Active Learning Grant Application 2024

1. TITLE

Active Learning with 3-D Modeling of Immersive Astronomical Simulations
Department of Physics and Astronomy
ASTR 1010, 1110, 1420, & 2030

2. PURPOSE

This collaborative initiative, spearheaded by Nandana Weliweriya (ALSI alumni, 2021) in conjunction with Dr. Inseok Song and more astronomy faculty members, aims to create an innovative 3-D immersive astronomical simulation platform. The project focuses on enhancing astronomy instruction through active learning, intending to evaluate the platform's impact on elevating educational quality. Beyond astronomy, this endeavor seeks to extend its benefits to broader STEM disciplines, exploring the potential for this immersive platform to revolutionize education and research across multiple fields. Additionally, this project aims to empower both undergraduate and graduate participants by providing hands-on programming experience, nurturing future professionals in programming, education, and research through their active involvement in the platform's development, implementation, and data analysis.

Project Description: Many students are attracted to the heavenly beauty of celestial objects. Students who typically enroll in our department's introductory astronomy courses expect fascinating, thought-provoking, engaging learning experiences when they sign up for these courses. However, because of various limitations, these courses are taught in a passive, unidirectional, lecture-based instruction mode essentially eliminating any chance for active learning experience for enrolled students.

One of the main aforementioned limitations is the lack of visual illustrations. Currently available astronomy illustrations for various astrophysical concepts and astronomical phenomena are 2-D figures inadequate to depict complex 3-D real-world scenarios accurately, often hindering student's comprehensive understanding. Moreover, limited opportunities to engage with and solve real-world problems, either individually or collaboratively, can diminish students' motivation to persist in astronomy. To address these challenges, we aims to bridge the gap by providing essential connections to real-life scenarios and enhancing the representation of 3-D concepts frequently overlooked in traditional educational resources. With our intended developments of 3-D open education resources, students can be provided with immersive, engaging active learning environments.

Several faculty members in the Department of Physics and Astronomy have been actively working in enhancing the STEM undergraduate education by adopting the great potential of virtual reality (VR) as education resources. Currently, nine USG faculty members including one member from Georgia State University are actively engaged in the education project called STEMin3D (https://STEMin3D.net) with the aim of developing immersive education resources by adopting the 3-D, VR, and/or augmented reality technologies. All investigators of the current proposal are active members of this STEMin3D project. Current astronomy education resources, especially illustrations and figures, are generally limited in 2D that falls short in providing chances to students to grasp the underlying concepts of fundamentally 3D phenomena. 2D static figures are not enough to meet the expectations of students and instructors, failing to provide motivation to continue in astronomy.

To overcome these constraints, we propose to develop a set of visually stunning, astrophysically correct, modular 3D simulations. These simulations can be projected on traditional 2D 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. These new platforms of education 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 where 3D simulations can immensely enhance students' comprehension of core concepts and ignite a heightened interest in those core concepts. Under the scope of this project, we will create simulations for a selected set of high priority topics (Celestial Sphere and Coordinate Systems, Diurnal Motion of Celestial bodies, Eclipses, Origin of Seasonal Constellations, Time & Calendar, and Retrograde motion of Mars).

Figure 1. 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 student

These simulations can provide cutting-edge, previously infeasible active learning experiences to students. For example, using realistically created Sun, Earth, and Moon in accurate orbits, we can simulate solar/lunar eclipses. By interactively adjusting camera viewing angles, object sizes, orbital inclinations, etc., students can be moticated to grasp the fundamental principles that govern the eclipse phenomenon. Such simulation can be made with any modern 3D engines such as Blender, Unity, Steam, or Unreal Engine. These simulations not only improve students' understanding of fundamental astronomy concepts but also refine their critical thinking and problem-solving abilities through active learning opportunities. Two freshman computer science majors already started the creation of the eclipse simulation module with Blender (see Figure 1). Our project can revolutionize astronomy education and greatly contribute to the open education resource community, liberating it from traditional limitations and ushering in a new era of exploration and comprehension for all.

Created astronomical simulations will be used in our 2024 Fall semester courses (ASTR 1010 and 1110 first). Undergraduate students play a major role in the creation of simulations by programming in 3D modeling software under close mentoring and guidance by faculty members. These in-depth involvements by students in developing and evaluating simulations provide invaluable experiential learning opportunities to student team members. They can learn details of real time programming while contributing to the project as paid student programmers. Currently, there are five undergraduate students and four graduate students involved in the project.

In addition to developing these 3D simulations as OERs, this proposal aims to offer innovative resources and engagement tools, fostering active learning, engagement and innovation in education. This proposal is firmly rooted in two pivotal pillars of instructional development, all strategically crafted to elevate active learning and engagement to new heights:

1. **Pre-Class Preparation**: Create pre-lecture videos with integrated near and far transfer questions, promoting active learning and deeper comprehension. Traditional methods relying on textbook reading have limitations, including time constraints, motivation issues, and missed discussions. Sole reliance on pre-lecture videos is passive and lacks practical applications, resulting in surface-level understanding. Our primary goal is to improve pre-lecture preparation by integrating near and far transfer questions. The proposed approach aims to: Promote Active Engagement: encourage students to actively engage with pre-lecture videos by solving integrated multiple-choice questions (MCQs) designed to assess their understanding, Enhance Comprehension: shift the focus of in-class discussions to practical applications and real-world examples, enabling deeper understanding and concept retention, and Improve Problem-Solving Skills: enhancing comprehension and fostering problem-solving proficiency.

   We seek to address the following research questions:

- How does integrating near and far transfer questions into pre-lecture videos impact student engagement, measured by quiz interactions and completion rates?
- What is the effect of near and far transfer questions in pre-lecture videos on students' comprehension and real-world application of STEM concepts, including in-class discussions, problem-solving, and worksheets?
- How can data collected through iPads, including voice and pen movements, provide insights into student problem-solving, learning patterns, and engagement? Can this data inform algorithms predicting student grades based on engagement and transfer question performance?

2. **In-Class Activities**: We create dynamic, interactive learning environments with 3-D visuals and engaging activities to foster active participation and critical thinking. To overcome the constraints described above, we propose to create a set of visually stunning, astrophysically correct, modular 3D simulations that can be used within an immersive platform including but not limited to virtual reality and augmented reality.

This approach revolutionizes astronomy education, liberating it from traditional limitations and ushering in a new era of exploration and comprehension for all.

We aim to addresses key research questions:

- 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 new approach affect students' problem-solving skills and representation transitions, with insights gained from eye-tracking during problem-solving?
- What is the comparative performance of simulations in 3D graphics, stability, and teaching effectiveness versus traditional methods, assessed through pre and post-test scores and representation analysis?

3. FORMAT

We plan to develop about two dozen astronomical simulations (6 under the scope of this proposal) whose underlying concepts are challenging for students to understand with traditional 2-D, static illustrations. By rendering the developed simulations in a dynamic, interactive, immersive environment such as Augmented Reality and/or Virtual Reality, students can engage in active learning activities that have been infeasible before. These simulation modules can be deployed to multiple introductory astronomy courses (ASTR 1010, 1110/H, 1420, and 2030L). The second major addition is developing pre-lecture preparation materials.

Based on these facts, our project is best categorized as "Active Learning Module Across Courses".

4. IMPACT

We are in the midst of departmental-level transition for introductory astronomy undergraduate education (https://STEMin3D.net) where five department faculty members are involved. The primary effort is to create a set of astronomical simulations that can be deployed into multiple introductory astronomy courses including ASTR 1010, 1110/H, 1420, and 2030L. The average number of students enrolled in these courses are 300 per academic year. ASTR1010 (and ASTR1110; Astronomy of the Solar System) is one of USG Core Curriculum Courses and ASTR1420 is a USG General Curriculum course. ASTR 2030L (and 1110) is a required course for majors.

The development of the 3-D immersive simulations platform not only impacts students as consumers but also significantly benefits those involved in its creation and implementation. Undergraduate students engaged in creating these simulations gain crucial hands-on programming experience, providing them with valuable skills and preparing them for future careers as programmers. This active involvement in platform development offers them real-time engagement, fostering their growth in the field.

Moreover, both graduate and undergraduate students involved in implementing these innovations within classrooms can receive experiential learning opportunities. Their engagement in the practical application of these advancements contributes to their development as future scientists/educators. Simultaneously, students engaged in analyzing and presenting data as part of this project undergo training that prepares them for future roles as educators and researchers.

This project's multifaceted impact aligns directly with UGA's 2025 Strategic Plan. By focusing on 'Promoting Excellence in Teaching and Learning' and 'Growing Research and Innovative

Approaches to Teach and Create Research Opportunities,' the initiative not only enhances the educational experience for students but also nurtures the next generation of skilled programmers, educators, and researchers.

5. TEM MEMBERS

TEAM FACILITATOR #1

- Nandana Weliweriya
- Lecturer
- ALSI Alumnus? **Yes** (if yes, year of completion ___2021___)
- nandanaw@uga.edu
- Specializing in physics education research. His research focuses on investigating students' problem-solving processes and techniques, with a particular interest in shaping instructional methods based on his findings.

TEAM FACILITATOR #2

- Inseok Song
- Associate Professor
- ALSI Alumnus? **No**
- song@uga.edu
- An observational astronomer with research interests include young stars and planets in the solar neighborhood, detection and characterization of exoplanets, and STEM education.

TEAM MEMBER

- Loris Magnani
- Professor
- ALSI Alumnus? **No**
- loris@uga.edu
- Radio astronomer with research interest on the interstellar medium of our Galaxy, primarily on radio spectroscopic studies of diffuse and translucent interstellar molecular clouds.

TEAM MEMBER

- Cassandra Hall
- Assistant Professor
- ALSI Alumnus? **No**
- cassandra.hall@uga.edu
- Theoretical astrophysicist with extensive experience in inclusive education, in particular as the physics coordinator for an equal access to higher education program.

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6. BUDGET		
Category	Details	$
Operational Expenses	Undergrad programmer support	5,000
Operational Expenses	Grad. Student support	5,000
Supplemental Salaries for Facilitators	Summer salary support for facilitator #1	2,500
Supplemental Salaries for Facilitators	Summer salary support for facilitator #2	2,500
Supplemental Salaries for Facilitators		0
Supplemental Salaries for Facilitators		0
TOTAL		15,000

7. ASSESSMENT PLAN - REQUIRED COMPONENTS	
Learning Outcomes	The proposed 3-D immersive platform can offer a variety of learning outcomes. **Improved understanding of astronomical concepts:** The three-dimensional immersive experience in our proposed 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 this 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 this platform to develop their spatial reasoning skills by visualizing and manipulating astronomical objects in three dimensions. **Increased engagement with astronomy:** A well-designed immersive 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 this platform allows users to gain exposure to these methods, such as observing phenomena, collecting data, and interpreting results.
Specific Measurements **Student Perspectives**	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 ASTR 1010, 1110, 1420, & 2030 to test the platform's effectiveness. Assessing the effectiveness of our 3-D immersive 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 to 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. **Peer Observations:** Apart from collecting student data, our research team intends to gather peer observational data. To facilitate this process, we aim to invite astronomy faculty, DEBER faculty via the SEER center, and also engage in MSFE conducted through the CTL. This inclusive approach seeks to broaden our perspective by incorporating insights and observations from diverse faculty backgrounds, enriching the depth and scope of our research. **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.

7. ASSESSMENT PLAN - OPTIONAL COMPONENTS	
In addition to student disciplinary knowledge indicators, other impact data, such as student perspectives on the active learning approaches used in these course(s), instructor peer observations, and/or instructor self-reflections, will be especially welcome.	
Instructor Peer Observations	**Peer Observations:** Apart from collecting student data, our research team intends to gather peer observational data. To facilitate this process, we aim to invite astronomy faculty, DEBER faculty via the SEER center, and also engage in MSFE conducted through the CTL. This inclusive approach seeks to broaden our perspective by incorporating insights and observations from diverse faculty backgrounds, enriching the depth and scope of our research.
Instructor Self-Reflection Components	At the conclusion of every semester, according to the outlined timeline, Facilitators #1 and #2 will engage in a self-reflection session alongside the other two astronomy faculty members before transitioning to the subsequent semester. This structured process aligns seamlessly with the mandatory annual evaluation for faculty members within the physics and astronomy department.

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8. TIMELINE

Year One (Fall)

Month/year	Objective or Goal	Person(s) Responsible
05/24 - 09/24	**Simulations and Platform development:** Evaluating existing limitations of current 3-D simulations, user engaging activities and developing new versions Fall 2024 Astronomy courses	Nandana Weliweriya (NW), Inseok Song (IS), Graduate and Undergraduate students
09/24 - 12/24	Implement initial simulations, activities developed for Fall 2024 Astronomy courses and outreach events	NW, IS, Loris Magnani (LM), Cassandra Hall (CH), Graduate and Undergraduate students
09/24 - 11/24	With the initial developments and trial data, Submit a collaborative Grant proposal to Unreal Engine: Mega grant	NW, IS, LM, CH, Kyle Jonsen (UGA engineering)
09/24 - 10/24	Collaborate with CTL to conduct mid-semester formative evaluations, utilizing the assistance of an education expert from CTL to gather valuable student perspectives.	NW, IS
10/24 - 12/24	Facilitators #1 and #2 convene with the Active Learning Assessment Coordinator to review progress and implement necessary adjustments for the remainder of the current semester and upcoming semesters.	NW, IS
12/24 - 01/25	Analyze data from initial trials. Begin work on publication of initial results	NW, IS, LM, CH, Graduate and Undergraduate students

Year One (Spring)

Month/year	Objective or Goal	Person(s) Responsible
01/25 - 05/25	Update and implement existing simulations, activities for spring 2025 Astronomy courses and outreach events	NW, IS, LM, CH, Graduate and Undergraduate students
03/25	Present initial findings at APS regional meeting, USG Teaching and Learning Conference, Engineering education conferences, UGA CURO	NW, IS, Graduate and Undergraduate students
03/25 - 04/25	Collaborate with CTL to conduct mid-semester formative evaluations, utilizing the assistance of an education expert from CTL to gather valuable student perspectives.	NW, IS

	03/25 - 04/25	Facilitators #1 and #2 convene with the Active Learning Assessment Coordinator to review progress and implement necessary adjustments for the remainder of the current semester and upcoming semesters.	NW, IS
	03/25 - 04/25	Submit a progress report on proposal to the Director of Active Learning.	NW, IS
	05/25 -07/25	Analyze data from initial, spring trials. Present and publish articles at AAPT (American Association of Physics Teachers) and PERC (Physics Education Research Conference)	NW, IS, LM, CH, Graduate and Undergraduate students
	05/25- 08/25	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

	Month/year	Objective or Goal	Person(s) Responsible
Year Two (Fall) Through Year Five (Spring)	08/25 - 09/25	Evaluate the developed simulations, activities for Fall 2025 Astronomy courses and outreach events	NW, IS, Loris Magnani (LM), Cassandra Hall (CH), Graduate and Undergraduate students
	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, IS, Graduate and Undergraduate students
	Over the academic year and beyond	Analyze data from spring and fall trials. Present and publish articles at local and national conferences.	NW, IS, LM, CH, Graduate and Undergraduate students
	After the academic year	Submit a final project report	NW, IS