BOARD # 238: Exploring the impact of Knowledge Acquisition in a CAVE (Cave Automatic Virtual Environment) on engineering students computational thinking skill levels.

Dr. Opeyemi Peter Ojajuni, Southern University and A&M College

Opeyemi Peter Ojajuni is a Post doctoral - Research Manager at Southern University and A&M College in Baton Rouge. He obtained his PhD in Science and Mathematics Education from Southern University, as well as a Bachelor's degree in Computer Engineering from Covenant University in Nigeria and a Master's in Mobile and Satellite Communication from the University of Surrey in the UK. With over three years of experience, Opeyemi applies machine learning and data science to solve complex problems. His research leverages emerging technologies including virtual reality and AI to quantify and advance computational thinking skills acquisition and retention. He has published in peer-reviewed journals and presented at major conferences on using immersive simulations to boost student engagement and learning outcomes.

Yasser Ismail, Southern University and A&M College

Dr. Yasser Ismail is an Associate Professor in the Electrical Engineering Department at Southern University and A&M College (SU). Dr. Ismail has over twenty (20) years of professional experience in teaching and research. With a focus on Electronics and Electrical Communication, he holds a bachelor's and a master's degree from Mansoura University in Egypt. He also got a master's and a doctorate degree in Computer Engineering from the University of Louisiana at Lafayette. Dr. Ismail has a broad background in machine learning-based applications, hardware accelerators for machine learning, modeling and design techniques for reliable, low-power, and high-performance VLSI and FPGA systems, Cloud Computing, Cybersecurity, Internet of Video Things (IoVT), digital video processing algorithms/architectures levels, and wireless and digital communication systems. Dr. Ismail has served as an NSF panel reviewer from 2019 – present. He served as a PI and Co-PI of over twelve (17) funded grants from NSF, State, and international fund agencies. Dr. Ismail participated in organizing several STEM programs and activities for undergraduate and K-12 students at the College of Sciences and Engineering and high schools.

Fareed Dawan, Southern University and Agricultural & Mechanical College

Dr. Fareed Dawan received his Ph.D. in Mechanical Engineering from Louisiana State University (LSU) in 2014. In 2006, he earned his Masters of Engineering degree in Mechanical Engineering from Southern University (SUBR), and his Bachelors in Science degree in Electrical Engineering in 2002 from LSU. He is currently an Assistant Professor of Mechanical Engineering at SUBR where he teaches Freshman Engineering and Mechanical Engineering courses, namely Materials Science and Engineering, Statics and Dynamics, and Materials Characterization. Dr. Dawan's expertise is in micro and nanofabrication of materials and his research involves advanced manufacturing of multi-functional composites for application in energy, aerospace, and personal healthcare. Patent-pending proprietary technology derived from his research includes a nanotube enhanced 3D solar cell, and a 3D-printable carbonated polymer. He is currently the Director of the US Department of Energy-funded Energizing Minds through Advanced Clean Energy Education (EMACE) Inspires and Partnership programs and an Air Force Office of Scientific Research-funded project investigating rapid 3D antenna manufacturing. Additionally, he serves as a Co-PI on several grants including two multimillion-dollar NSF-funded projects. Within 5 years he has secured over $1.2 million in STEM grants. Prior to his professorship appointment, Dr. Dawan served as the Assistant Director of the NSF-funded NextGenC3 CREST Phase I project and further beyond this, he was a research associate in the Microfabrication Group at LSU's J. Bennett Johnston's Center for Advanced Microstructures and Devices (CAMD). There he served as a manager of a class 100 clean room facility and as a process engineer for standard photolithography processing and for high-aspect ratio microstructures technology (HARMST) using UV, X-ray, and e-beam lithography, and LIGA. Dr. Dawan, an Honored Listee in the 2023 Marquis Who's Who in America, has received several awards for his research, is published in leading journals, is a TEDx Speaker, and has presented his work nationally and internationally.

Dr. Albertha Hilton Lawson, Southern University and A&M College

Albertha H. Lawson currently serves as Professor and Interim Chair of the Graduate School at Southern University and A&M College (SU). Previously, she served as the Professor and Chair of the Science and Mathematics Education Doctoral (SMED) Program at the University. Dr. Lawson has over 30 years of professional experience at the Louisiana State University System, Louisiana Community and Technical College System, SU and Corporate America combined in the areas of actuarial science, higher education administration, teaching, institutional research, mathematical and statistical analysis. She has a Bachelor of Science in Mathematics from Johnson C. Smith University in Charlotte, North Carolina, Masters of Applied Statistics from the Ohio State University in Columbus, Ohio and a PhD in Education Administration and Research from the University of New Orleans in New Orleans, Louisiana.

brian Warren, Southern University and Agricultural & Mechanical College

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Abstract

Research in this study investigates the effectiveness of Virtual Reality (VR) interventions, specifically within Computer Automatic Virtual Environment (CAVE) systems, in enhancing Computational Thinking (CT) skills among engineering students at a Historically Black College and University (HBCU). Using a validated five-point Likert scale developed by Korkmaz et al. (2017) and adapted by Ojajuni et al. (2024) for immersive learning environments, the study assessed CT using 29 observed variables across five latent factors: Creative Thinking, Algorithmic Thinking, Cooperative Thinking, Critical Thinking, and Problem-Solving. The research employed a quasi-experimental design, comparing VR-based instruction with traditional teaching methods in the context of cybersecurity-additive manufacturing training. Results indicate positive trends in CT development, particularly in Algorithmic Thinking and Problem-Solving, with medium effect sizes suggesting practical benefits of the VR intervention. The results underscore the need for balanced instructional design to address all CT components and highlight the value of adaptive VR systems for personalizing learning experiences and fostering interactive, engaging educational environments. Funded by the National Science Foundation (NSF grant #1915520), this study aligns with NSF's goal of strengthening the nation's additive manufacturing engineering workforce. It provides valuable insights into the integration of VR in engineering education, emphasizing the importance of VR systems and balanced instructional design.

Background and Motivation

Recent technological advancements have made Virtual Reality (VR), particularly Computer Automatic Virtual Environment (CAVE) systems, increasingly accessible and effective as educational tools, offering transformative potential for traditional teaching methods [1], [2], [3], [4]. These immersive systems address key challenges in engineering education, such as experiential learning and spatial understanding of complex concepts. Integrating VR with Computational Thinking (CT) frameworks represents a pivotal advancement, with CT being a problem-solving approach that formulates problems for computational solutions. Building on foundational research by Papert (1980) [5] and Wing (2006) [6], recent studies underscore CT's critical role in enhancing cognitive capabilities and preparing future engineers [7].

Korkmaz et al. (2017) [8] developed a validated and reliable five-point Likert scale with 29 observed variables to assess CT across five latent factors: Creative Thinking, Algorithmic Thinking, Critical Thinking, Problem-Solving, and Cooperative Thinking. The scale's validity was confirmed through exploratory and confirmatory factor analyses, alongside item distinctiveness and consistency evaluations. This tool provides a robust framework for measuring CT skills and contributes significantly to the literature by addressing the need to evaluate individuals' CT levels in the digital age. O. P. Ojajuni et al. (2024) [9] modified the CT scale, originally developed by Korkmaz et al. (2017) [8] to suit underrepresented engineering students in CAVE systems.

Analysis of pre- and post-surveys revealed a strong correlation between VR and the development of CT skills, supported by factor analysis that refined the CT scale for use in immersive learning environments at HBCUs. Semi-structured interviews further uncovered key correlations and emerging themes linking VR to CT, while also highlighting engineering students' enthusiasm for VR, its scalability, and its potential to enhance learning experiences. Despite these promising findings, a significant gap remains in fully understanding VR's effectiveness as a tool for fostering CT skill development in engineering education.

This project now, in its fourth year, examined the effectiveness of VR intervention in enhancing CT skills among engineering students. Motivated by the need to expand on NSF-funded research, the project focused on the impact of VR in enhancing CT skill levels in the context of cybersecurity-additive manufacturing training, aligning with the NSF Improving Undergraduate Science, Technology, Engineering and Mathematics (STEM) Education Program's goal of strengthening the nation's additive manufacturing engineering workforce. The primary objective was to evaluate changes in engineering students' CT skills before and after the VR intervention using the CT scale developed by Korkmaz et al. (2017) [8] and adapted by Ojajuni et al. (2024) [9]. The study compared CT skill development between students participating in the VR intervention and those who did not), while assessing the overall effectiveness of VR as an educational tool through pre- and post-test survey analysis.

Methodology

This study employed a quasi-experimental design to evaluate the impact of a VR-based intervention on students' CT skills. A pre-test/post-test approach was used, with control and experimental groups to assess changes in CT skills over time. The quasi-experimental design allowed for meaningful comparisons while addressing practical constraints, such as the inability to randomly assign participants. The inclusion of a control group ensured that the effects of the VR intervention could be isolated from external factors, providing a rigorous framework for evaluating its efficacy.

Participants were drawn from a freshman engineering class at a HBCU, with a total sample of 37 students divided into a control group (17 students) and an experimental group (20 students). The participants, primarily underrepresented minorities in engineering, were selected for their enrollment in an introductory engineering course, ensuring a comparable baseline of foundational knowledge. The control group received traditional classroom instruction, while the experimental group engaged in immersive VR-based modules delivered in a CAVE, enabling a direct comparison of traditional and VR-enhanced learning methods.

The control group followed conventional teaching methods, including lectures and textbook-based exercises, focusing on theoretical understanding. In contrast, the experimental group participated in VR-based learning activities within the CAVE, emphasizing visualization, design, and prototyping in engineering education. Students explored immersive VR environments, interacted with three dimensional (3D) models, and collaborated in small groups to refine designs using joystick controllers. The intervention extended to hands-on activities in a 3D printing lab, culminating in reflective essays and portfolio presentations. This multi-phase, student-centered approach integrated immersive learning, collaboration, and practical application to enhance CT skills.

The study used the CT Scale, a validated tool developed by Korkmaz et al. (2017) [8] and adapted by Ojajuni et al. (2024) [9] for underrepresented engineering populations. This five-point Likert scale evaluates five core CT dimensions: Creative Thinking, Algorithmic Thinking, Cooperative Thinking, Critical Thinking, and Problem-Solving. Pre- and post-tests measured CT skills before and after the intervention, with all assessments conducted under controlled conditions to ensure accuracy and reliability. Statistical analyses included paired t-tests for within-group comparisons, independent t-tests for between-group comparisons, and the Mann-Whitney U test for non-parametric data. Effect sizes were calculated using Cohen's d to quantify the magnitude of observed differences, ensuring a comprehensive evaluation of the VR intervention's impact on CT skills. Ethical guidelines, including informed consent and institutional review board approval, were strictly followed throughout the study.

Results

Descriptive statistics revealed differences in CT skills between the control and experimental groups across pre-test and post-test scores. The experimental group demonstrated improvements in Creative Thinking (mean = 4.21) and Problem-Solving (mean = 3.01), while the control group showed minimal changes or declines across most CT factors. Variability was generally low, with the experimental group exhibiting more pronounced positive changes in Algorithmic Thinking and Problem-Solving. A Shapiro-Wilk test identified mixed normality across factors, with 55% adhering to normality. Non-normal distributions informed the use of non-parametric tests, such as the Mann-Whitney U test, to ensure accurate statistical analysis.

Baseline comparisons using independent samples t-tests and Mann-Whitney U tests revealed no statistically significant differences between control and experimental groups across all five CT factors. Creative Thinking, Algorithmic Thinking, Cooperative Thinking, Critical Thinking, and Problem-Solving were well-matched at baseline, confirming that pre-existing disparities did not influence the post-test results. Although Critical Thinking showed the largest variation, the differences were still non-significant ($p = 0.092$), providing a reliable starting point for evaluating the intervention's impact.

Within-group comparisons of pre-test and post-test scores indicated minimal changes for the control group, with no statistically significant differences across all factors. In contrast, the experimental group showed notable improvements, particularly in Algorithmic Thinking and Problem-Solving, though these changes were not statistically significant. Between-group comparisons revealed larger positive changes in the experimental group for most CT factors, with Algorithmic Thinking showing the strongest improvement (mean difference = 0.584). However, none of the observed differences were statistically significant, likely due to the small sample size.

Effect size analysis highlighted practical impacts of the VR intervention, with Algorithmic Thinking (Cohen's $d = 0.538$) and Problem-Solving (Cohen's $d = 0.557$) showing medium positive effects. Creative Thinking and Cooperative Thinking demonstrated small positive effects, while Critical Thinking exhibited a negligible negative effect. An anomalously large effect size for Problem-Solving in the control group ($r = 13.097$) suggests a possible calculation error, warranting further investigation. While the null hypothesis could not be rejected, the effect size analysis underscores the potential benefits of VR interventions, particularly in enhancing Algorithmic Thinking and Problem-Solving. Future research with larger samples and refined methodologies is needed to confirm these trends and address inconsistencies.

Discussion, Implication, Recommendation and Future Direction

The findings underscore significant implications for educational practices and curriculum development. The VR intervention demonstrated positive effects on Algorithmic Thinking and Problem Solving, highlighting VR environments as effective tools for teaching structured problem-solving in STEM education. Improvements in Cooperative Thinking further suggest VR's potential for fostering meaningful peer collaboration through group-based activities. However, the varied impacts across CT components indicate a need for balanced instructional design that addresses all aspects of CT.

Curriculum strategies should prioritize VR-based modules in areas with the strongest benefits, such as algorithmic thinking and problem-solving, while integrating targeted activities to strengthen critical thinking, which showed minimal improvement. Recommendations include incorporating guided reflection activities and analytical challenges to support critical thinking within VR environments, maintaining small group sizes to optimize collaboration and resource access, and continuing pre- and post-CAVE activities to link virtual and physical learning. Diverse assessment methods, including rubrics for critical thinking and longitudinal measures, are essential for evaluating and tracking the comprehensive impact of VR-based interventions over time.

This study's limitations include a small sample size, a short intervention duration, and potential measurement issues, such as an unusually large effect size for Problem-Solving in the control group, which may have impacted the ability to detect significant differences. Future research should address these limitations by employing larger samples, longer interventions, and more robust research design. Additionally, exploring VR features that enhance algorithmic thinking and problem-solving, integrating adaptive and Artificial Intelligence driven-VR systems for personalized learning could further improve educational outcomes. Developing advanced assessment tools to capture real-time student performance within VR environments is also critical for refining the effectiveness of these interventions.

Conclusion

The results showed positive trends, particularly in Algorithmic Thinking and Problem-Solving, demonstrating VR's potential to complement traditional learning. Despite limitations like a small sample size and short intervention duration, the study highlights the feasibility and promise of VR in enhancing CT skills. This study contributes to the growing field of educational technology and CT by providing empirical evidence of VR's impact on algorithmic thinking and problem-solving skills. It demonstrates the feasibility of integrating comprehensive VR-based modules into engineering education, emphasizing practical considerations for pre- and post-intervention activities. The findings highlight the need for balanced instructional design to address all CT components, including areas where VR interventions were less effective. Additionally, the study offers valuable insights into the unique challenges and opportunities of implementing VR in HBCU settings, enriching discussions on technological innovation in diverse educational contexts. These findings lay a foundation for advancing immersive learning in engineering education and preparing students for evolving technological demands.

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