statistical analyses for the outcomes assessed in the pre- and postsurveys. All outcomes were measured on a 5-point scale, except for science identity and content knowledge which were assessed on a seven-point scale. Significant p-values ($p < 0.05$) are indicated with * and large effect sizes are bolded.

		Precourse	Postcourse		
Outcome	Sample size	Mean ± SD	Mean ± SD	p-value	Effect Size
Research self-efficacy[a]	24	3.146 ± 0.939	3.903 ± 0.556	<.001*	**0.728** (Large)
Science identity (Fall)[b]	12	4.417 ± 2.065	4.417 ± 1.676	1	0
Science identity (Spring)[b]	12	1.667 ± 1.155	4.583 ± 1.730	.002*	**1.983** (Large)
Sense of belonging (Astronomy)[b]	24	4.056 ± 0.679	4.208 ± 0.721	.372	0.218 (Small)
Sense of belonging (ASU)[a]	24	4.177 ± 0.549	4.375 ± 0.711	.140	0.368 (Small)
Content knowledge[b]	26	4.308 ± 0.788	5.577 ± 0.987	<.001*	**1.421** (Large)

[a] p values were based on Wilcoxon signed-rank tests due to violations of the assumption of normality; effect sizes are reported as a Wilcoxon effect size (r).

[b] p values were based on paired t tests; effect sizes are reported as Cohen's d.

Students' responses to the post-test-only benefits section of the CURE survey showed consistent self-reported gains on many of the skills typically incorporated into CUREs ($N = 24$). On average, students responded positively to 20 out of the 21 items on this component of the survey. The only item that received a negative response from the students was "*Skills in how to give an oral presentation*." This is unsurprising considering there were no opportunities in the ERE for students to formally present their findings via oral presentations. This item was included because we chose to use the entire research-validated survey. The skill that received the strongest positive response was "Understanding of how scientists work on real problems," ($M = 4.250$, $\mathrm{SD} = 0.676$), with 87.5% of the students reporting a large to very large gain postcourse.

Students also reported that they participated in three out of five overarching components of a CURE addressed by the LCAS: discovery, collaboration, and iteration ($N = 24$) [50]. In the items pertaining to discovery, students most positively responded to the item: "In this course, I was expected to explain how my work has resulted in new scientific knowledge" ($M = 4.292$, $\mathrm{SD} = 0.624$). About 92% of students responded that they agreed or strongly agreed with that statement. Students also felt as though they were encouraged to collaborate in the ERE; 100% of the students agreed or strongly agreed that they were encouraged to: help other students with data collection and analysis ($M = 4.708$, $\mathrm{SD} = 0.464$), contribute their ideas during class ($M = 4.708$, $\mathrm{SD} = 0.464$), reflect on what they were learning ($M = 4.708$, $\mathrm{SD} = 0.464$), and discuss the investigation with their peers and instructors ($M = 4.708$, $\mathrm{SD} = 0.464$). Finally, the students also reported that they had time for iteration. All ($N = 24$) of the students indicated that they had time to revise paper drafts based on feedback ($M = 4.708$, $\mathrm{SD} = 0.464$) and to revise or repeat work to address errors or fix problems ($M = 4.583$, $\mathrm{SD} = 0.504$).

Overall, the students reported a high level of project ownership ($M = 4.278$, $\mathrm{SD} = 0.433$) in the Spring 2023 semester dataset ($N = 12$). Students most positively responded to the item, "The findings of my research project gave me a sense of personal achievement," ($M = 4.667$, $\mathrm{SD} = 0.492$) with 100% of the students agreeing or strongly agreeing with that statement. The full results for course performance self-efficacy, benefits, components of CUREs, and project ownership are presented in Appendix A.

D. Qualitative data

Once all the interviews were coded, specific codes were chosen that directly related to the key outcomes of this study: research self-efficacy, science identity, sense of belonging in astronomy, sense of belonging in ASU, and project ownership. Content knowledge was excluded from the qualitative analysis due to the limited information gained from the interviews. The applications of these key codes are summarized in Table IV below. The following subsections explore these results in detail.

1. Research self-efficacy

The qualitative results suggest improvement across all the outcomes summarized in the quantitative data in Table III. Table IV shows the application of certain key codes relevant to the primary outcomes studied. Regarding research self-efficacy, we found that every student indicated that their confidence regarding the use of research tools and methods increased due to this course, corroborating the significant change in research self-efficacy found in the quantitative data. Every student could also identify specific skills they gained from this course, with some of the most common being coding or software use (10/12), organizing a research paper (8/12), and a general understanding of the research process (8/12). As one student shared, "I feel like the main thing I took away from it is that it kind of demystified the process…I've seen…academic journals before, these papers… your head kind of spins when you're first trying to come to grips with some of this information. And I feel like this course really helped break

TABLE IV. Qualitative results for key codes applied to student interviews, organized by outcome. The sections below provide examples of student responses that correspond to these codes.

Outcome	Code	Number of student responses [N (%)]
Research self-efficacy	Confidence in using research tools and ideas increased	12 (100)
Science identity	Felt like a scientist post-course	10 (83.3)
	Course changed perception of what it means to be a scientist	9 (75)
Sense of belonging (astronomy)	Course improved sense of belonging	12 (100)
	Course improved sense of belonging, but still didn't feel as if they fully belong	2 (16.7)
	Felt part of the scientific community	6 (50)
Sense of belonging (ASU)	Felt more connected with ASU post-course	8 (66.7)
	Felt more connected to ASU specifically via people and relationships gained	3 (25)
	Felt appreciative towards ASU	5 (41.7)
Project ownership	Felt empowered to take leadership	11 (91.7)
	Felt like they contributed	9 (75)
	Work felt meaningful	11 (91.7)

down the process for me. It is not as intimidating a process as it was to me when I started the class."

Another student shared that they had struggled with their confidence in their ability to do science due to difficulties in specific classes. "I've had some struggles over the years with certain applied mathematics, calculus…specific chemistry courses…that works against my confidence and against my consideration that I…may be able to do science. This course had the opposite effect. It showed that if I'm able to apply skill and interest and methodology in certain areas, that I really do have the passion, drive, and competency for science."

2. Science identity

The students interviewed also shared that the course had a large impact on their science identity. While ten students stated that they felt like a scientist after the course, many of them added qualifiers such as "nascent-", "in lower-case letters-", or "junior-" scientist. It was clear from the interviews that the way students defined "scientist" varied significantly. For one student, the idea of being published had a lot to do with their science identity, as they shared: "I would say at this point I might have graduated up to science contributor, and then once we get-if we get our paper published, then I'll consider myself to be, like, a scientist, but I'll say it like in lower case letters just so it doesn't draw too much attention by people who have more publications." For other students, the participation in what they perceived as genuine research had a big contribution to their science identity: "We were doing actual research…I've had some academic background, but I've never actually done research like that, where I got to reduce data…You know these certain things that sort of, like, the traditional: what it is like to be a scientist, like check. I got that check now. So, it did make me feel a lot better."

Nine students indicated that the course changed their perception of what it means to be a scientist, with the most common change being focused on the idea of collaboration. As one student said, "We used to think that scientists, you know, went into a lab as an individual and came out with great ideas and wrote those ideas down and delivered them to the world. But even if that were a reality at one point, it is not today. Today it is extraordinarily important to work collaboratively, and that collaboration can be across long distances, or it can be locally, but either way there's a lot of collaboration required in all the work that I see being done today. So that's been a real eye opener." Seven students also shared that one of the main skills they gained from this course was collaboration or working with other students to conduct research: "So, I think my confidence level has increased tremendously in working with others particularly in small group settings…But you know, working with others is always more productive than working by yourself." This went along with the theme of positive social interactions among the students in the class, with all 12 interviewees feeling as if the students were friendly and colloquial. Ten of the interviewed students also mentioned some element of peer mentoring or feedback, wherein they could reach out for or provide assistance to their classmates, further aligning with the quantitative results.

3. Sense of belonging (astronomy)

All 12 students also indicated an improved sense of belonging in astronomy or science, but the reasoning varied significantly across the interviewees. Several students mentioned feeling as if they lacked the academic skills to belong in the field, but this course helped them feel more comfortable. “Math is kind of my fear point in academia,” one student explained, “But with these experiences so far… [they’ve] helped me understand, and it really makes me feel okay, we all start somewhere, and I’m starting here and that’s okay.” For one student, their improved sense of belonging came from an increased desire to be in a scientific field, “[This course] made me want to be in it more…it solidified that research is what I want to do.” Another student felt like the act of publishing a paper had the largest impact on their sense of belonging, explaining “It’s very fulfilling and very exciting to have something like that. I definitely feel like I’m part of the science community.” Two students indicated that although their sense of belonging improved, they still did not feel as if they fully belonged. As one student shared, “It has definitely helped my sense of belonging. It has also shown me some areas that I need to improve on, which is okay, and I’m okay with that, you know, it’s definitely kind of showing me what I need to work on in order to feel more like I belong.”

Six interviewees explicitly mentioned that they felt like a part of the broader scientific community thanks to the connections they made with researchers, either the instructors of the course or collaborators they met at JPL and Exoplanet Watch. One student explained the benefits of the connections they made from this class: “We have begun to communicate, at least some of us have, with academics and scientists and the broader global environment who are doing similar kinds of work and have shown themselves to be completely open…So I think that, you know, those relationships to me are a huge asset, just as much as learning any particular skill.”

4. Sense of belonging (ASU)

Regarding the sense of belonging at ASU or the School of Earth and Space Exploration (SESE), student responses varied based largely on their prior experiences with the school. Of the 12 interviewees, 8 indicated that they felt more connected to ASU after completing the course, with five indicating appreciation and admiration that the school offered a course such as this one. For some of those students, the synchronous nature of the course design had a large role in that connection: “I think, being an online student without these opportunities, it’s very hard to not feel mildly isolated. A lot of the classes…it’s prerecorded…it’s like a very expensive Khan Academy. I’m not saying that as a knock, but it’s not-it’s fundamentally not very different. So, like, it’s hard to feel like you’re part of that SESE community when you’re doing classes that are just like that. So, the research class made me feel more part of, like, a more defined group, I guess.” Several students also felt that their improved sense of belonging at ASU was due to forming connections with their instructors who made them feel a part of the department, as one student explains: “So we got to know [the instructor] so well during this process…she’s been with us each step of that process… making me feel that I know and belong and have a…role in the ASU environment and particularly this one.” Another student felt that they were able to connect with their classmates and feel more a part of the ASU community through them as well as the instructors: “I think a good combination of being involved with people who are actually there and then people who are also within the same school with a similar goal kind of made me feel a little bit more connected.” For the four students who did not feel more connected, three of them shared it was largely due to other experiences with ASU that they could compare with the online environment. As one student (who had previously been an undergraduate on a physical campus) stated, “I feel a little bit more disconnected because I’m online.” Another student shared “I am like a die-hard Sun Devil, so this class didn’t like connect me any more. I don’t know if I could be any more connected, to be honest with you.”

5. Project ownership

Finally, the interviews suggested a strong sense of empowerment and ownership among the students. Eleven students reported feeling empowered to take on leadership roles in the class, with nine feeling as if they consistently contributed to the work of the class. As one student said, “So there’s direct, you know, impact. If you do or don’t do something and you have to figure it out. You have to take ownership and even the work that you produce is yours, and you can take pride in it… So, on that level, it’s very in your face that you know your work matters to not only just yourself, but to other individuals.” Some students felt as if their work was well represented in the final paper, sharing, “And I can look at it and see, here’s the part that I did, I know that’s my diagram, because that’s my, you know, Oh, that one’s mine!…So I feel like all of us are being equally incorporated because we all have something, you know, worth contributing.” Similarly, some students felt as if they had a lot of autonomy during the research process which made it feel more like a legitimate experience: “I guess just that it wasn’t intimidating, it was open, like there was room for us to do the research on our own and come to our own conclusions and ask our own questions, everything wasn’t set in stone, and I never felt like, you know, what I did didn’t matter. I always felt like what I was doing I had to do right, and it was important to me.” However, one student who had a prior research experience disagreed, sharing as if it felt like the course was too structured: “part of me, I think, was kind of expecting more of that from this course, and I don’t totally know how you do that fully remote, or if you can to the same degree. But I remember, you know, kinda missing that…just because there is a little bit more oversight. There’s… less of a capability to kind of, you know, answer that question…to… be more in control, or… kind of have more of a say.” Even with that sentiment, 11 of the 12 interviewees mentioned that the work they were doing felt meaningful and like they were contributing to real scientific research.

VI. DISCUSSION

In this study, we presented the development of one of the first online CUREs for astronomy majors. Additionally, we performed an analysis of student affective outcomes (i.e., research self-efficacy, course performance self-efficacy, science identity, sense of belonging at ASU and in astronomy, and project ownership), student conceptual understanding of exoplanet transits, students' perceived benefits, and students' perceived components of a CURE using the first year of student data. Using paired t tests and Wilcoxon signed rank tests, we found that students reported an increase in their research self-efficacy and science identity (Spring 2023 only) and additionally, experienced an increase in their exoplanet transit content knowledge. Students also reported experiencing an increase in their sense of belonging to ASU and the larger astronomy community in the interviews. Through descriptive statistics, we found that students experienced feelings of project ownership regarding their research. They also reported gaining almost all the CURE benefits and participating in all three overarching components of a CURE assessed by the LCAS: collaboration, iteration, and discovery. For the remainder of this section, we explore the relationship between the quantitative and qualitative results as they pertain to research self-efficacy, science identity, sense of belonging, and project ownership.

A. Research self-efficacy

The qualitative results mostly mirrored these findings and can be used to explain several of the statistically significant changes. For example, we can explain the large increase seen in research self-efficacy using the interview responses. As explored in Usher and Pajares [58], the main sources of self-efficacy are mastery experiences, emotional or physiological states, social persuasion, and vicarious experiences. The mastery experience component is particularly relevant, as students spent a lot of time in the course doing hands-on research. All 12 students interviewed noted that they felt much more confident in their ability to use the tools and ideas involved in the research project. As one student put it: "Well, of course, part of it is just simply that we were having to use those tools repeatedly throughout the semester to reach the point where we had the data and the results that were needed. So oh, you know, as I said, we learn by doing, and in the process of this class we ended up…having a lot of use and experience with those tools." This indicated a strong sense of mastery over the relevant tools that may explain the increased self-efficacy. The qualitative data also showed the course had strong elements of vicarious experience and social persuasion. Most of the research process happened within groups of peers, so students could work together and recognize the work of others. When asked if students felt their contribution to the research was valued by their peers, ten of the interviewees indicated that there was some form of peer mentoring and support, with one stating "I think that my contributions were useful in that I was able to help others. You know, when they had questions with the math or with the software we were using. I pick things up like that pretty quickly. So, I think I was able to… pass that on to others." The ability of students to help each other and observe their peers' knowledge base and abilities also helped to explain the increased self-efficacy. A majority of the interviewees also noted that the course instructors valued student work, with one sharing "they really made a point to let us know that what we were doing was so important and valued that … I might feel like what I did wasn't very helpful, but they, you know they sure as heck let me know that what I was doing was very valued." This sort of social persuasion from both their classmates and instructors likely contributed to the observed increases in self-efficacy.

B. Science identity

The survey item used to assess science identity (STEM-POI-1) was modified between the Fall 2022 and Spring 2023 semesters. Because of this modification, science identity was reported separately for the two semesters in Table III. As mentioned in Sec. IV, the original form of the survey, given in Fall 2022, presented students with Venn diagrams with varying degrees of overlap between the participant, me, and a STEM professional and prompted students to "Select the picture that best describes the current overlap of the image you have of yourself and your image of what a STEM professional is" [42]. Based on the additional explanation that students were prompted to provide along with their response choice, we believed that the students might have taken issue with the term STEM professional. For example, one student who indicated that they had very little overlap with a STEM professional wrote: "Well, I'm simply not a STEM professional. I only study it, I don't get paid." Due to the student responses, in the Spring 2023 survey, we replaced the term STEM professional with scientist and administered the item as a retrospective pre- and post-question. Another aspect that could partially account for the disparity between the Fall 2022 and Spring 2023 science identity scores is students' past research experiences. In the Fall of 2022, more than one-third (6/15) of the students enrolled in the ERE had participated in a course-based undergraduate research experience the previous summer. Additionally, in Spring 2023, we added a question to the postsurvey asking if the students had any research experience prior to the ERE. Of the 12 respondents, 10 indicated that they had no prior research experience. Despite the differing reported science identity scores from the survey in the fall and spring semesters, students still reported a gain in their science identity across both semesters in the interviews. We will continue to ask students about their prior research experiences on the surveys in future iterations of the course, as this could have an impact on students' science identity pretest scores.

C. Sense of belonging

Although the interview responses supported most of our findings from the quantitative analysis, the qualitative results suggested large improvements in the sense of belonging that were not reflected in the quantitative data. All 12 interviewees said their sense of belonging in science improved as a result of this course and 6 of the 12 interviewees explicitly mentioned that they felt a part of the broader scientific community thanks largely to connections they made with other researchers. Additionally, 8 of the 12 interviewees indicated that they felt more connected to ASU after completing the course, with 5 indicating appreciation and admiration that the school offered a course such as this one. The disparity between the qualitative and quantitative data results could be attributed to students entering the course with a high sense of belonging at ASU ($M = 4.177$, $\mathrm{SD} = 0.549$) and a sense of belonging in astronomy ($M = 4.056$, $\mathrm{SD} = 0.679$). Additionally, many of the students (6/15) in the Fall 2022 semester took another online astronomy CURE at ASU in the Summer 2022 semester. At the end of this summer CURE, students reported a high sense of belonging [59]. These inflated pretest scores could be responsible for lower gains from the pre- to postcourse surveys through a ceiling effect. Students were not explicitly asked if they participated in a prior research experience during the interviews, although five students (two from the fall semester and three from the spring semester) did mention over the course of the conversation that they had no prior research experience. Future iterations of the interviews will include a question about previous research.

D. Project ownership

Project ownership was not assessed in the first iteration of this course (Fall 2022) but was assessed in the Spring 2023 semester. Project ownership was also included in Corwin *et al.*'s "large CURE model" but was originally omitted from this study because it did not meet Corwin *et al.*'s definition of a hub, which has at least six connections to additional outcomes [16]. However, after conducting formal interviews with selected student volunteers from the CURE's pilot offering, project ownership became a recurring theme in the interview responses. For example, when asked, "Did you feel empowered during the research experience to take charge of the research, discussions, or any related activities?" one student responded, "I would say to a certain degree, because we were tasked with ultimately…creating the output from the project and…a scientific paper. And in doing that…a lot of that's our own creative skills and training…[W]e had to call up on our own experiences in order to make that happen." Based on this finding, we decided to implement a subset of items from the Project Ownership Survey [47], from which we found that the students reported experiencing a strong sense of project ownership ($M = 4.278$, $\mathrm{SD} = 0.433$).

Our mixed-methods analysis from the first two offerings of the course suggests that student participation in the ERE led to significant gains across many of the outcomes identified in studies of in-person CUREs across a variety of disciplines: research self-efficacy, science identity, content knowledge, and sense of belonging. Although independent data collection was not emphasized as a component of the ERE (the exoplanetary target was selected and observations were collected prior to the students starting the course), students' gains across these outcomes were comparable to those reported by students who participated in CUREs with a data collection component [16,54–57]. This study serves as a first look into demonstrating the efficacy of a new, accessible type of research course for online astronomy majors.

VII. LIMITATIONS

The strength of our conclusions is limited by the rather small sample size of participants presented in this study ($N = 24$). Even at the culmination of this effort, we expect to have a relatively small sample size ($N \sim 90$). This is due to our decision to keep the ERE capped at 15 students per offering. We performed a power analysis to determine the required sample size using an effect size of 0.4, significance of 0.05, and power of 0.8. The values used for significance and power were chosen based on convention. The value for effect size was chosen based on common effect sizes reported in previous literature [60–62]. We determined that we would need a minimum sample size of 41, which will be easily obtained with our planned six semesters of data collection. In addition to a small sample size, this study did not administer any of the surveys or interviews to a control group. Future work could include administering the same surveys to a traditional astronomy lecture or laboratory course. This would enable us to more conclusively determine if the benefits that the students reported were a direct consequence of their participation in the ERE.

Self-reported responses introduce their own bias into the study. Although self-reporting provides the benefit of being relatively inexpensive in human resources and time, it is important to acknowledge the bias that it introduces [63]. Asking students to report gains is particularly difficult because it requires strong metacognition and reflection from the student. Reporting gains requires students to assess where they are currently, where they were at the beginning of the semester, and to quantify that change and map it to a response [63]. Because of this, we tried to avoid reported gains in the affective survey wherever possible. One instance where we could not avoid reported gains was with the benefits scale of the CURE Survey. We decided that the pros of using this widely implemented survey, and therefore the ability to eventually compare the ERE to other existing CUREs, outweighed the potential biases that student-reported gains may introduce. Additionally, we do not rely on self-reporting results alone in this study. The self-reporting of affective outcomes is complemented by both independent student learning and qualitative data. Specifically, we have two independent measures of the benefits that students gain: the reported learning gains and the students' actual scientific production in terms of their data analysis and paper writing. In addition to self-reporting, the affective survey only contains one reverse-scored question. Due to our decision to use preexisting, prevalidated surveys, we chose not to edit any of the questions to add more reverse-scored questions.

As students volunteered to be interviewed, there is the possibility that the sample used in the qualitative analysis is biased toward students who were more active participants in the ERE or who had strongly positive or negative attitudes toward the course. We tried to mitigate this effect by offering a $25 gift card to all participants. This additional incentive was implemented to attract students who may not have otherwise volunteered. However, some bias is unavoidable when it comes to self-selected participants which should be kept in mind when analyzing the interview responses [64]. Additionally, 9 of the 12 interviewees identified as men, which may or may not have impacted the qualitative findings.

VIII. IMPLICATIONS FOR INSTRUCTION AND FUTURE WORK

Currently, all our data analysis is limited to the first and second iterations of the course, which greatly limits our sample size. As the course continues to be offered every Fall and Spring, we plan to continue collecting both affective survey and content knowledge assessment data. The course will have run a total of 6 times at the culmination of this effort. After six course offerings, we will perform our final analyses using the combined dataset. The goal of those analyses will be the same as has been shown with the results in this paper, but the larger sample size will also allow us to formally demonstrate the validity of our survey instrument. The survey was built using previously published items, so we do not anticipate validity issues, however, this step is expected whenever items have been modified and recombined [65]. Validation will be done through a confirmatory factor analysis. In addition, we plan to use the data obtained from this course to test a simplified version of the CURE map from Corwin *et al.* [16]. The CURE map is widely referenced in the field, but, to our knowledge, has not yet been statistically validated. Although at the culmination of our data collection, our sample size will still be relatively small ($N \simeq 80$–90), we have begun to implement our survey into other new online CUREs at ASU. With a bolstered sample size, we hope to perform a path analysis to assess the accuracy of the CURE map.

The ERE deviates from the traditional CURE as defined by Corwin *et al.* and Auchincloss *et al.* [6,16] in that students did not participate in the data collection process and that it was offered in an online format. The findings presented in this work show that students who participated in the ERE experienced similar benefits to those who have participated predominantly in in-person CUREs in other disciplines. These include increased research self-efficacy, science identity, sense of belonging at ASU and in astronomy, content knowledge, and project ownership. The quantitative gains in the sense of belonging were also smaller than in some prior studies, most likely owing to a high precourse sense of belonging. Additionally, students reported participating in all three overarching components of a CURE measured by the LCAS: collaboration, iteration, and discovery.

Traditional REUs, UREs, and internships benefit only a small number of students, but participation in undergraduate research is considered a requirement for many graduate and professional school programs in STEM. In the physical sciences in particular, 90% of students who intend to pursue a graduate degree in physics participate in an undergraduate research project. A CURE may be students' only opportunity, due to personal or institutional barriers, to participate in research [66]. CUREs allow all students enrolled in the course to engage in research, rather than just the select few that can secure an internship [6]. By broadening access to research experiences through CUREs, rather than emphasizing individual research experiences exclusively, the research community will be more representative of our nation's diverse population of learners. This work highlights the efficacy of using CUREs, particularly in online programs, as a way to make authentic research accessible to more students. We hope that the success of the ERE will serve as motivation for the development and implementation of other astronomy CUREs, especially those that serve the online student population.

ACKNOWLEDGMENTS

We would like to acknowledge Isabela Huckabee and Dr. Ara Austin for their helpful discussions and support which greatly improved this work. We thank Catherine Tremblay for her help with the qualitative portion of the data analysis. This publication makes use of data products from Exoplanet Watch, a citizen science project managed by NASA's Jet Propulsion Laboratory on behalf of NASA's Universe of Learning. This work is supported by NASA under Grant No. NNX16AC65A to the Space Telescope Science Institute, in partnership with Caltech/IPAC, Center for Astrophysics | Harvard & Smithsonian, and NASA Jet Propulsion Laboratory. We would like to acknowledge MicroObservatory, specifically Dr. Mary Dussault and Frank Sienkiewicz, for providing data and assistance with

DIY Planet Search. The observations in the ERE were conducted with MicroObservatory, a robotic telescope network maintained and operated as an educational service by the Center for Astrophysics | Harvard & Smithsonian. MicroObservatory is supported by NASA's Universe of Learning under NASA Grant No. NNX16AC65A to the Space Telescope Science Institute. This work was supported by Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration (80NM0018D0004). This work is supported by the National Science Foundation (NSF) under Grant No. IUSE 2121225.

APPENDIX A: AFFECTIVE SURVEY ITEMS AND RESULTS

Table V presents the entirety of the pre- and postsurvey questions, as well as the question type, scale, timing, pre and/or post mean and standard deviation (if applicable), and a reference to the original survey.

TABLE V. Affective survey items and results ($N = 24$).

Item	Question type	Scale	Timing	Pre Mean $\pm SD$	Post Mean $\pm SD$	Reference
Science Identity: Fall 2023 ($N = 12$)						
Select the picture that best describes the current overlap of the image you have of yourself and your image of what a STEM professional is.	Likert style	7	Pre/Post	4.417 ± 2.065	4.417 ± 1.676	[42]
Please describe why you chose the image that you did in the above question.	Short answer	Not applicable	Pre/Post	Not applicable	Not applicable	[42]
Science Identity: Spring 2023 ($N = 12$)						
Select the picture that best describes the current overlap of the image you have of yourself and your image of what a scientist is.	Likert style	7	Pre/Post	1.667 ± 1.155	4.583 ± 1.730	Modified from Ref. [42]
Please describe why you chose the image that you did in the above question.	Short answer	Not applicable	Pre/Post	Not applicable	Not applicable	[42]
Sense of Belonging in Astronomy: Fall 2022, Spring 2023 ($N = 24$)						
I feel like I belong in astronomy.	Likert style	5	Pre/Post	4.625 ± 0.576	4.375 ± 0.770	[43]
People in astronomy accept me.	Likert style	5	Pre/Post	4.042 ± 0.859	4.292 ± 0.690	[43]
I feel like an outsider in astronomy. (*Reversed Scored*)	Likert style	5	Pre/Post	3.500 ± 1.251	3.958 ± 0.955	[43]
Sense of Belonging at ASU: Fall 2022, Spring 2023 ($N = 24$)						
I feel I belong within my department.	Likert style	5	Pre/Post	4.167 ± 0.702	4.208 ± 0.833	[44–46]
I am satisfied with my academic experience.	Likert style	5	Pre/Post	3.875 ± 0.797	4.375 ± 0.824	[44–46]
I feel comfortable at Arizona State University.	Likert style	5	Pre/Post	4.417 ± 0.717	4.417 ± 0.881	[44–46]
People at Arizona State University accept me.	Likert style	5	Pre/Post	4.250 ± 0.737	4.500 ± 0.722	[44–46]
Research Self-Efficacy ($N = 24$): *Fall 2022, Spring 2023*						
Use technical science skills (use of tools, instruments, and/or techniques).	Likert style	5	Pre/Post	3.583 ± 1.213	3.958 ± 0.751	[40,41]
Generate a research question to answer.	Likert style	5	Pre/Post	2.875 ± 0.992	3.750 ± 0.989	[40,41]
Figure out what data/observations to collect and how to collect them.	Likert style	5	Pre/Post	3.042 ± 1.160	3.875 ± 0.797	[40,41]
Create explanations for the results of the study.	Likert style	5	Pre/Post	3.208 ± 1.062	3.792 ± 0.779	[40,41]

(Table continued)

TABLE V. *(Continued)*

Item	Question type	Scale	Timing	Pre Mean ±*SD*	Post Mean ±*SD*	Reference
Use scientific literature and/or reports to guide research.	Likert style	5	Pre/Post	3.208 ± 1.351	4.250 ± 0.608	[40,41]
Develop theories (integrate and coordinate results from multiple studies).	Likert style	5	Pre/Post	2.958 ± 1.197	3.792 ± 0.509	[40,41]
Course Self-Efficacy ($N = 24$): *Fall 2022, Spring 2023*						
I believe I will receive an excellent grade in this class.	Likert style	5	Pre	4.250 ± 0.608	Not applicable	[39]
I'm confident I can understand the most difficult material presented in the readings for this course.	Likert style	5	Pre	3.875 ± 0.797	Not applicable	[39]
I'm confident I can learn the basic concepts taught in this course.	Likert style	5	Pre	4.667 ± 0.482	Not applicable	[39]
I'm confident I can understand the most complex material presented by the instructor in this course.	Likert style	5	Pre	3.958 ± 0.690	Not applicable	[39]
I'm confident I can do an excellent job on the assignments and tests in this course.	Likert style	5	Pre	4.250 ± 0.676	Not applicable	[39]
I expect to do well in this class.	Likert style	5	Pre	4.375 ± 0.647	Not applicable	[39]
I'm certain I can master the skills being taught in this class.	Likert style	5	Pre	4.333 ± 0.637	Not applicable	[39]
Considering the difficulty of this course, the teacher, and my skills, I think I will do well in this class.	Likert style	5	Pre	4.333 ± 0.702	Not applicable	[39]
Project Ownership ($N = 12$): *Spring 2023*						
My research will help to solve a problem in the world.	Likert style	5	Post	Not applicable	3.667 ± 0.888	[47]
My findings were important to the scientific community.	Likert style	5	Post	Not applicable	4.500 ± 0.522	[47]
I faced challenges that I managed to overcome in completing my research project.	Likert style	5	Post	Not applicable	4.333 ± 0.888	[47]
I was responsible for the outcomes of my research.	Likert style	5	Post	Not applicable	4.083 ± 0.515	[47]
The findings of my research project gave me a sense of personal achievement.	Likert style	5	Post	Not applicable	4.667 ± 0.492	[47]
I had a personal reason for choosing the research project I worked on.	Likert style	5	Post	Not applicable	4.083 ± 0.793	[47]
The research question I worked on was important to me.	Likert style	5	Post	Not applicable	4.417 ± 0.515	[47]
In conducting my research project, I actively sought advice and assistance.	Likert style	5	Post	Not applicable	4.167 ± 0.718	[47]
My research project was exciting.	Likert style	5	Post	Not applicable	4.583 ± 0.515	[47]
Benefits Gained ($N = 24$): *Fall 2022, Spring 2023*						
Skills in interpretation of results	Likert style	5	Post	Not applicable	4.083 ± 0.654	[48,49]
Tolerance for obstacles faced in the research process	Likert style	5	Post	Not applicable	3.625 ± 1.056	[48,49]
Readiness for more demanding research	Likert style	5	Post	Not applicable	3.958 ± 0.955	[48,49]

(Table continued)

TABLE V. *(Continued)*

Item	Question type	Scale	Timing	Pre Mean $\pm SD$	Post Mean $\pm SD$	Reference
Understanding how knowledge in constructed	Likert style	5	Post	Not applicable	3.792 ± 0.833	[48,49]
Ability to integrate theory and practice	Likert style	5	Post	Not applicable	3.667 ± 0.917	[48,49]
Understanding of how scientists work on real problems	Likert style	5	Post	Not applicable	4.250 ± 0.676	[48,49]
Understanding that scientific assertions require supporting evidence	Likert style	5	Post	Not applicable	3.708 ± 0.999	[48,49]
Ability to analyze data and other information	Likert style	5	Post	Not applicable	3.917 ± 0.929	[48,49]
Understanding science	Likert style	5	Post	Not applicable	3.958 ± 0.751	[48,49]
Understanding how scientists think	Likert style	5	Post	Not applicable	4.125 ± 0.797	[48,49]
Learning to work independently	Likert style	5	Post	Not applicable	3.167 ± 0.963	[48,49]
Clarification of career path	Likert style	5	Post	Not applicable	3.625 ± 1.013	[48,49]
Understanding of the research process in your field	Likert style	5	Post	Not applicable	4.167 ± 0.761	[48,49]
Learning ethical conduct in your field	Likert style	5	Post	Not applicable	3.083 ± 1.316	[48,49]
Learning laboratory techniques	Likert style	5	Post	Not applicable	3.542 ± 0.932	[48,49]
Self-confidence	Likert style	5	Post	Not applicable	3.583 ± 1.060	[48,49]
Becoming a part of a learning community	Likert style	5	Post	Not applicable	4.125 ± 0.741	[48,49]
Confidence in your potential to be a teacher of science	Likert style	5	Post	Not applicable	3.625 ± 1.209	[48,49]
Ability to read and understand primary literature	Likert style	5	Post	Not applicable	3.958 ± 0.908	[48,49]
Skill in how to give an effective oral presentation	Likert style	5	Post	Not applicable	2.708 ± 1.367	[48,49]
Skill in science writing	Likert style	5	Post	Not applicable	3.750 ± 0.944	[48,49]
CURE Components—Collaboration ($N = 24$): *Fall 2022, Spring 2023*						
In this course, I was encouraged to…						
Discuss elements of my investigation with my classmates or instructors.	Likert style	5	Post	Not applicable	4.708 ± 0.464	[50]
Reflect on what I was learning.	Likert style	5	Post	Not applicable	4.708 ± 0.464	[50]
Contribute my ideas and suggestions during class discussions.	Likert style	5	Post	Not applicable	4.708 ± 0.464	[50]
Help other students collect or analyze data.	Likert style	5	Post	Not applicable	4.708 ± 0.464	[50]
Provide constructive criticism to classmates and challenge each other's interpretations.	Likert style	5	Post	Not applicable	4.292 ± 0.859	[50]
Share the problems I encountered during my investigation and seek input on how to address them.	Likert style	5	Post	Not applicable	4.708 ± 0.550	[50]
CURE Components- Discovery ($N = 24$): *Fall 2022, Spring 2023*						
In this course, I was expected to…						
Generate novel results that are unknown to the instructor and could be of interest to the broader scientific community or others outside the class.	Likert style	5	Post	Not applicable	3.917 ± 0.830	[50]

(Table continued)

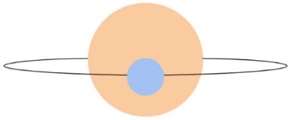
TABLE V. *(Continued)*

Item	Question type	Scale	Timing	Pre Mean ±*SD*	Post Mean ±*SD*	Reference
Conduct an investigation to find something previously unknown to myself, other students, and the instructor.	Likert style	5	Post	Not applicable	3.917 ± 0.776	[50]
Generate my own research question or hypothesis to guide an investigation.	Likert style	5	Post	Not applicable	3.000 ± 0.885	[50]
Develop new arguments based on data.	Likert style	5	Post	Not applicable	3.833 ± 0.702	[50]
Explain how my work has resulted in new scientific knowledge.	Likert style	5	Post	Not applicable	4.292 ± 0.624	[50]
CURE Components- Iteration ($N = 24$): *Fall 2022, Spring 2023*						
In this course, I had time to…						
Revise or repeat work to account for errors or fix problems.	Likert style	5	Post	Not applicable	4.625 ± 0.495	[50]
Change the methods of the investigation if it was not unfolding as predicted.	Likert style	5	Post	Not applicable	4.333 ± 0.702	[50]
Share and compare data with other students.	Likert style	5	Post	Not applicable	4.583 ± 0.584	[50]
Collect and analyze additional data to address new questions or further test hypotheses that arose during the investigation.	Likert style	5	Post	Not applicable	4.250 ± 0.794	[50]
Revise or repeat analyses based on feedback.	Likert style	5	Post	Not applicable	4.583 ± 0.504	[50]
Revise drafts of papers or presentations about my investigation based on feedback.	Likert style	5	Post	Not applicable	4.708 ± 0.464	[50]

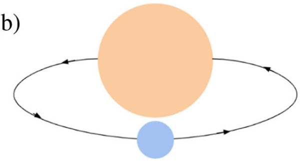
APPENDIX B: CONCEPTUAL KNOWLEDGE ASSESSMENT

1. Which of the following inclination angles of a planet would produce a light curve?

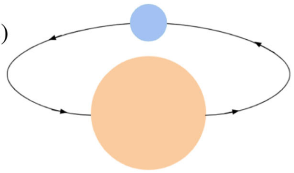
(a)



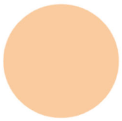
(b)



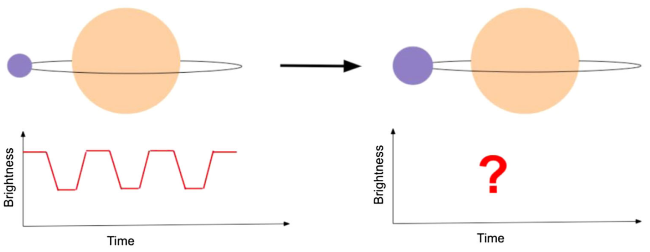
(c)



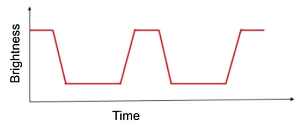
(d)



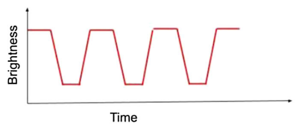
2. How would the light curve change if only the radius of the planet were increased (i.e., distance from the star and radius of the star remain the same)? A simplified light curve for a hypothetical planet-star system is given below.



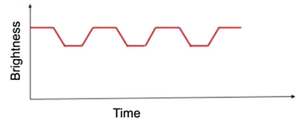
(a)



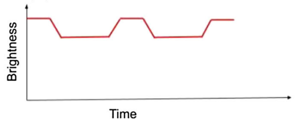
(b)



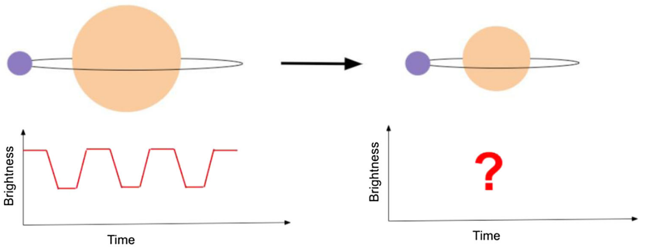
(c)



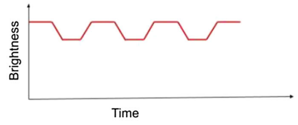
(d)



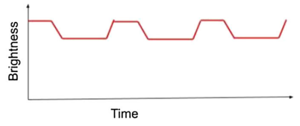
3. How would the light curve change if only the radius of the host star were decreased (i.e., distance from the star and radius of the planet remain the same)? A simplified light curve for a hypothetical planet-star system is given below.



(a)



(b)



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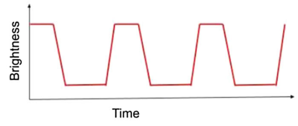
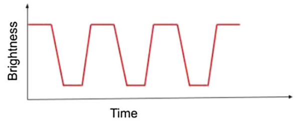
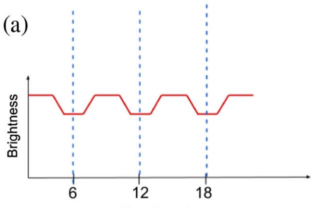


(d)

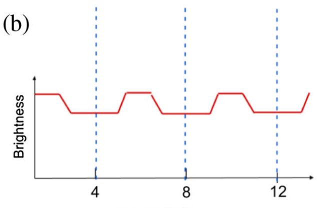


4. Based solely on the light curves provided below, which of the following indicates a planet-star system with a planet that completes a full orbit (and only one full orbit) every 5 hours?

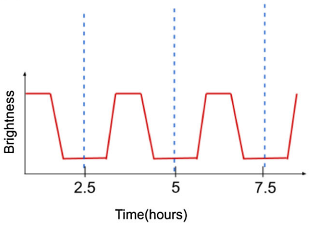
(a)



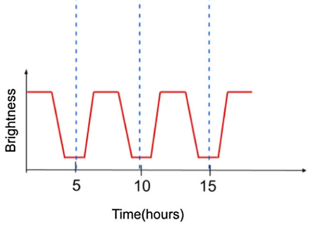
(b)



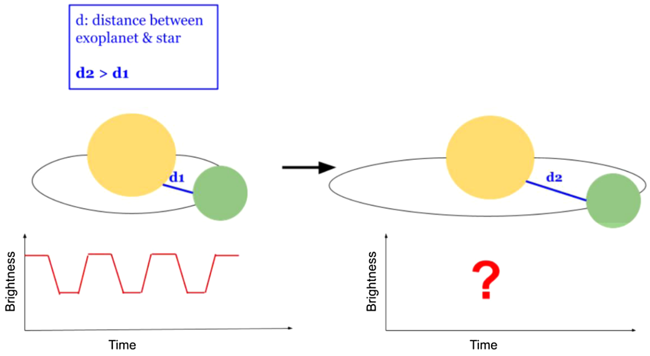
(c)



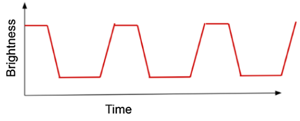
(d)



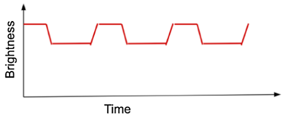
5. How would the light curve change if only the distance of the exoplanet from the host star was increased, meaning the exoplanet is closer to us (i.e., radius of the planet & radius of star remain the same)?



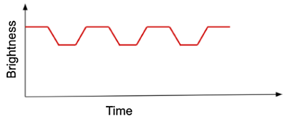
(a)



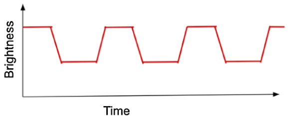
(b)



(c)



(d)



6. What conditions are necessary for an exoplanet transit to be visible from Earth?
7. In your own words, describe what multiobject photometry is.

APPENDIX C: INTERVIEW QUESTIONS

1. Describe your experiences with other students in the class.
2. Did you feel that you connected with the other students during the course?
3. Did you pursue further connections with peers during or after the class? How did those connections happen?
4. What were your impressions of the instructors who led the course?
5. Did you feel that you connected with the instructors during the research experience?
6. Do you feel more connected to ASU now that you participated in this course?
7. Did you feel like the classroom environment or atmosphere was conducive to your learning and the overall research experience?
8. Did you feel empowered during the course to take charge of aspects of the research, discussions, ideas, or related activities?

9. Did you feel your contribution to the research was valued by your peers and your research mentors?
10. How confident were you in your ability to use the technology, tools, and instruments needed at the start of the course?
11. How would you rate your confidence about the use of those tools now that you have completed the course?
12. What are the research skills that you gained from participating in the course?
13. What other skills did you gain from this experience? This includes both technical and soft skills.
14. Do you feel like you gained a deeper understanding of exoplanet transits and light curves?
15. Did you feel that the research experience as a whole met your expectations? What were you trying to gain from participating in this course?
16. Do you feel that the course better equipped you to pursue more research experiences or further your career/academic opportunities?
17. What impact did this experience have on your academic or career-related goals?
18. What did you think about the pacing of the course throughout the semester?
19. If applicable, did the experience respect/support any learning or physical disabilities that you may have?
20. Do you think the experience helped you develop the skills necessary to work effectively with people from diverse backgrounds?
21. Do you feel that the experience encourages participation in science by people from multiple cultures or diverse personal backgrounds?
22. Did this experience change your perception of what it means to be a scientist?
23. Do you view yourself as a scientist? How has that view changed (if at all) throughout the semester?
24. Do you feel that participating in this course has had an impact on your sense of belonging in science?
25. In general, what do you think are the benefits of participating in an online research experience like this class?
26. Is there anything that we haven't covered that you feel was important or interesting about your experience that you want to share?

APPENDIX D: DEMOGRAPHIC INFORMATION

Table VI presents the demographic information of the students who participated in the survey and consented to their responses being used for research purposes.

TABLE VI. Demographic information obtained from the affective survey for the Fall and Spring semesters of the ERE.

	N	Count
Is this course your first time conducting scientific research?	12	
Yes		10
No		2
Gender identity	14	
Man		7
Woman		6
Transgender		0
Nongender binary		1
Genderqueer or gender nonconforming		0
I prefer not to specify		0
An identity not listed (please specify if you wish)		0
Racial or ethnic group	24	
Asian or Pacific Islander		0
Black or African-American		3
White or Caucasian (non-Hispanic)		19
Hispanic or Latina/o		4
Arab or Middle Eastern		0
Native American		2
I prefer not to specify		0
An identity not listed (please specify if you wish)		0
College credits earned	24	
Less than 30		4
30–60		2
61–90		4
91 or more		14

(Table continued)

TABLE VI. *(Continued)*

	N	Count
Do you consider yourself a full-time or part-time student?	24	
Full time		13
Part time		9
Did you receive a Federal Pell Grant as part of your financial aid package?	24	
Yes		5
No		16
I don't know		3
What is the highest level of education completed by either of your parents (or those who raised you)?	24	
Did not finish high school		1
High school diploma or GED		7
Attended college but did not complete degree		4
Associate degree (A.A., A.S., etc.)		3
Bachelor's degree (B.A., B.S., etc.)		4
Master's degree (M.A., M.S., etc.)		2
Doctoral or professional degree (Ph.D., J.D., M.D., etc.)		3

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