2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
ASEE
Paper ID #36939

Work in Progress: Toward an Augmented Reality (AR) Learning Environment for Hispanic High School Students to Visualize and Embody STEM Spatial Transformations

Dr. Daniel A. Tillman, University of Texas, El Paso

Dr. Tillman is an Associate Professor in Educational Technology, working primarily within the El Paso region of the southwestern United States. His research focuses on the implementation and assessment of innovative pedagogical approaches that address STEM inequities.

Wei Yan, Texas A&M University
Song An, University of Texas, El Paso
Jeffrey Liew, Texas A&M University
Dr. Kien H. Lim

Dr. Lim's research interests are on studentsâ€™ problem-solving disposition and instructional strategies to advance their ways of thinking. Dr. Lim is particularly interested in impulsive disposition, studentsâ€™ propensity to act out the first thing that

Lisa Garbrecht, University of Texas, Austin
Philip B. Yasskin

Introduction

Mathematics has historically been taught in ways that are a barrier to minority students pursuing advanced STEM courses in high school and college [1] while current teaching methods are heavily reliant on spoken and written language, which can be particularly problematic for bilingual students [2]. Consequently, too few underserved students such as Hispanics graduate from high school prepared to begin a STEM degree program or career [3][4]. This project aims to overcome Hispanic students' barriers by improving both cognitive and socio-emotional outcomes and enhance students' informal learning communities by: (1) increasing participants' interest and engagement with mathematics and geometry specifically, (2) increasing participants' productive dispositions toward STEM subjects, and (3) enhancing the culture and broadening participation in students' informal learning communities. The after-school activities will be modeled on the Math Circles which are a nationally recognized outreach program which allows teenagers to investigate interesting and fun math concepts through inquiry-based learning under the guidance of experienced math researchers. Our activities will use manipulatives produced in makerspaces in combination with Artificial Intelligence (AI)-powered Augmented Reality (AR), to bridge the gap between educational research and practical relevance in culturally responsive ways. In particular, students will see the physical models they build and move appearing synchronously on a computer screen with overlaid graphics, and during this process they will learn the mathematics which makes AI-powered AR possible.

Project Design and Outcomes

A key barrier to lifelong learning in STEM, particularly among underserved and underrepresented students, is engagement and retention [5]. By providing Hispanic students with the opportunity to engage in hands-on, experiential learning activities related to geometry, this project seeks to not only increase their exposure to and interest in STEM subjects but help students build both engaging memories in applying spatial reasoning and the identity of themselves as scientists who are doing science in their everyday lives and in their own communities. Additionally, the project aims to advance our understanding of the ways in which informal STEM learning can support the academic and career success of Hispanic students. AI-powered AR during geometry instruction can be particularly helpful for first-generation Hispanic high school students because it can overcome barriers that may exist during their bilingual life. Hispanic students who do not speak English at home and may face significant challenges when it comes to learning mathematics in high school. A lack of support and resources at home can make it even more challenging for these students to succeed in math; however, with the right support and resources, these students can overcome these challenges and excel in math. AR allows students to see and interact with the objects in a more engaging and immersive way, which can help them to better understand the concepts being taught. Additionally, AI can be used to provide real-time feedback and guidance to students as they work on geometry problems, helping them to improve their skills and knowledge. Overall, we will empirically research the use of AI within AR technology to enhance informal geometry instruction for students participating in after-school programs that are designed to be culturally relevant and experiential.

The overarching goal for this project is to bring AI-powered AR into education for advancing STEM learning. A major obstacle to improving student success and disposition in secondary STEM education is the abstract and decontextualized nature of math, which this project intends to address through innovative instruction within an AI/AR-powered learning environment that integrates embodied learning and immersive visualization. Hypothesized results include improvement to both cognitive and socio-emotional student outcomes, specifically: (1) increased participants' interest and engagement with mathematics especially geometry, and (2) increased participants' engagement and other positive dispositions toward STEM learning. The learning modules designed could significantly impact math outcomes for at-risk minority students, by leveraging a multi-tiered interdisciplinary approach that involves STEM educators and practitioners providing interactive educational experiences using AI, to improve students' spatial reasoning (e.g., geometrical reasoning & proportional reasoning), which has become a prerequisite for entry into many STEM fields, such as computer graphics, robotics, artificial intelligence (AI), automated visual analytics, and quantum mechanics. The stark difficulties many students face when learning transformations and spatial visualization are well documented, and therefore our main objective for this project is to build upon our teams prior NSF project in middle grade STEM education (Award #1342038) and a current research project (Award #2119549) investigating college students learning of spatial reasoning, by significantly expanding this line of research to systematically investigate the impact of AI-powered learning environments on informal after-school STEM education for high school students.

Although this project is not focused on formal educational systems or outcomes, it is nevertheless important for the project personnel to understand the academic context in which the project will occur, specifically: the Texas Essential Knowledge and Skills Standards (TEKS) and the Common Core State Standards (CCSS). In Texas, students also must pass the State of Texas Assessments of Academic Readiness (STAAR) exams. 10^{th} grade TEKS emphasize: (a) recognizing the foundations of geometric concepts, motions described by translations and rotations are foundational; (b) using different representations for geometric relationships while solving problems, such as motions are represented physically on a physical model airplane, visually on the virtual airplane as simple math in equations, and as advanced math in vectors and matrices; (c) using geometric representations to solve problems, such as the math of motion allows us to solve physical problems such as navigating; and (d) using the concept of congruence in figures, such as a translation or rotation of an object preserves the congruence of the shapes involved, whereas a dilation (which cannot be done physically) loses congruence but preserves similarity. The project will engage students to more deeply conceptualize these four domains of math knowledge and skills through a transdisciplinary instructional model.

Research Strategy and Data Significance

Overall, the use of AR/AI can be beneficial for students by creating lessons and activities tailored to their cultural interests, in ways that the mathematical concepts are relevant in their lived experiences. Additionally, AR technology can create interactive and immersive lessons allowing students to manipulate the geometric objects in a more engaging way. This project will identify which aspects of an AI-powered environment can help high school students with mathematical concepts necessary to learning spatial transformations and allied mathematical representations. The project will also provide the foundation for planned further research adding a language-processing component to an AI for high school students, which would be trained on a large dataset of common high school math topics and language used by students. To ensure rigorous evaluation of the project, the research team will anticipate confounding factors so as to minimize their effects, and two learning conditions (AI-powered and non-AI) will be employed and compared with the same essential visualization and functional manipulation, thus advancing instruction that applies across multiple STEM disciplines.

The project will create a multi-scale AI/AR-powered environment to integrate embodied learning and visualization into informal math learning. It will enable the interplay of physical systems (objects that one can grab and manipulate such as a LEGO or other model airplane) and virtual systems (a virtual image of the object which moves in synch with the physical object). Student participants will build the physical objects in after-school STEM makerspaces hosted by the El Paso Leadership Academy. This will enable spatial learning and tracking at multiple levels: object transformations, hand gestures, and body transformations, in relation to each other and to the built environment, visible on a computer using GeoGebra [6]-[8] or through AR glasses (e.g., HoloLens) visualizing, for example, a Building Information Model [8]. High school students need to primarily learn 2D geometry, but 3D geometry can be used as motivation and an eventual goal. Besides standard motions (translations and rotations), the virtual model can be used to study scaling (dilations), reflections and shears which are not possible with the physical model. For example, a 2D reflection can be implemented by lifting a triangle up out of the 2D plane into 3D space, flipping it over and putting it down again in the plane [9]. From an educational technology design and development perspective, the team's general theoretical context and learning sciences framework includes several key components, which have collectively demonstrated effectiveness during previous NSF funded projects. *Embodied cognition* is a primary component of this approach, and is based on the idea that human cognition is rooted in the perceptual and physical interactions of the body with the world [10]. *Cognitive neuroscience* research has identified neural models that support using an embodied approach in the teaching of abstract STEM concepts, specifically that abstract concepts are understood using processes of embodied representations in brain areas associated with the senses, through which those representations were acquired [11].

Conclusion

Research shows that embodied spatial learning helps students develop mental rotation [12]–[14] and spatial perspective-taking [15], and embodied interaction improves mathematical learning [16]-[18]. Overall, our project's participants will learn about the importance of geometric transformations and their mathematical representations in AI-powered AR. The research will innovate data collection methods for multimodal learning analytics to accurately understand students' learning progress with precise motion tracking of models, students, the STEM makerspaces, and other analytics to help identify behaviors that improve student learning. In order to achieve these outcomes, this proposal is an authentic partnership with the individuals and communities who experience inequities, specifically the leaders and communities that are part of the El Paso Leadership Academy school system, where this project will take place. This partnership is essential for ensuring that the project is grounded in the experiences, perspectives, and needs of those who are most affected by the intervention. By involving members of the El Paso Leadership Academy school system in the planning and implementation of the project, the proposal will be able to benefit from their expertise, insights, and connections within the local community. Furthermore, by involving those who are part of the informal school system, the proposal will also support the development of local community members, empowering them to take ownership of the project and drive positive change within their own communities.

Acknowledgements

This research is based upon work supported by the national Science Foundation under Grant No. Grant No. HRD-2119549. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the national Science Foundation.

References Cited

[1] L. C. Landivar. "Disparities in STEM employment by sex, race, and Hispanic origin." *Education Review*, vol. 29, no. 6, pp. 911-922, 2013.

[2] A. Bicer, R. M. Capraro, and M. M. Capraro. "Hispanic students' mathematics achievement in the context of their high school types as STEM and non-STEM schools." *Int. J. of Math. Ed. in Science and Tech.*, vol. 49, no. 5, pp. 705-720, 2018.

[3] J. Paschal and A. Taggart. "An examination of the role of first-year college-level mathematics in STEM field major persistence at a Hispanic-serving institution." *Journal of Hispanic Higher Education*, vol. 20, no. 3, pp. 297-312, 2021.

[4] M. F. Rogers-Chapman. "Accessing STEM-focused education." *Education and Urban Society*, vol. 46, no. 6, pp. 716-737, 2014.

[5] J. L. Petersen and J. S. Hyde. "Trajectories of self-perceived math ability, utility value and interest across middle school." *Ed. Psych.*, vol. 37, no. 4, pp. 438-456, 2017.

[6] D. L. and Z. Lavicza, "Dissecting a Cube as a Teaching Strategy for Enhancing Students' Spatial Reasoning," *Proceedings of Bridges 2019*, pp. 319–326,

[7] u/diegolieban, "GeoGebra and 3D printing: Mathematics as a creative practice," *GeoGebra*, Feb. 03, 2020. www.geogebra.org/m/pkfzccjw (accessed Jan. 16, 2021).

[8] Y. Gao, S. Liu, M. M. Atia, and A. Noureldin, "INS/GPS/LiDAR Integrated Navigation," *Sensors*, vol. 15, no. 9, Art. no. 9, Sep. 2015.

[9] Tomaschko, M., & Hohenwarter, M. (2019). Augmented reality in mathematics education. In *Augmented Reality in Educational Settings* (pp. 325-346). Brill.

[10] M. Wilson, "Embodied cognition," *Psychon. Bull. Rev.*, vol. 9, no. 4, pp. 625–636, 2002.

[11] J. C. Hayes and D. J. Kraemer, "Grounded understanding of abstract concepts: The case of STEM learning," *Cogn. Res. Princ. Implic.*, vol. 2, no. 1, pp. 1–15, 2017.

[12] S. Kaltner, B. E. Riecke, and P. Jansen, "Embodied mental rotation: a special link between egocentric transformation and the bodily self," *Front. Psychol.*, vol. 5, 2014.

[13] M.-A. Amorim, B. Isableu, and M. Jarraya, "Embodied spatial transformations: 'Body analogy' for the rotation," *J. Exp. Psychol. Gen.*, vol. 135, no. 3, pp. 327–347, 2006,

[14] D. Moreau, J. Clerc, A. Mansy-Dannay, and A. Guerrien, "Enhancing spatial ability through sport practice," *Journal of Individual Differences*, 2012.

[15] K. Kessler and L. A. Thomson, "The embodied nature of spatial perspective taking," *Cognition*, vol. 114, no. 1, pp. 72–88, 2010.

[16] S. J. Pape and M. A. Tchoshanov, "The role of representation(s) in developing mathematical understanding," *Theory into Practice*, vol. 40, no. 2, pp. 118–127, 2001.

[17] T. Ionescu and D. Vasc, "Embodied cognition: challenges for psychology and education," *Procedia-Social Behavioral Sciences*, vol. 128, pp. 275–280, 2014.

[18] Z. Shaghaghian, H. Burte, D. Song, and W. Yan. "Learning spatial transformations and their math representations through embodied learning in augmented reality," in *International Conference on Human-Computer Interaction*. Springer, pp. 112-128, 2022.