PROJECT TITLE:

Empowering Experiential Learning: A Hands-On Game Engine Programming Initiative for Engineering majors

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PROJECT ABSTRACT:

Current resources for astronomy education often fall short in effectively conveying complex 3D phenomena, as they are primarily limited to two-dimensional mediums such as paper, whiteboards, or computer images. The STEMin3D project, accessible at, seeks to address this limitation by pioneering immersive learning environments. We plan to engage current and former engineering majors who have taken introductory physics courses with PI, to offer them hands-on learning opportunities through game engine programming, while also creating immersive learning environments. Through these environments, students experience real-world scenarios, offering them unprecedented opportunities to grasp intricate astronomical concepts and refine their problem-solving abilities. Initial success will be assessed through pilot studies focusing on six topics including celestial sphere, eclipse, and parallax, with future plans aimed at expansion and securing additional funding for ongoing development. Evaluation strategies encompass standardized assessments, user feedback surveys, and comparative analyses against conventional instructional methods. Looking ahead, separately, the project seeks funding to further develop simulations for astronomy courses and to collaborate with faculty from UGA's College of Veterinary Medicine, with the ultimate goal of extending the initiative to encompass a broader range of STEM disciplines.

PROJECT DESCRIPTION

Examples from Astronomy: Solar eclipse shown in figure 1 depicting the positions of the Sun, Earth, and Moon exemplifies a visual semiotic mode commonly utilized in astronomy textbooks. When it comes to representing complex astronomical phenomena like solar eclipses, 2-D images in textbooks often fall short in conveying the full richness and depth of the phenomenon. While they may provide a basic visual representation of the alignment of the Sun, Moon, and Earth during an eclipse, they lack the dynamic and **spatial** nature required to fully grasp the intricacies of such events. For instance, 2-D images cannot effectively illustrate the changing positions of celestial bodies over time, the varying phases of an eclipse, or the three-dimensional spatial relationships involved. Furthermore, the affordances of 2-D images are limited in terms of engagement and interactivity. Students may passively view a static image in a textbook without the opportunity to manipulate or explore different aspects of the eclipse. This passive consumption may hinder their ability to develop a deeper understanding of the event and its underlying concepts.

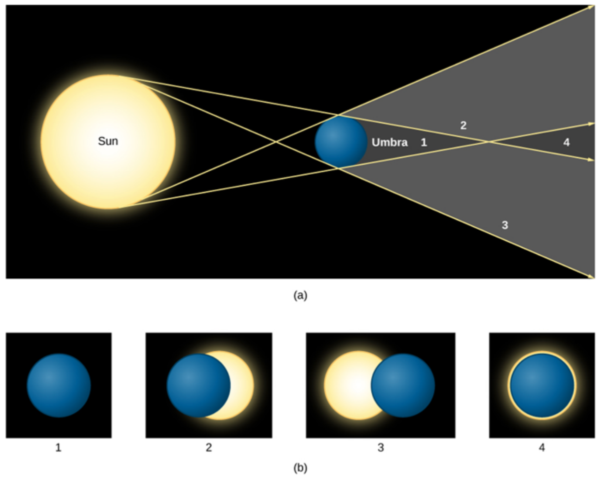

Figure 1 a: The shadow cast by a spherical body (the Moon, for example) is shown. Notice the dark umbra and the lighter penumbra. Four points in the shadow are labeled with numbers.

Figure 1 b: you see what the Sun and Moon would look like in the sky at the four labeled points. At position 1, you see a total eclipse. At positions 2 and 3, the eclipse is partial. At position 4, the Moon is farther away and thus cannot cover the Sun completely

Figure 1. Textbook image of a solar eclipse

In contrast, 3-D simulations allow students to explore the solar system, observe celestial events from different perspectives, and interact with the components of an eclipse in real-time. One key benefit of 3-D simulations is their ability to depict the three-dimensional nature of eclipses accurately. Students can visualize the relative positions of the Sun, Moon, and Earth in space, understand the complex movements and alignments that lead to eclipses, and observe the changing phases of an eclipse dynamically. This spatial representation enhances students' spatial reasoning skills and promotes a deeper understanding of astronomical concepts. Moreover, the interactive nature of 3-D simulations encourages active engagement and inquiry-based learning. Students can simulate different scenarios by adjusting parameters of an eclipse, fostering a hands-on and exploratory approach to learning.

The above example shows the strategic selection and integration of semiotic modes are crucial in effectively conveying complex scientific concepts and enhancing students' understanding. This grant proposal seeks to address the shortcomings of traditional representations first in astronomy education and then in other stem disciplines by advocating for the development of dynamic, interactive representations that harness the full potential of social semiotic resources.

To overcome the limitations of the current 2-D education resources, we propose to develop a set of visually stunning, scientifically correct 3D simulations. These simulations can be projected on traditional 2-D displays or projected into a virtual reality (VR) headset. Simulations can also be ported easily as separate augmented reality (AR) versions that can be viewed with smartphones or tablets (see this AR example from the project website).

Furthermore, in-depth involvement by students in developing, adopting, and evaluating simulations provides invaluable experiential learning opportunities to undergraduate and graduate student team members. They can learn details of real time programming while contributing to the project as paid student programmers. Currently, there are eleven undergraduate students and four graduate students involved in the project.

In addition to developing these 3D simulations, this project includes research components to study their effectiveness and activities around them. These include:

- How does the integration of 3D simulations impact students' grasp of fundamental astronomical concepts?
- What are the levels of student engagement and satisfaction in new immersive 3D simulation-based astronomy education, measured by session metrics and feedback, and how do they compare to conventional teaching?
- How does the student performance with newly created 3D graphic simulations compare to traditional teaching methods in terms of stability, teaching effectiveness, and learning outcomes?

Empact: for Engineering student

The PIs aim to engage both current and former engineering majors who have completed introductory physics courses with us, providing them with hands-on learning experiences through game engine programming. Our STEMin3D project benefits from a strong collaboration with Kyle Johnsen, a faculty member from UGA's engineering college. Together, we plan to advance beyond the “Unity platform” to more contemporary tools like **Unreal Engine**, which is prevalent in today's industry. Engineering undergraduates involved in this project will gain firsthand experience with a cutting-edge game engine, enhancing their skills for future coursework and capstone projects.

Additionally, our project boasts an impressive track record of offering undergraduates valuable opportunities and achieving notable accomplishments, as detailed below.

- Gioia Zincone: Fall 2024 - CURO Research Assistantship
- Anna-Sophia Mehta: 2024 - CURO Summer **Research Fellowship**
- Gioia Zincone: 2024 - CURO Summer **Research Fellowship**
- Emre Aliya: Spring 2024 - CURO Research Assistantship
- Gioia Zincone: Spring 2024 - CURO Research Assistantship
- Ridwan Haque: Spring 2024 - CURO Research Assistantship
- Maxwell Baxley: Spring 2024 - CURO Research Assistantship

Alongside the current students, we're excited to welcome a new group of freshmen from PI’s PHYS 1251, PHYS 1211 courses to the project. Additionally, high school students from Gwinnett School of Mathematics, Science, and Technology have made valuable contributions over the summer, with more expected to continue their involvement throughout this academic year.

Action Plan

The new immersive education resources can increase the student motivation (e.g., Atta et al. 2022, Educ. Sci., 12, 890; Blanco et al. 2018, ASP conf. 524). However, improving students' understanding of the related scientific concepts is critically dependent on the appropriateness of selected topics (Blanco et al. 2018) emphasizing the importance of identifying suitable astronomical topics for simulations. We have already identified about two dozen relevant topics (Table 1 and Table 2) where 3D simulations can immensely enhance students' comprehension of core concepts and ignite a heightened interest in those core concepts. Under the scope of the previous round of learning technologies grant, we initiated the development of simulations for three topics outlined in Table 1. With this current proposal, we seek continued support to complete the ongoing developments for these topics and expand our scope to encompass all six topics listed in Table 1. These simulations are intended for implementation in classrooms during the spring semester of 2025.

Table 1 3-D simulations to be created, implemented under the scope of this LTG proposal

No.	Topic	Note
1	Virtual Night Sky	see Dr. Hall's stellarium-based intro video: here
2	Eclipses	Sun-Earth-Moon system with NASA ephemeris
3	Diurnal Motion of Celestial bodies	Build upon "Virtual Night Sky. Need to develop a controlling python script.
4	Origin of Seasonal Constellations	Build upon "Virtual Night Sky. Need to develop a controlling python script.
5	Time & Calendar	Build upon "Virtual Night Sky. Need to develop a controlling python script.
6	Solar rotation and cycle	Use real solar surface images and put on textured map on a Blender Sun.

These simulations can be made with any modern 3D engines such as Blender, Unity, Steam, or Unreal Engine. Simulations created in this project not only improve students' understanding of fundamental astronomy concepts but also refine their critical thinking and problem-solving abilities.

Project progress:

Eclipse simulation: Identified as a key priority and proposed as one of the initial modules in the previous round of EETI grant proposal. Ridwan Haque and Emre Aliya; two freshman computer science majors already started the creation of the eclipse simulation module with Blender (see Figure 2). Their work was displayed during the 2024 CURO Symposium. The deployment and testing of the **soon-to-be fully developed eclipse 3-D model** are planned within courses such as Astronomy of the Solar System (ASTR 1010) and Introductory Astronomy for Majors I (ASTR

1110) in the upcoming 2025 spring semester. This initiative endeavors to revolutionize astronomy education and make substantial contributions to the open education resource community. Driven by Dr. Weliweriya and Dr. Song, who have a proven track record of collaboration with UGA's Provost's Affordable Course Materials Grant and USG's Affordable Materials Grant, where they seek to provide additional support to students involved in these projects.

Figure 2: A snapshot image rendered from a 3-D simulation of the Sun-Earth-Moon system created by Blender V3.6.2. This simulation was created by two freshmen UGA students.

Virtual Night sky: recognized as another high priority topic. Michael Cai, who joined the research team as a high school student and has continued to contribute significantly as a main program developer, even now as a freshman at *Columbia University* is working on his project to simulate a realistic night sky in Blender. Michael's simulation is in progress as shown below in Figure 3, it can be used in a handful of other simulations such as 'diurnal motions of celestial objects', 'seasonal constellations', 'time and calendar', etc. These additional topics, we plan to create simulations for topics detailed in Table 2 in the near future, leveraging support from other grants, including future LTG rounds and external NSF: IUSE grants. He will explore using Unreal Engine 5 (UE5) in creating a different version of the night sky tracker since UE5 provides two advantages over Blender: (1) real-time rendering and (2) multi-user environment (i.e., a version of virtual classroom).

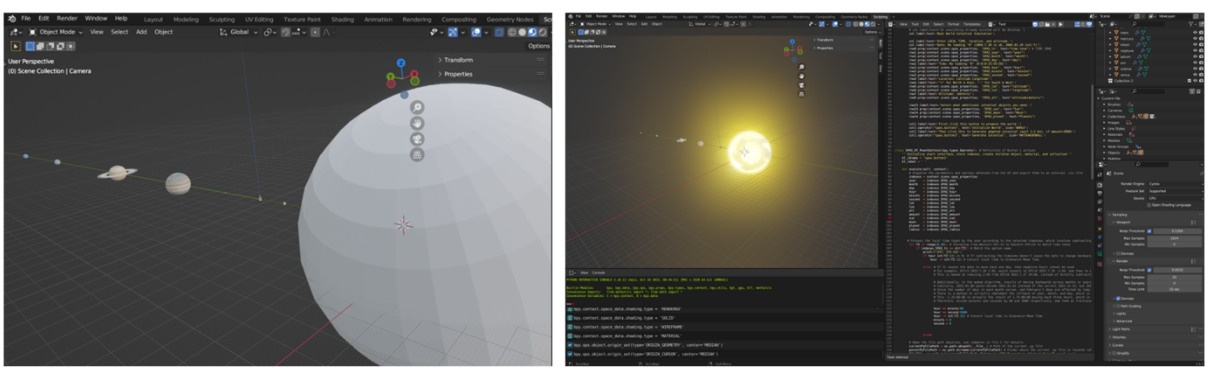

Figure 3 a: Blender Virtual Night Sky 3D-Viewport.This is one of the many windows in Blender for the SkyTracker *(aks Virtual Night Sky)* model development

Figure 3 b: A Full-Screen view of the SkyTracker Blender window. A full window screenshot taken during the development of the *SkyTracker Blender Model.* 3D-viewport, Script editor, (object) Properties window, Scene, ViewLayer, and Console are displayed.

The intended simulations in both table 1 and table 2 are curriculum/topic driven rather than limited by a single adopted platform. Maxwell Baxley, an undergraduate research student involved in the CURO project, has been tasked with gathering information on the latest 3-D simulation development platforms. He constructed a summary table detailing the advantages and disadvantages of each relevant technology (see Max's story at https://stemin3d.net/students/showcases/max_baxeley). As a result of this, the team identified some simulations can be most optimally created with one platform (e.g., Blender) while others are more suitably developed with other platforms. For example, AR implementation of a 3-D model can be best handled by *Unity* currently.

Upcoming Actions

Three astronomy faculty members (Drs. Song, Hall, & Magnani) will create a detailed simulation requirement document for each topic in Table 1 so that student programmers can be guided during the actual development of the simulations. Simulation requirement documents will be later transformed to "storyboard" files by non-programming undergraduate students under the guidance of faculty members and these documents will be reviewed and evaluated in regular group meetings. Storyboard files are like lesson plans but with modern technology components like animatics (read Gioia Zincone's Story on Storyboard at https://stemin3d.net/students/showcases/gioia_zincone). Dr. Weliweriya science education expert, will lead efforts in implementing developed simulations into actual courses. This includes: (1) coordinating with astronomy course instructors (Song/Hall/Magnani) for securing IRB approvals, (2) developing student surveys, and (3) analyzing collected data.

Created simulations will be provided through the project webpage, published reports, the Active Learning at UGA webpage, and the OpenStax OER common. All results including the resultant simulations, script files, relevant documents will be openly accessible under Creative Commons Attribution License (CC-BY).

Three critical tasks from the support of this round of EETI are:

- Create simulation requirement documents and storyboard files: This effort will be carried out by Song/Hall/Magnani. A simulation requirement document describes details of the intended simulation like a scenario for a short movie. Then, each file will be transformed into a storyboard file. We anticipate about 2 weeks of total efforts (~60 hours) per single topic.
- Develop actual simulations: This will be done by undergraduate programmers under the close mentoring by Song and Weliweriya. As has been done already, we will continue announcing opportunities and recruiting capable undergraduate students among physics/astrophysics majors and engineering students. Involved undergraduate project team members can receive UGA's experiential learning program credits and they are encouraged to register for faculty mentored research courses (PHYS 4960/4970/4980/4990 or ASTR 4960/4970/4980/4990). Although the range of scope and depth for each simulation varies extensively, we anticipate

about 15-20 students' hours to create one draft simulation. Experienced students can teach the next group of new students through hand-on interactive sessions and/or detailed tutorials and act as UGA's *Peer Learning Assistant*s.

- Use the created simulations in actual classroom lectures, perform prepared surveys, analyze data, and present the result.

MEASURES OF SUCCESS

The research team's proposal involves creating visually captivating and scientifically accurate modular 3D simulations, aimed at evaluating their efficacy in improving student comprehension. The study will focus on six astronomy topics outlined in Table 1.

The proposed three-dimensional immersive platform offers a variety of learning outcomes,

Enhanced Grasp of Abstract Concepts: 3-D immersive experience that aids students in comprehending fundamental astronomical concepts and, these simulations foster a deeper understanding of complex conceptual ideas.

Improved critical thinking and problem-solving skills: involve analyzing data, making predictions, and evaluating evidence. Using a 3-D immersive platform, users can develop their critical thinking and problem-solving skills by exploring scientifical phenomena, interpreting data, and testing hypotheses.

Enhanced spatial reasoning skills: Astronomy challenges students to contemplate objects and phenomena on a grand scale, often at distances and dimensions that can be hard to grasp. Our proposed immersive platform empowers users to enhance their spatial reasoning abilities by immersing themselves in three-dimensional visualizations and interactive manipulations of key concepts.

Increased engagement with astronomy: A well-crafted 3-D immersive platform has the potential to captivate users, igniting their curiosity to delve deeper into astronomy. Such engagement can foster a heightened interest, potentially inspiring users to seek out additional information or resources across various STEM disciplines.

Exposure to scientific research methods: As integral components of STEM disciplines, physics and astronomy rely heavily on data-driven approaches and scientific research methodologies. Utilizing our 3-D immersive platform provides users with invaluable exposure to these methods, including observing phenomena, gathering data, and interpreting findings. Moreover, our project presents an excellent experiential learning opportunity for research students, allowing them to gain hands-on experience in educational research through implementation, data collection, and classroom feedback.

Quantitative and Qualitative Measures

Our 3D simulations will be deployed in multi-forms including animations in 2-D screen, through virtual reality (VR) headsets, and augmented reality (AR) versions viewable with smartphones or

tablets. As we evaluate the efficacy of these simulations and associated activities, our research team intends to gather data across various instructional modes used by students.
For instance, let's consider the Eclipse simulation,

- **Interactive Simulation Activities:** Students will immerse themselves in an interactive simulation, guided by specific instructions tailored to achieve precise learning outcomes; boost engagement with concepts, enhance grasp of abstract ideas, and develop spatial reasoning skills among students.
- **Video-Embedded Activities:** The same activities will be designed with video narrations guiding students step by step, providing a more scaffolded learning experience. These activities can be presented on 2-D screens or VR headsets, allowing us to gather data from two distinct teaching environments.
- **Pre-Lecture Videos:** The simulation can also be utilized to create pre-lecture videos with narrations. These videos encourage active engagement with course material before each class, a strategy the PI already employs in introductory physics courses through eLC quizzes. Data collected from these quizzes includes number of student visits to specific quizzes, completion dates, time spent, and revisitation frequency.
- **Augmented Reality (AR) Activities:** AR activities will be integrated into lectures and lab sessions, allowing students to use smartphones or tablets for hands-on, in-class engagement more feasible to be used in the whole class compared to VR headsets. See this example for the AR Physics example.

These varied approaches not only enhance student learning experiences but also provide valuable data insights across different instructional modalities, contributing to ongoing efforts in improving STEM education accessibility and effectiveness.

The research team anticipates assessing the effectiveness of our three-dimensional immersive platform in astronomy courses in spring 2025 such as ASTR1010, ASTR1110, and ASTR1420. The team will gauge the effectiveness of our three-dimensional immersive platform under various key factors below.

Testing Conceptual Mastery:
Method 1: collect pre- and post-test scores from students using established assessments such as the Test of Astronomy Standards (TOAST), Astronomy Diagnostic Test 2.0 (ADT2), and Star Properties Concept Inventory (SPCI).

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

Gathering User Feedback: collect end-of-session survey questions (using established astronomical assessments like Introductory Astronomy Questionnaire [IAQ], Astronomy Self-Efficacy survey), and follow-up think-aloud interview queries to delve into user satisfaction, learning outcomes, and potential areas for enhancement.

Measuring Engagement: monitor student engagement by tracking the number of students accessing the platform, their session durations, and frequency of return visits. Additionally, the VR headsets will allow us to capture eye movement data and vital indicators of user engagement.

Comparative Assessment: compare the platform's performance with traditional classroom instruction and existing online learning modules, evaluating its 3D graphics quality and stability.

Exploring Representation Analysis: investigate how students interpret, construct, and switch between different representations (algebraic, gestural, graphical, verbal). By tracking students' eye movements while solving problems, we seek to understand which aspects of representations *they focus on.*

PERSONNEL CONTRIBUTIONS AND STATEMENT OF UNIT-LEVEL SUPPORT

Research Team:

PI: Nandana Weliweriya, serves as the project director is a lecturer, Physics Education Researcher, Department of Physics & Astronomy. Affiliated with the Scientists Engaged in Educational Research (SEER) Center, Engineering Education Transformations Institute, and Owens Institute for Behavioral Research.

Co-PI: Inseok Song, Associate Professor of Astronomy, Associate department head of Physics and Astronomy.

Team members: Drs. Song & Magnani are Astronomy faculty at Physics and Astronomy.

This project proposal builds upon and expands the objectives of a previously funded project with support from EETI, ALG, LTG, and Provost Office. As project director, Weliweriya will be responsible for adhering the team to the project timeline, managing the project's financials, managing Institutional Review Board (IRB) submissions and approvals as needed for data collection, and communicating with the LTG team, make arrangements for the mid-semester formative evaluations, providing reports to CTL as required by the grant terms. Weliweriya was recently recognized with the esteemed Franklin College's Sandy Beaver Excellence in Teaching Award (2024) and UGA's Creative Teaching Award (2024), and an Active learning faculty mentor for the CTL.

In addition, Drs. Song, Hall and Magnani are the instructors for the proposed undergraduate astronomy courses and have ample experience with astronomy research.

BUDGET

Financial support for this project will not only be limited to this round of EETI, but the project also develops on the previous rounds of LTG, EETI funds, and the PIs have already applied for and secured several internal and external grants. The financial support from this EETI proposal will ensure the timely creation progress of the project. With the support of this round, we aim to (1) create simulation requirement documents and storyboard files for 6 selected topics in Table 1, (2) create simulations for the 6 astronomy topics, (3) use simulations in AY24-25 courses, (4) perform surveys to assess effectiveness, and (5) analyze the effectiveness of new OERs. We will likely propose for continued support under EETI rounds in the future. Even if external grants are not secured soon, the project can continue with already secured UGA's internal grants for this project. The main budget item is listed below.

- **Graduate and undergraduate students support ($4,000):** We request this money to support a graduate research assistant so he/she can focus on the program developments, deploy into the classroom and collect data. The direct support from this grant will allow graduate student 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. Further we continue to pay undergraduate students at an hourly rate who will work around the graduate student. Further the financial support undergraduate students' programming tasks integral to the project's execution (to support engineering undergraduate students at a competitive rate of $12 per hour), each engaging for approximately 6 hours per week. This ensures fair compensation for their valuable contributions.

TIMELINE

- Simulation requirement documents and storyboard files for 6 selected topics (**by Sept. 20, 2024**): Song/Hall/Magnani
- External Funding Initiative (**OCT. 2024**): seek external funding by submitting a grant proposal to the Unreal Engine's Epic Megagrant opportunity.
- Finish the development of simulations by student programmers (**by Nov 1, 2025**): Song/Weliweriya and undergrad students.
- Adopt new simulations in 2025 Spring semesters: Song/Hall
- Submission of the progress Report to EETI team (**Jan 2025**).
- Student surveys: Weliweriya and graduate students obtain data from the initial in-class trials and initiate the analysis (**during 2025 Spring**).
- Conduct a mid-semester formative evaluation with the help of CTL (March **2024**).
- Submission of the Final Report to LTG team (**June 2025**).
- Data Analysis and Publication (**Summer 2025**): Finish the analysis of the data obtained in 2025 Spring trials. Present results at prominent conferences, including AAPT (American Association of Physics Teachers) and PERC (Physics Education Research Conference). Undergraduate students will apply for CURO opportunities. Five undergrad student team members applied for the AY2024 CURO Research Awards and all of them were selected.