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BOARD # 213: Perspectives of Junior Scholars: Calculus Learning Outcomes from Middle School Students After Use of an Educational Video Game (Work in Progress)

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Abigail Tran is a Psychology undergraduate student with the LIVE Lab at Texas A&M University. She volunteers with the research team, having aided in conducting a study with middle school students about an educational video game and writing the qualitative research paper for it.

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Advay Bhattacharya is a second-year Statistics major at Texas A&M University and an undergraduate researcher at the LIVE Lab, where he contributes to interdisciplinary projects at the intersection of computer science, education, and data analysis. Over the past two years, he has supported the lab's structural equation modeling (SEM) efforts to evaluate learning outcomes and has worked with teams exploring how game-based learning environments affect student motivation, engagement, and conceptual understanding. His contributions span educational research, technical infrastructure, and community outreach, including helping manage and expand the lab's database of educational video games and supporting updates to the corresponding website. He has also been involved in the design and facilitation of summer camp experiences, including analyzing data from students interacting with the Variant: Limits game. Advay is particularly interested in the role of technology in shaping modern education and seeks out opportunities to blend programming, data science, and human-centered research to support evidence-based learning tools and strategies.

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Meet Gamdha is a Computer Science student at Texas A&M University, minoring in Engineering Entrepreneurship through the Meloy Program. He is a researcher and project manager at the LIVE Lab and an AI Consultant for NeuroX1 through the Aggies Create program, where he leads and supports cross-functional teams focused on educational technology innovation and AI-powered research solutions. Meet's work spans building scalable AI search infrastructures, backend development, and DevOps solutions, with a strong focus on practical, high-impact applications in education and healthcare. His technical expertise includes machine learning, web development, and cloud technologies, with hands-on experience deploying tools using PyTorch, Hugging Face, PostgreSQL, and AWS. Meet has also contributed to award-winning projects such as Connections AI, a machine learning solution for puzzle solving, and has led data optimization efforts for large-scale industrial challenges

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Dr. Michael S. Rugh is an Associate Research Scientist at the LIVE Lab at Texas A and M University and Director of STEM Education Research for the Aggie Research Program. He leads interdisciplinary research teams investigating game-based learning and the impact of educational technologies, including video games, simulations, apps, and virtual environments created by the LIVE Lab. With a master's degree in Mathematics and a Ph.D. in Curriculum and Instruction, his research examines how people learn, with a particular emphasis on interactive and immersive experiences. Dr. Rugh brings several years of K–16 teaching experience in mathematics and science and has served as a reviewer, committee member,

editorial board member, and associate editor for organizations such as the National Science Foundation, the Journal of Urban Mathematics Education, and the School Science and Mathematics Association. His recognitions include the Graduate Merit Fellowship from the Association of Former Students and being named the College of Education and Human Development Distinguished Honor Graduate.

Perspectives of Junior Scholars: Calculus Learning Outcomes from Middle School Students After Use of an Educational Video Game (Work in Progress)

Introduction

We have utilized an educational video game (EVG) in a summer camp environment to instruct calculus to middle school students to determine the educational needs that the game both achieves and misses. As time goes on, EVGs increase their presence in standardized curriculum. This type of tool is primarily seen in K-8 environments, decreases utilization in high school settings, and becomes even more scarce when reaching higher curriculum. Primary school students (includes middle school) benefit most with results significantly better than secondary and higher educated students (Wang et al., 2022). Compared to paper-and-pencil activities, the use of an EVG has higher overall engagement and higher behavioral and emotional engagement from students (Chang et al., 2016). Despite this, an observable, gradual increase is occurring in all three educational pools due to their specialized potential for augmenting and supporting classroom engagement. Our definition for EVGs will be borrowed from a previous study**:** "video games designed to help people understand concepts and learn domain knowledge" (Jones et al., 2024). Regarding the research conducted at Aggie STEM Summer Camp 2024, this paper asks the following research question: What were the experiences of the middle school students while playing the game? This question helps future EVG production with a focus on better educational content, presentation, communication, and overall engagement.

This study builds off previous studies that have used *Variant: Limits* (*VL*) in higher education environments to gauge student outcomes, faculty opinions, and accessibility (Li et al., 2021; Tiede & Grafe, 2018; Wang et al., 2022). *VL* was used to teach calculus concepts, including limits, trigonometry, and geometry during a STEM summer camp to middle school students, an audience not immediately targeted by the EVG itself. In *VL*, the player is immersed in a "3D environment where they must solve a series of increasingly challenging calculus problems in order to stop the geomagnetic storms threatening their planet's survival" (Thomas et al., 2017, see Figure 1 and Figure 2).

Figure 1

In-game Screenshot of Player Character Looking at Scenery

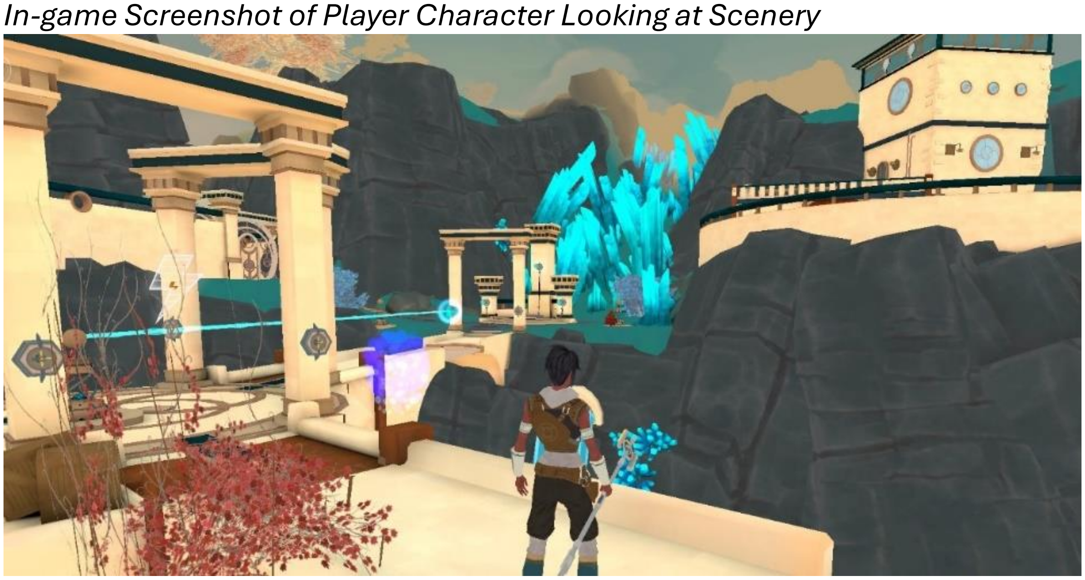
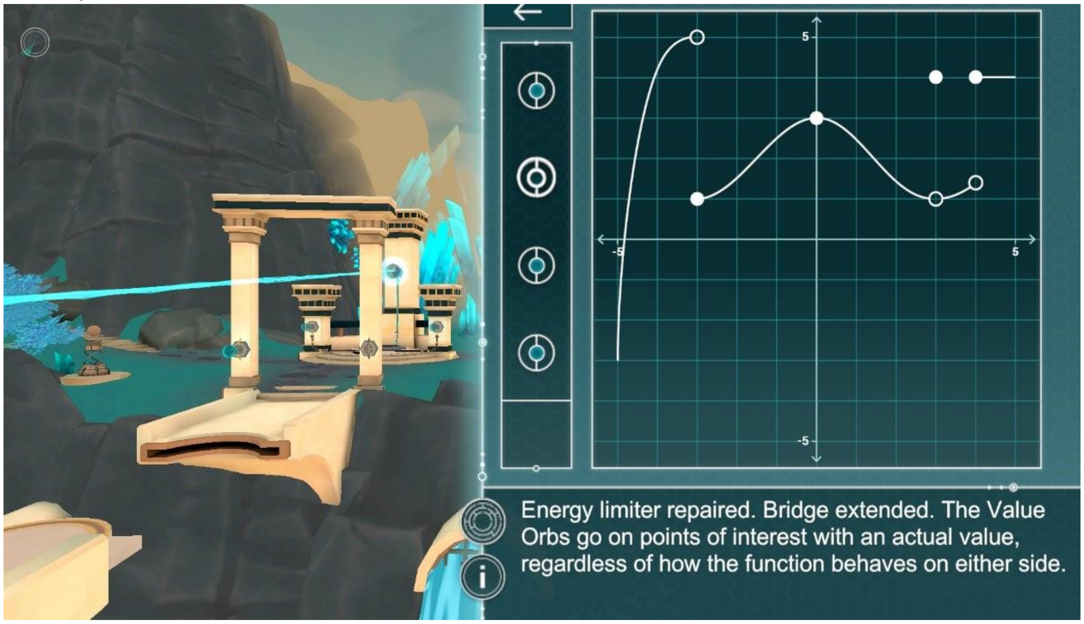


Figure 2

Example of a Puzzle From VL



Methods

Participants

Participants were 30 middle school students that were a part of a university STEM summer program. Participants played *Variant: Limits* on university-provided computers for a week, for approximately an hour and thirty minutes every day in small groups. Researchers were available during these sessions to assist and answer questions related to calculus and the curriculum. Following this, several students volunteered to complete verbal interviews in which they were asked questions related to the game's teaching and their overall experience playing. These were recorded and transcribed.

Data Analysis

The transcribed interviews were segmented into questions and the relevant answers. The initial analysis of these interviews was done by determining relevant chunks of answers to best analyze for the study. The second analysis involved coding these chunks into shorter descriptions and then making themes based on the general responses. These themes included Controls, Instruction, Quest Design, Narrative Design, Visual Design, Previous Math Experience, Previous Game Experience, Embodied Cognition, EVG Opinion, and *Variant*: *Limits (VL)* Opinion. A priority number was then applied to each theme to determine how relevant they were to the study and how important they were to the students (1 – low priority; 5 – high priority).

Definitions of themes were created in order to better assign them to the chunks. Controls referred to movement throughout the game and orientation of the camera. Instruction was about the integration of teaching into the game through tutorials, the lessons, and explanations of concepts. Quest Design focused on the actual quests themselves, such as moving nodes, opening doors, collecting batteries, and similar tasks to progress in the game. Narrative Design was about how impactful and effective the storyline of the game was. Visual Design focused on how the game looks and its impact on gameplay. Previous Math Experience referenced any math a student has done in the past, more specifically calculus. Previous Game Experience referenced any gaming a student has done in the past. Embodied Cognition is about experiential learning and how students best learn. EVG Opinion is about a student's overall opinion on EVGs, specifically their enjoyment, engagement, and how effective it would be in a classroom or teaching setting. *VL* Opinion is about a student's overall opinion on *Variant*: *Limits*, and how effective and enjoyable the game was.

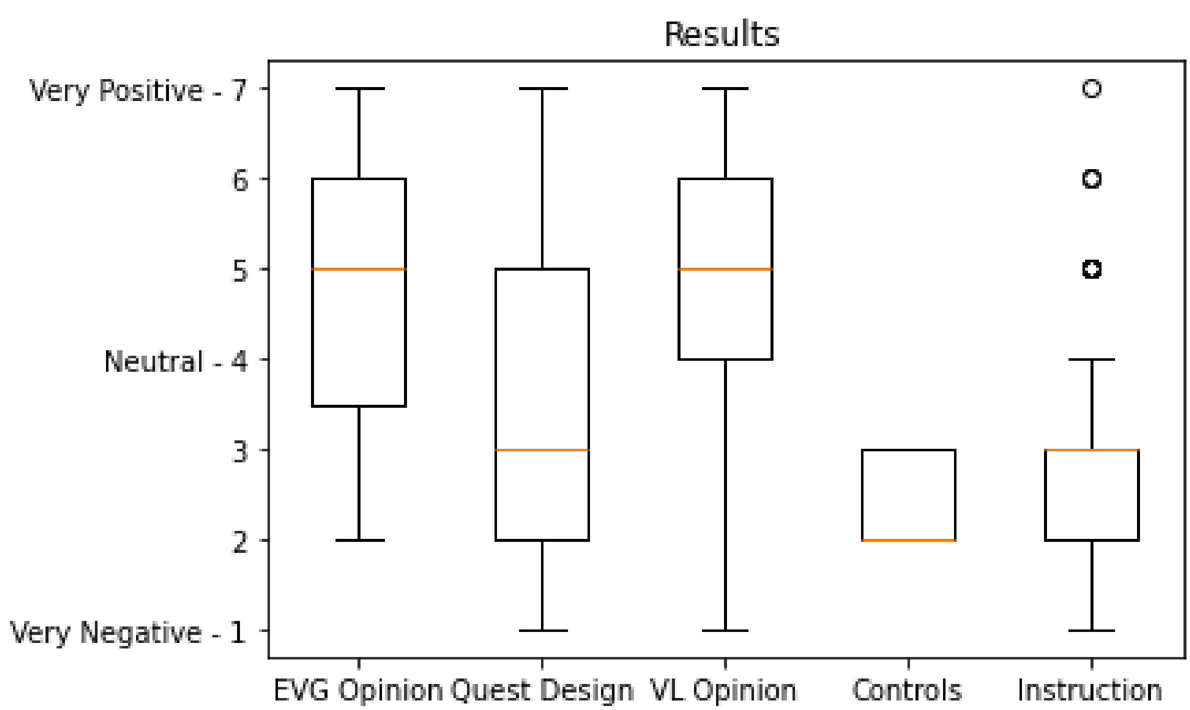
A sentiment analysis was performed in which the themes with the highest priority numbers and their corresponding codes and chunks were taken and analyzed according to a Likert scale from 1 (very negative) to 7 (very positive) depending on the responses. The averages of these responses were then calculated in order to gather the collective opinions and results on these different themes.

Results

Analysis of student feedback from 30 surveys and 6 interviews, yielding 181 relevant text chunks, focused on understanding middle schoolers' perceptions of *VL*. A mixed-methods approach combined thematic analysis with sentiment scoring (on a 1-7 Likert scale: 1=Very Negative, 4=Neutral, 7=Very Positive). Six key themes emerged as priorities during analysis: Instruction, Quest Design, Controls, *VL* Opinion, EVG Opinion, and Narrative Design. Figure 1 provides a visual summary of the sentiment score distributions for the five themes where quantitative scoring was finalized. The findings in Table 1 present the preliminary results from the thematic and sentiment analyses.

Figure 3

Preliminary Results of the Thematic and Sentiment Analyses Using a Likert Scale



Instruction (M = 2.88, SD = 1.29, n = 81 chunks)

When it came to giving instructions, many students noted that the game often did not meet their needs. Instead, it merely gave them the problem and expected them to know how to solve it. Any tips that were given were often vague, leading to students having to guess on the problem to progress in the game.

Quest Design (M = 3.56, SD = 1.49, n = 65 chunks)

Students' thoughts on the quest design were slightly more mixed when compared to the previous themes, with the combined results being more neutral but still slightly lower. Some explained that they felt rewarded when they completed the quests, and that the game helped them learn fast. However, others noted that the lack of guides in the quests could have made them difficult to complete, and that it was a bit more complex than their level of understanding of math and calculus.

Controls (M = 2.44, SD = 0.527, n = 9 chunks)

Many students reported that the controls for the game, while simplistic, were frustrating and negatively impacted their gaming experiences.

VL Opinion (M = 4.56, SD = 2.01, n = 9 chunks)

The overall opinion on the game was neutral, though slightly closer to the positive side. Some felt it was well made, while some feelings on it were swayed more negatively by the difficulty level.

EVG Opinion (M = 4.67, SD = 1.83, n = 12 chunks)

The students' combined opinions on educational video games were also neutral. Students commented on the way that education is advancing with the times and being done with technology, as well as how video games are appealing to younger audiences. However, some feel as though educational video games still need work to be properly implemented into a teaching curriculum.

Discussion

Our results show that whilst the students had generally neutral or higher opinions on educational video games, when it came to the actual components of the specific game, *Variant: Limits* game, they had more negative feelings. While most reported that they enjoyed the game, the consensus was that there was a lack of guidance and instruction provided in this game, and that the controls made navigation difficult. Along with expanding the results, we will expand the discussion section to explore how the findings contribute to the evolving role of game-based learning in K-12 education and how these insights can inform future curriculum design. Educating younger generations who may not have had exposure to advanced math also begs the question of when it is appropriate for these kids to start interacting with these subjects for optimal performance while learning. For many of these students the level of math they are exposed to may indicate how successful they will be while tackling the problems in games such as *Variant: Limits*. Ensuring that the learning curve is less steep upon working through the initial topics and also a more in-depth tutorial may also yield better results in terms of how digestible the content is for the player. Allowing for multiplayer with one of the players functioning as the teacher for more enhanced guidance may also bolster the shaky tutorials and increase reassurance for the students, as many felt "thrown into it."

Limitations and Future Research

Our study focused on the reactions and opinions of middle school students regarding *VL,* a group that typically has not yet been exposed to calculus concepts. Consequently, we gathered insights from participants who approached the study without prior knowledge of limits, which occasionally led to initial or ongoing confusion. To address this, researchers provided instruction on limits during the sessions. Additionally, logistical constraints impacted the study: the limited number of computers required students to work in groups rather than individually, which may have influenced their experiences and opinions of the game. Compounding this, some computers failed to save progress, forcing certain groups to restart daily, potentially affecting their engagement and overall perception of the game.

Future research on this game could include implementing the game into diverse educational contexts, such as after-school programs or online learning platforms, to evaluate its adaptability and effectiveness across different learning environments. Alternatively, we could explore strategies for effectively integrating *VL* into classroom instruction, including teacher training and curriculum alignment, to maximize educational outcomes.

Conclusion

Educational video games introduce a new and interactive way of teaching concepts to students. They are appealing in that younger audiences are able to engage in playing games while also learning. Still, these can be applied to higher level education, such as high school and college, with the right strategies and games. The work here demonstrates both the potential and challenges of using *VL* to teach calculus to middle school students. While students showed interest in educational video games, issues with unclear instructions, difficult controls, and a steep learning curve hindered engagement. These factors contribute to the neural or negative feelings some students had towards instructions and the game as a whole. Improving instructional design, simplifying mechanics, and incorporating guided support can enhance effectiveness. As seen by student opinions on GBL, students enjoy game-based learning but are wary of how effectively it integrates with education. For educational games to succeed, they must strike a good balance between engagement and instruction. Future research should examine how prior math exposure impacts game-based learning and assess long-term knowledge retention. By refining these elements, educational video games can become more effective tools for teaching complex concepts.

References

Chang, M., Evans, M. A., Kim, S., Norton, A., Deater-Deckard, K., & Samur, Y. (2016). The effects of an educational video game on mathematical engagement. *Education and Information Technologies*, *21*, 1283-1297. https://doi.org/10.1007/s10639-015-9382-8

Jones, A. D., Rugh, M. S., Gamdha, M. M., Norman, T. J., Myers, R., Meek, K., ... & Nguyen, E. T. (2024, June). Paving digital infrastructure: Innovation through an educational video game database. In *2024 ASEE Annual Conference & Exposition*. https://peer.asee.org/47834

Li, Y., Sutedjo, A., Ramos, S.J., Garcimartin, H.R., Thomas, A. (2021). A naturalistic inquiry into digital game-based learning in STEM classes from the instructors' perspective. In: Aprea, C., Ifenthaler, D. (eds) *Game-based Learning Across the Disciplines. Advances in Game-Based Learning*. Springer, Cham. https://doi.org/10.1007/978-3-030-75142-5_10

Thomas, A., Lima-Filho, P., Pederson, S., Ramadan, H., & Bologan, A. (2017). *Variant: Limits* [Educational Video Game]. Triseum. https://hdl.handle.net/1969.1/188002

Thomas, A., Weng, W., Muenzenberger, A., & Ramadan, H. (2019, October). Game-based course design: A new approach for effective online teaching. In *European Conference on Games Based Learning* (pp. 741-XXI). Academic Conferences International Limited.

Tiede, J., & Grafe, S. (2018, September). Piloting two educational games in five european countries: Teachers' perceptions of student motivation and classroom engagement. In *2018 10th International Conference on Virtual Worlds and Games for Serious Applications* (VS-Games) (pp. 1-8). IEEE.

Wang, L. H., Chen, B., Hwang, G. J., Guan, J. Q., & Wang, Y. Q. (2022). Effects of digital game-based STEM education on students' learning achievement: A meta-analysis. *International Journal of STEM Education*, *9*(1), 26. https://doi.org/10.1186/s40594-022-00344-0