Designing an augmented reality exoplanet lab app to facilitate interaction and active learning in the planetarium

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Planetariums are inherently immersive and effective learning spaces for astronomy concepts, but they lack interaction and become mere lecture environments. We explore how technology can support interaction and active learning with an initial prototype of the extrasolAR app designed through interviews with exoplanet educators. The educators shared four common learning goals: 1) detection methods, 2) properties and biases of each detection method, 3) what these properties imply about life in the universe, and 4) the plurality of exoplanets. Through the extrasolAR app, students explore the dome using their tablet and tapping on stars. The students are tasked with finding exoplanets and filling an *Exoplanet Catalog* with their calculations of various properties of the exoplanet. They look for bigger patterns in the *Exoplanet Table*, where the lab class' discoveries are shared. Our extrasolAR app incorporates the educators' four learning goals and design goals and explores how technology can create authentic, interactive experiences for students in the planetarium.

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I. INTRODUCTION

Planetariums, with their 360° visuals, are inherently immersive spaces that take people to new places. Planetariums provide a desirable learning environment through immersion and experiential learning, but active learning is hard to facilitate in the dome. Active learning aids student performance [1], but conversation, planetarians' main method of interaction, does not equate to active learning [2]. Interactive technology used by planetarians are mostly iClickers [3]. Augmented reality (AR) has been used in a variety of astronomy and physics educational contexts to highlight the abstract [4] and scaffold concepts [5] but not in planetariums.

To leverage the benefits of both the planetarium and AR, we present the initial prototype of extrasolAR, an augmented reality application for tablets that enables students to explore stars and find exoplanets. We share the results of our interviews with four professors and one planetarian about how they teach exoplanets and if they use labs and the planetarium. We highlight the common learning goals and design inputs from the educators as support for future research on exoplanet education. We explain our design of extrasolAR based on the learning goals and design inputs that emerged from these interviews. We discuss how the use of AR and technology addresses the wants of the educators and can facilitate interaction and learner-driven experiences in the planetarium.

II. BACKGROUND

A. Education in the Planetarium

Planetariums immerse their audiences in new places and sights, creating meaningful experiences [6]. Professors use the immersion of the planetarium to excite their undergraduate students [3]. Planetariums increase the audience's sense of "being there", capturing more of their attention [7]. Many studies show that planetariums are an effective way to teach various astronomy concepts [8–13], especially for affective learning outcomes [3, 6]. In the context of students' understanding of moon concepts, Yu et al. found that the large screen and wide field-of-view held students' attention, improving their learning [12]. Planetariums with their immersion and experiencing models directly also lessen the cognitive load of students, improving their understanding[13]. However, planetariums lack interaction [3].

Planetariums should not merely be a lecture space. Planetarians try to increase interactivity through conversation, but this interactivity does not equate to active learning [2]. Interactive observational astronomy lessons have great potential of making students active participants in the planetarium as shown by previous results [8]. Sumners et al. saw multimodal education in the dome improved learning in the full-dome [14], but they did not explore technology as a modality. Planetarians' use of interactive technology is mostly limited to iClickers [3].

B. Augmented Reality and Physics Education

Augmented reality (AR) enhances our senses by integrating the virtual world with the real world [16]. AR can highlight phenomena in three dimensions and visualize the abstract like the magnetic fields [4]. Like planetariums, AR in laboratory settings has been shown to lessen the cognitive load for students [16]. Laboratory AR also increases students' sense of self-efficacy as it shows abstract concepts as dynamic, interactive content [17]. In astronomy classroom activities, AR applications scaffold the learning of models and concepts [5]. AR enables student motivation and interest [15] as well as collaboration and teamwork [16].

Augmented reality applications have been made based off of planetarium content and astronomical observations to instill excitement in its users [18][19][20]. Tian et al.'s AR application for seasonal constellation observation tries to bring the planetarium's virtual scenes into real life by overlaying grid lines and other guiding markers onto the night sky [19], but no work has explored implementing augmented reality in the planetarium. Its effectiveness in learning and student interest highlight AR's potential to be a compelling medium to bring agency and interaction to students in the dome.

C. Exoplanets

Exoplanets, or planets outside of our solar system, are a fast-growing field of study in astrophysics [21], but due to the novelty of the topic, planetarium audiences are least interested in exoplanets [22]. In the current state of Astronomy Education Research, it is also a limited topic of focus [23]. Better planetarium experiences about exoplanets can foster enhanced interest and appreciation of astronomers' current search for habitable exoplanets.

III. METHODS

We conducted exploratory interviews with four astronomy professors and one planetarian (n = 5) who teach exoplanets formally in university classes or informally with planetarium visitors at one institution. We reached out to professors and lecturers who recently taught classes with exoplanets mentioned in their syllabus via email. The planetarian is also a lecturer at the same institution, recruited in the same search as the professors.

We conducted half-hour solo, semi-structured interviews with each professor to inform our design of our extrasolAR app. We asked them about their teaching methods around exoplanets and their wants of an exoplanet lab. We took detailed notes of their responses throughout the interview. We framed the interview around the following six questions:

1. What classes have you taught about exoplanets?
2. How and what do you teach about exoplanets?

TABLE I. Responses and themes from interviews with exoplanet educators. The centered, bold headings show topics from the interview. The two columns show the responses and themes of each topic. The parentheses contain the number of educators who said the theme or response.

Classes Taught with Exoplanet Curricula	
Introductory Astronomy - for majors (4/5)	Planetary Systems (2/5)
Introductory Astronomy - for non-majors (2/5)	Observation and Instrumentation Lab (1/5)
Special Topics (2/5)	Planetary Atmospheres (1/5)
Exoplanet Topics	
Detection methods (5/5)	Characteristics of other solar systems (2/5)
Properties of exoplanets (5/5)	Chance of biodiversity (1/5)
History of exoplanet discoveries and technology (2/5)	Rossiter-McLaughlin Effect (1/5)
Use of the Planetarium	
Showing all known exoplanets (3/5)	Using it as a spherical space (1/5)
Flying to exoplanets (3/5)	Light curves (1/5)
Lacks interactivity (3/5)	Does not like relying on navigator (1/5)
Biases of known exoplanets (2/5)	Lacks meaningful material (1/5)
Current Orrery Lab Criticisms	
Not to true scale (3/5)	Only covers transit method (1/5)
Oversimplification (3/5)	Does not emphasize biases of the detection method (1/5)
Exoplanet Lab Design and Learning Goals	
Different detection methods (5/5)	Exoplanet properties' implications about life (3/5)
Properties of exoplanets (5/5)	Plurality of exoplanets (3/5)
Student-driven exploration (5/5)	Different methods lead to different properties (3/5)
Biases & limitations of each detection method (4/5)	Animations to show what the data represents (3/5)
Scaffolding & guidance for the students (4/5)	Use real data to determine properties (2/5)
Activity goal (3/5)	

3. Do you use the planetarium for any of these classes, especially around exoplanets?
4. Is there a lab associated with finding exoplanets? What would you want to change about it?
5. What learning goals do you have surrounding an exoplanet lab?
6. We are designing an augmented reality exoplanet lab in the planetarium, where students can look around the dome and tap on stars to get information and data. What are your thoughts? What would you want out of an AR exoplanet lab?

We conducted a thematic analysis [24] of our interview notes to identify patterns in educators' responses. We open-coded the notes, generating initial codes by annotating the interview notes. We compared and grouped similar codes and responses together into themes and recurring ideas within each interview question. For questions 4, 5, and 6–which focused on educators' current planetarium and lab experiences and their wants–we examined themes that reflected core needs and design goals. These themes directly informed our design and prototype of the extrasolAR app.

IV. INTERVIEW INSIGHTS

Table I summarizes the responses and themes we found from the interviews. There is no dedicated exoplanet class at the professors' institution, which they all noted was due to its newness as a field. The professors instead teach exoplanets as a part of various undergraduate and graduate classes. Yet, all the professors teach exoplanets in their introductory astronomy courses (either for majors or non-majors). The planetarian presents exoplanets and extrasolar systems mainly to K-12 groups who visit the planetarium, complying with Next Generation Standards [25].

In terms of what topics they cover about exoplanets, the educators all teach the different detection methods, what properties can be determined from found exoplanets, and what this means for the possibility of life. Two also cover the history of exoplanets and detections that were later determined to be false. Two professors and the planetarian use the planetarium for lecture to show all the known exoplanets in the sky, the exoplanets themselves, comparing extrasolar systems to our own, and the biases of the exoplanets we have found due to detection methods and where we have looked. They see limitations with teaching in planetarium, specifically in that it is hard to add interaction beyond iClicker questions. The planetarian also found that in the planetarium, it is hard to immerse students in all the exoplanets and their patterns since all their details cannot be shown at once. The other professors found the planetarium experience to lack insightful material for exoplanets and to be intimidating to use due to the dark environment and reliance on the navigator. In the planetarium, the professor relies on the navigator to control the dome and display what they want to see.

At their institution, three of the professors use an undergraduate exoplanet lab for their introductory astronomy course, involving an orrery. An orrery is a mechanical model of a solar system, where students shape their own planets out of clay or styrofoam balls. Attached to the orrery is a light meter, which produces a transit light curve (a plot of the star's brightness versus time). Students figure out the period and size of the planet based on the dips on light curve from the planet passing in front of the star. Professors expressed that they felt the light meter was too close to the system compared to how measurements are made in real life. Other limitations the professors mentioned were that it only focuses on the transit method, it has issues with scale, and it does not emphasize detection biases.

In an exoplanet lab, we thematically found that the educators shared four common learning goals:

1. *Exoplanet Detection Methods* - methods and data astronomers use and analyze to find exoplanets
2. *Properties and Biases of the Detection Methods* - what each detection method can tell astronomers about the exoplanet and what exoplanets each method is more likely to find
3. *Properties Implications' on Life* - what the properties can tell astronomers about the possibility of life on the exoplanet and in the universe
4. *The Plurality of Exoplanets* - most stars in the universe are expected to have at least one exoplanet

The educators also had similar design goals for an AR exoplanet lab. They liked the idea of the students choosing what to explore in AR. One said, "it was like putting the universe in their hands." They wanted the students to look at real data (e.g., transit light curves) to calculate properties of potential exoplanets. They also wanted the activity to have an overall goal such as finding potentially habitable planets. They thought scaffolding within the app was important such as highlighting what stars in particular to look at and guiding students on calculations based on the class level. They also liked having double representations of the light curves with an animation along with the data, showing what the data represents. Educators expressed they wanted the lab to be authentic, use real data, and have a goal.

V. DESIGN & PROTOTYPE OF EXTRASOLAR

With the professors' learning goals and suggestions, we designed a prototype to determine the user flow and what information and interactions to include in the extrasolAR app. Figure 1 shows the app interface along with the learning goals they focus on. To use the app, students move and tilt their tablet around, looking at stars in the Stars Display (Figure 1a) screen. When they tap a star, they will see properties of the start in the Star Information (Figure 1b) screen. They can navigate to The Transit Data (Figure 1c) and Radial Velocity Data (Figure 1d) tabs to look at data and determine if there is an exoplanet. In *Exoplanet Catalog* (Figure 1e) tab, students submit their calculated values for the whole class to view in the *Exoplanet Table* (Figure 1f) screen. The activity goal of lab will be for students to be astronomers for the night and catalog the newly discovered data to find a potential habitable planet.

Learning Goal 1 - Exoplanet Detection Methods

The Transit Data (Figure 1c) and Radial Velocity Data (Figure 1d) tabs display actual data from the respective detection methods observed from a star that was tapped in the Stars Display (Figure 1a) screen. The data is sourced from Exoplanet Archive [26]. Some stars will have both Transit Data and Radial Velocity, but others will only have one dataset. These tabs also have an animation showing what the light curves mean (the potential exoplanet moving in front of the star) to provide another visualization of the data. These graphs provide the data for the students to determine if there is an exoplanet around this star and the properties and habitability of the potential exoplanet, supporting active learning.

Learning Goal 2 - Properties and Biases of the Detection Methods

The *Exoplanet Catalog* (Figure 1e) page is where students input values they calculated from the information in the Transit and Radial Velocity Data tabs. Here, students are first prompted to determine if there is an exoplanet around this star and calculate certain properties of this exoplanet. Some properties may not be calculable with the data given, which students will determine for themselves–emphasizing on what properties each method provides. The *Exoplanet Table* (Figure 1f) screen contains all the information calculated by class for their cataloged planets like methods discovered by, orbital period, etc. This provides them a space to look for bigger patterns and relationships between the exoplanets they found, its properties, and the detection methods used.

Learning Goal 3 - Properties' Implication on Life

In the *Exoplanet Catalog* (Figure 1e) page, students calculate various properties of a potential exoplanet. These properties are scaffolding to determine if this exoplanet may be habitable and record it in the *Exoplanet Catalog* page. Depending on the data of the star, students may not be able to determine habitability for the exoplanet due to not being able to calculate certain properties, highlighting which properties are important to determine habitability.

Learning Goal 4 - Properties' Implication on Life

The homepage of the app is the *Stars Display* (Figure 1a) screen. Here, the user is able to look around the dome in the app and see stars to tap on. The stars are color-coded based on whether they have been cataloged and if they have an exoplanet. The UI has different filters to have different color codes like what methods were used on the star, the type of

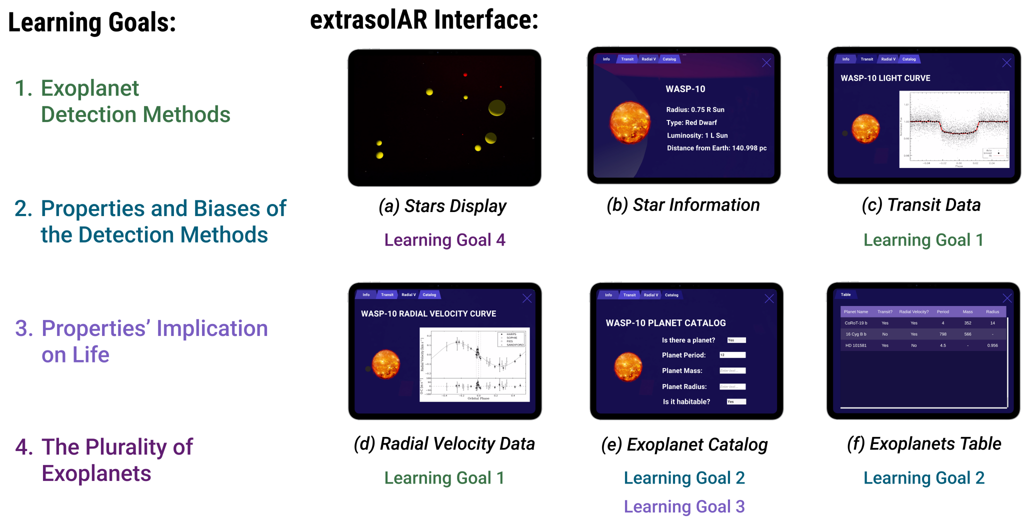

FIG. 1. Screenshots of the extrasolAR app. There are 6 screens labeled with the learning goals they address: (a) *Stars Display* where students tap on stars on the dome, (b) *Star Information* which displays basic information of the star like mass, (c) *Transit Data* which shows the transit light curve data of a star, (d) *Radial Velocity Data* which shows the radial velocity light curve data of a star, (e) *Exoplanet Catalog* where students record their calculations, (f) *Exoplanets Table* where their shared calculations are shown

star, and if the star has an exoplanet. Students can look around the dome with the different filters to look for patterns. Students are able to explore the dome freely and choose which stars to learn more about instead of relying on a navigator to control the dome, giving them agency over their experience in the planetarium.

VI. DISCUSSION

We present the design and initial prototype of our extrasolAR app. Through interviews with four astronomy professors and a planetarian, we found four common learning goals about exoplanets. The educators also emphasized the importance of authenticity, providing real data, and structuring the lab around a meaningful goal. We designed our extrasolAR around these four learning goals, the design input of the educators, and the aim of giving students agency over their experience on the planetarium.

As seen in the interviews, exoplanets have no dedicated class in this institution due to its novelty as a field. It is a topic that may get part of a lecture or weeks in class, completely dependent on the instructor. Despite the variety of classes exoplanets are taught in, we found that the educators share similar learning goals regarding exoplanets. Current literature has little work on exoplanet education; we hope this work provides a foundation of common learning goals for exoplanetary science, establishing a basis for future research on effective exoplanet pedagogy.

The educators also had criticisms of their current lab and their experiences using the planetarium. We designed extrasolAR in response to these criticisms. With the current lab, the educators found it oversimplified. Technology enabled extrasolAR to have different levels of interaction with different screens, facilitating student exploration of bigger patterns of exoplanets and their detection methods. The educators found the planetarium lacked interactivity. With extrasolAR, the students control their experience in the planetarium without relying on a navigator to control the dome. Technology can be a medium of providing students agency in the planetarium. extrasolAR represents an initial exploration of how technology can bridge the gap between the immersive planetarium and interactive, student-driven learning.

VII. LIMITATIONS & FUTURE WORK

This study reflects the perspectives and goals of a small sample of educators from a single institution, which may limit the generalizability of our findings. We also did not evaluate the application. For future work on this project, we plan to implement extrasolAR in an introduction to astronomy class to evaluate its effectiveness. First, we will contact the interviewees again to reflect on the design. Then, we will conduct pilot testing with students on the current prototype to provide insight into the app's usability and educational impact and iterate based on feedback. We will further develop the app to ensure stability and scalability of use for a lab class with minimal problems and troubleshooting during the lab.

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