Project Title:

Exploring Virtual Reality in Astronomy Education: Enhancing Student Understanding through Immersive Learning Environments

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Project Abstract:

Nandana Weliweriya, an education researcher collaborating with astronomy research faculty, Dr. Inseok Song, proposes to develop an astronomical virtual reality (VR) platform with specific modules to test the effectiveness of the VR platform for enhancing the quality of astronomy instruction and research, broadly STEM. The project aims to overcome the limitations and issues in current astronomy lab courses and provide a method for students to engage in real-world scenarios and practice problem-solving and decision-making skills in astronomy courses. The proposed VR platform will include specific modules like Virtual Night Sky, Eclipses, Tides, and Parallax, which will be tested for effectiveness in enhancing student understanding. The team proposes to develop on the existing technological developments made from the support of previous rounds of Learning Technologies grants that the PI collaborated with the College of Engineering. With encouraging result from this proposed pilot study, the team plan to expand the scope with more modules and seek external funding support, like submitting a grant proposal to the National Science Foundation's Improving Undergraduate STEM Education Program to measure the physics to engineering transformation.

Project Description

The University of Georgia has many programs that train current students to become well-qualified for their future procession to tackle real-world issues by joining the workforce to fulfill this demanding request. In that sense, the University of Georgia's 2025 strategic plan is particular. The strategic plan has several initiatives and priorities specifically focused on strengthening STEM education and research. The key goals of this plan are to enhance the quality and impact of STEM education at the university by a.) Expanding access to STEM education, b.) Enhancing the quality of STEM instruction, c.) Strengthening STEM research.

UGA is a single institution, and undergraduate institutions worldwide invest in their STEM instruction as STEM courses are essential to the undergraduate curriculum, providing students with the skills and knowledge necessary to succeed in a rapidly evolving global economy. These courses are critical because they help students develop teamwork, critical thinking skills, and evidence-based problem-solving approaches, allowing them to analyze complex data and make informed decisions. Importantly, these are the essential skills for our college graduates to succeed in a wide range of industries, including healthcare, finance, and technology.

As an essential part of STEM courses in the undergraduate curriculum, physics is a fundamental science that underpins many other disciplines within STEM, including engineering, chemistry, and mathematics. Physics provides students with a foundation in the principles that govern the physical world, including energy, force, motion, and matter. Studying physics helps students to develop critical thinking and problem-solving skills that require students to think abstractly, analyze complex problems, and develop creative solutions. On the other hand, astronomy courses provide students with a comprehensive understanding of the universe, from its origins to its current state. Astronomy courses cover a wide range of topics, from forming galaxies and stars to searching for extraterrestrial life. These courses help students develop a sense of wonder and appreciation for the universe and provide a context for understanding humanity's role in the cosmos. Furthermore, astronomy courses foster critical thinking and problem-solving skills as students learn to analyze and interpret astronomical data and observations. Overall, physics and astronomy courses are essential components of the undergraduate curriculum, providing students with a strong foundation in the physical sciences, critical thinking, and problem-solving skills critical for success in various fields.

While educators, policymakers, and the general public agree that education in STEM is essential, many studies suggest that middle and high school students are increasingly interested in STEM as a major when they get to college. An article published in the Journal of Research in Science Teaching in 2016 found that middle school girls who had positive attitudes towards science were more likely to express an interest in pursuing STEM careers later in life. Another study published in Frontiers in Psychology in 2018 found that students who participated in an after-school program focused on STEM education showed increased interest in STEM careers. In 2020, the National Girls Collaborative Project reported an encouraging finding that 74% of middle school girls express an interest in STEM as a major when they get to college. Students choose to pursue STEM disciplines in college because they want to learn about the world around them and find innovative solutions to real-world challenges: like developing a much-needed vaccine for the COVID-19 pandemic. Further, playing a role in some of the country's significant discoveries and developments: like working with NASA's Perseverance rover, Ingenuity helicopter projects, or SpaceX's mission to colonize Mars. These ambitions also motivate STEM disciplines to lead to the most substantial employment rates and salaries.

Driven by many reasons mentioned above, when these highly motivated first-year students enter their introductory-level courses, the material and traditional instruction methods we currently use in our programs play a significantly destructive role in students' interest in remaining in physics courses. Besides, undergraduate-level physics courses often heavily feature solving textbook problems by applying conceptual knowledge and problem-solving techniques. These textbook problems, often modeled after real-world scenarios, are usually situated through narrative and illustrations that provide known values, constraints, and the requirement to find unknown values to achieve the desired outcome. Two fundamental assumptions upon which this approach is based are (a) that students can relate the textbook problems represented on 2-D paper to the real-world 3-D problems that they intend to mimic, and (b) that students, given the ability to obtain the known values themselves, would know how to do so correctly. The gap between textbook problem representations and real-world problems, growing frustration comes with 2-D illustrations that textbooks try to represent scenarios in the real world in 3-D, and limited opportunities to solve real-world problems individually or collaboratively dampen students' motivation to persist in physics or broadly in STEM.

Over the years, technology has also begun to change the roles of teachers and learners in all settings. Educators and researchers looked for solutions to incorporate technology to overcome the above barrier. Technology facilitates collaborative learning because it helps students research subjects, share ideas and learn specific skills. Taking this lead, the PI, Nandana Weliweriya, proposed a virtual reality collaborative project with the College of Engineering, in which he received CTL's Learning Technologies Grant for two consecutive years. In these projects, in addition, to transforming current lab activities in the first-semester studio physics I course (PHYS 1251), Nandana proposed to incorporate VR headsets and iPads for collaborative problem-solving within and outside of the classroom. During this semester's mid-semester formative evaluations, students in PHYS 1251 had excellent feedback about the modifications we did for the class. The link here will take you to the current development of our platform, which we used successfully to collect data in think-aloud interviews.

This month, we use them for end-of-the-semester projects in studio physics I (PHYS 1251) and Engineering statics courses. Further, later this summer, PI and his team will submit a grant proposal for the National Science Foundation's Improving Undergraduate STEM Education Program (NSF: IUSE) to follow a SEED proposal in late fall to measure physics to engineering transformation.

Link to the shared folder: VR and Ipad developments shared

New directions with this project:

After transforming the studio Physics 1-course activities, aligning with the 2025 strategic plan, the PI and the research team propose expanding technological developments to the departments' astronomy courses, strengthening STEM research which will help us enhance the quality of instruction in the physics department and across other STEM disciplines. We propose to develop an astronomical VR platform with specific modules to test the effectiveness of the VR platform in enhancing student understanding.

After discussing with the department's Astronomy research and instructional faculty, graduate and undergraduate students, the research team identified many limitations. Below we list a couple of identified limitations and how the proposed virtual environments could improve research and instructions allowing students to engage in real-world scenarios and practice problem-solving and decision-making skills in astronomy courses.

Current limitations and issues:

Current Astronomy Lab Courses at UGA utilize both indoor theoretical activities as well as outdoor observational activities. The indoor activities cover vital concepts such as parallax calculations, light pollution, Kepler's Laws, and more. Current indoor lab exercises rely on students making basic measurements and/or interpreting pre-generated graphs. These activities would benefit from the addition of virtual reality tools by providing realistic depictions of the various phenomena in the night sky. Labs can be updated to involve observations made virtual reality headsets that otherwise cannot be made due to time constraints and technological limitations. These simulated observations can replace the pre-generated graphs currently being used to allow students to experience the process of data collection and the interpretation of that data.

The other component of current astronomy labs is the outdoor observing sessions. The main limitation faced by students in the courses is the weather. Often outdoor observing sessions must be postponed or canceled due to cloudy skies. Additionally, the light pollution on campus makes most observations difficult, if not impossible, especially when the stadium lights are on at Sanford Stadium. Other obstructions, such as trees, buildings, and construction equipment, block critical viewing windows. Simulated observation environments will allow students to observe regardless of weather and other factors. Moreover, simulated environments will provide instructors with a method to demonstrate a range of observing conditions from optimal dark sky sites to poor viewing conditions in light polluted and obstructed city skies. This is currently not possible as astronomy courses are limited to the viewing conditions on campus.

Planned Virtual environments include:

Virtual Night Sky: The main component of astronomy lab courses is learning the night sky and how it maps to the celestial sphere, which requires both indoor activities and outdoor observations. Understanding how the night sky maps to the celestial sphere and how to orient oneself under the sky are foundational concepts for students to learn. Implementing an environment that displays the night sky from any location on Earth will provide students with a method to learn the locations of stars, constellations, and planets. Additionally, instructors will be provided with methods to control this environment to show the movement of these astronomical bodies throughout the night. This environment can be extended to show an outside view of the celestial sphere and the 3D nature of the cosmos.

Eclipses: Students will be immersed in a virtual environment demonstrating the Sun-Earth-Moon system's relative size and distance. Within this virtual environment, students can observe the locations of the Earth's umbra and penumbra from various locations around the planet, including vantage points that show the Moon's location relative to the respective portion of Earth's shadow. These observations will demonstrate the effect of the inclination of the Moon's orbit around the Earth, particularly as it leads to the low number of lunar eclipse events. This same environment can be implemented to show solar eclipses and demonstrate how the size of the Sun, in conjunction with the distance to the Moon, lead to a small region of totality.

Tides: The virtual environment used to demonstrate eclipses can be modified to demonstrate how the Sun and Moon's gravitational influence on the Earth gives rise to tides.

Parallax: Parallax measurements are vital to current astronomical and astrophysical research and allow researchers to measure the distance to nearby stars. Parallax measurements require multiple observations, often six months apart, which prevents making actual measurements within a semester. Implementing a virtual environment will allow instructors to show sample observations from different times of the year that aid student visualization. These visuals will include the observations made from Earth or satellites paired with an outside observer's view.

MEASURES OF SUCCESS

We propose to develop an astronomical VR platform with two specific modules to test the effectiveness of the VR platform in enhancing student understanding. The two specific modules for the pilot study,

- Eclipse
- Parallax and proper motions

With an encouraging result from this pilot study, we plan to expand the scope with more modules and seek external funding support. With the UGA LTG grant, we propose to create a platform with two specific modules above. In the proposed astronomical 3D VR platform, students can add components such as stars and planets. Then, students can define added components' dynamical, kinematic properties, such as space and orbital motions. Lastly, students can control viewing parameters such as the location of an observer. Key parameters can be adjusted on the fly, and the dynamical system will reflect the changed parameters accordingly.

Learning Outcomes of astronomical VR platform:

The proposed astronomical VR platform can offer a variety of learning outcomes.

Improved understanding of astronomical concepts: The three-dimensional immersive experience in our proposed VR platform can help students better understand basic astronomical concepts, such as the solar system's structure, and more complex concepts, Eclipses, Tides, and Parallax.

Improved critical thinking and problem-solving skills: Astronomy involves analyzing data, making predictions, and evaluating evidence. Using a VR platform, users can develop their critical thinking and problem-solving skills by exploring astronomical phenomena, interpreting data, and testing hypotheses.

Enhanced spatial reasoning skills: Astronomy involves thinking about objects and phenomena on a vast scale, often at distances and sizes that are difficult to comprehend. Users can use a VR platform to develop their spatial reasoning skills by visualizing and manipulating astronomical objects in three dimensions.

Increased engagement with astronomy: A well-designed VR platform can be highly engaging, motivating users to explore and learn more about astronomy. This can lead to a greater interest in astronomy and may encourage users to seek further information or resources.

Exposure to scientific research methods: Astronomy is a highly data-driven field, and scientific research methods are essential to the discipline. Using a VR platform allows users to gain exposure to these methods, such as observing phenomena, collecting data, and interpreting results.

Assess the effectiveness of the VR platform:

With the approval from UGA's IRB office, we will use the students enrolled in relevant astronomical courses ASTR1010, ASTR1110, and ASTR2030L to test the VR platform's effectiveness.

Assessing the effectiveness of our astronomical VR platform can involve several factors.

Testing students' understanding of concepts:

Method 1: Collect pre-post test scores of students using standardized astronomic tests like the **Test of Astronomy Standards (TOAST)**, **Astronomy Diagnostic Test 2.0 (ADT2)**, and **Star Properties Concept Inventory (SPCI). (Link:** https://www.physport.org/recommendations/Entry.cfm?ID=124938**)**

These tests will measure students' general astronomy content knowledge across topics but not limited to gravity, the universe's evolution, star and stellar evolution, evolution and structure of the solar system, seasons, scale, yearly patterns, daily patterns, and moon phases.

Method 2: Collect data using individuals or groups of students in think-aloud interviews. These interviews will be follow-ups for the user surveys we collect after each session.

Collecting user feedback: End-of-the-session survey questions and follow-up think-aloud interview questions will be designed to explore user satisfaction, learning outcomes, and any areas for improvement. Responses to both these methods can help us collect student feedback on their experiences using the platform.

Measure user engagement: We will track the number of users who access the platform, how long they spend on it, and how frequently they return to use it. Most importantly, the new Meta VR headsets allow us to collect the users' eye-movement data and vital information about user engagement.

Further, STEM research on students' ability to solve physics problems found that students have difficulties interpreting, constructing, and switching between representations (algebraic, gestural, graphical, and verbal). PI's recent work on upper-division student problem-solving processes (https://www.researchgate.net/publication/329461297_Case_study_Coordinating_among_multiple_semiotic_resources_to_solve_complex_physics_problems), we use students' oral exam data to look at representations at a microscopic level. He uses social semiotic resources' disciplinary affordances to describe how the representations are developed, determined to be insufficient, and replaced or augmented by new ones brought in by the students. Previous analysis solely depends on student reasoning and the interviewer's notes on the reason for students' thought processes. As the next step of this project, we wonder if we could track students' eye movements to investigate what representations or features of representations, they pay attention to while solving problems.

Comparison with other instructional methods and technical performance: The platform's performance will be compared with traditional classroom instruction or online learning modules already available. We will also assess the quality of 3D graphics and the platform's stability.

Future Work and Sustainability:

With the new astronomical VR platform, remote virtual laboratories will complement in-person and remote physical laboratories by focusing on real-world problems that are impractical to introduce in any other way. Beyond merely providing these learning opportunities to students, the project will increase our capacity to build and study remote laboratories' innovations in several ways. First, targeting the most populous astronomy courses will significantly increase the number of students and faculty involved in these laboratories. Second, it will add to the diversity of remote virtual laboratories that students can access regularly. This will be vital to be competitive for large-scale funding research into the approach. Finally, it will continue to evolve our technological infrastructure and knowledge base to support such large-scale projects. This project is one step towards strengthening the entire pipeline of courses physics and astronomy students go through by building a more collaborative relationship between STEM programs and interdisciplinary education research within and beyond UGA.

Statement of Unit-Level Support

This project connects and extends the aims of a project funded in the previous round of grants awarded to Dr. Kyle Johnsen by the EETI Augmented, Remote, and Virtual Experimentation Grant. Also, the previous round of Learning technology grants was awarded to Dr. Nandana Weliweriya.

Also, Nandana Weliweriya will use the research funding he received as a part of the M.G. Michael Award (2022), Franklin College of Arts & Sciences, The University of Georgia, which he received for the existing technological developments made from the support of previous rounds of Learning Technologies grants with the collaboration with the College of Engineering.

Further, The PI and astronomy research faculty Dr. Inseok Song has initiated discussions within Physics (Department Head and Associate head, instructors, lab manager) towards using the VR platform for departments' science communication outreach and open house events.

Dr. Cassandra Hall, Assistant Professor of Computational Astrophysics, has shown strong interest in similar approaches of incorporating VR platforms for her research studies and instructions in ASTR1010, ASTR1110, and ASTR2030L courses.

Budget And Personal Contributions

Research Team:

PI: Nandana Weliweriya, Lecturer, Physics Education Researcher, Department of Physics & Astronomy

Inseok Song, Associate Professor of Astronomy,

Robin Allen, Graduate Assistant, Department of Physics & Astronomy

Kyle Johnsen, Professor. School of Electrical and Computer Engineering

Brook Bowers, a Ph.D. candidate in Computer Science working under Dr. Kyle Johnsen in the School of Electrical and Computer Engineering,

Item	Quantity	Total Cost	$ Requested from LTG	$ Provided by other sources
VR headsets	10	$10,000	$1500	The PI has 7-8 of older versions of VRs acquired from previous EETI, LTG. The new request, $1,500.00 would be earmarked for purchasing any extra equipment, primarily one new Apple VR headset, if deemed necessary.
Request for Domain Name and Webhosting Funding: $300 total for 3 years	1	$300	$300	Our research project currently maintains a dedicated website at https://cosmos.physast.uga.edu/VRedu/. As we progress with our initiatives, we are in the process of preparing an external grant proposal for the "UnrealEngine Epic MegaGrant," which specifically stipulates the need for a project website. To enhance our outreach efforts, broaden our project's visibility, and effectively recruit undergraduate and graduate students who share our passion for this work, we are seeking funding to acquire a unique and concise domain name. This investment in our online presence is aligned with our commitment to expanding educational opportunities. We will perchage a webhosting service that includes one free domain name. So, we will secure the domain name "3D_STEM_edu.net" for our project and our project webpage will be accessible from https://3D_STEM_edu.net. Then, free sub-domain names such as https://astro.3D_TEM_edu.net, https://physics.3D_TEM_edu.net, etc. can be used to direct relevant web traffics.
Request for Equipment purchase: One fully equipped workstation	1	$3200	$3200	The research team currently comprises one graduate student and three undergraduate students actively engaged in coding for the development of topic-based basic simulations. The next phase involves having them work on more intricate modules and converting them into simulations with user interactivities that allow changes in some aspects of simulations in realtime. These advanced tasks require a workstation with high computing power, as the current equipment is limited in its

				capabilities. Therefore, this budget amendment seeks funding to acquire a suitable workstation capable of supporting the programming demands (e.g., i9 12900KF to 5.2Ghz 16 Core, Windows 11 Pro, 64GB RAM, 1000GB NVMe 4.0 SSD, Quadro RTX A4000 GPU, 10TB RAID storage).
Research funding support for Graduate Students and undergraduate students	1	$20,000	$20,000	Over the academic year, the physics department will support him as a teaching assistant, but the funding is limited. We request this money to support Robin as a graduate research assistant so he can focus on the program developments. The direct support from this grant will allow him to devote more time to developing resources and the rest of the allowed time to spend in lab classes towards using the developed platform for collecting data.

The main budget item of this LTG proposal is to support a Physics & Astronomy department Ph.D. graduate student (Mr. Robin Allen) who is co-advised by two investigators (Drs. Weliweriya and Song). Also to pay hourly for undergraduate research student.

Mr. Allen finished his coursework already and began the dissertation project of developing a 3D VR environment to enhance and innovate the introductory teaching of astronomy. As aforementioned, developing a 3D VR environment platform (with a couple of content modules within the support of LTG) for commonly accessible VR headsets (e.g., Meta Quest) will require a significant amount of programming time, and Mr. Allen will carry out the programming task. Therefore, we request support for Mr. Allen for one year. To debug/test the 3D platform on a VR headset, we plan to purchase two sets of VR headsets and two sets of iPad Pro (and pens).

In a previous communication, I introduced the idea of purchasing IF-AT cards for student-centered activities utilizing paper-based tools. Subsequent discussions led to the decision to initiate a computer science undergraduate project. This project aims to create a web-based version of the IF-AT cards, aligning seamlessly with our primary project's goals. We intend to develop and access 3-D simulations and 3-D user interactive activities using iPads and VR headsets, with the ultimate objective of transforming it into a standalone app. This app will be shared with CTL and other instructors at UGA and beyond.

While Robin will primarily work on developing the computational program, Dr. Kyle Johnsen and his research group will collaborate with the expertise to integrate it into the VR environment.

The research team intends to compensate undergraduate students at an hourly rate while recruiting majors from Computer Science, Physics, and Astronomy. This opportunity will grant undergraduates invaluable research experience and enable them to offer feedback on our module development efforts. Collaborating with the main graduate student, Robin Allen, the hired undergraduate researchers will receive mentorship from project faculty members and actively contribute to module development, data collection and analysis. Additionally, they will have the opportunity to present their findings at esteemed local and national conferences including CURO, PERC, and AAPT.

While the PI, Nandana Weliweriya, co-advises the Ph.D. student, Nandana will lead on reaching out to the nearby school, community centers, and libraries to host science communication events with the new tools we develop in this project. Further, Nandana is one of the committee members of the department's open house committee.

TIMELINE

Date or Month	Objective or Goal	Person(s) Responsible
05/23 - 09/23	**Software and VR interface development:** Evaluating existing limitations of current VR software and developing a new version Fall 2023 Astronomy courses (ASTR 1010, 1010L/1020L)	RA, KJ, BB, NW, IS undergraduate students
09/23 - 12/23	Implement initial software developed for Fall 2023 Astronomy courses and outreach events	RA, NW, IS undergraduate students
09/23 - 11/23	With the initial developments and trial data, Submit a collaborative SEED Grant proposal	NW, IS, KJ
12/23 - 02/01	Analyze data from initial trials. Begin work on publication of initial results	RA, NW, IS undergraduate students
01/24 - 05/01	Update and implement existing software for spring 2024 Astronomy courses (ASTR 1010, 1010L/1020L) and outreach events	RA, KJ, BB, NW, IS undergraduate students
03/24	Present initial findings at APS regional meeting, USG Teaching and Learning Conference, Engineering education conferences	RA, NW, IS undergraduate students

03/24 - 04/24	Submit a progress report on proposal	NW, IS
05/24 -07/24	Analyze data from initial, spring trials. Present and publish articles at AAPT (American Association of Physics Teachers) and PERC (Physics Education Research Conference)	RA, NW, IS undergraduate students
05/01- 08/30	Submitting a grant proposal to the National Science Foundation's Improving Undergraduate STEM Education Program to measure the physics to engineering transformation.	NW, IS, KJ
Over the academic year and beyond	Reaching out to the nearby school, community centers, and libraries to host science communication events with the new tools we develop in this project.	NW, RA, IS undergraduate students
After the academic year	Submit a final project report	NW, IS