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Board 296: Immersive Engineering Learning and Workforce Development: Pushing the Boundaries of Knowledge Acquisition in a CAVE

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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.

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Immersive Engineering Learning and Workforce Development: Pushing the Boundaries of Knowledge Acquisition in a CAVE

Abstract: This study provides insight into the use of virtual reality (VR) to enhance engineering curriculums and develop engineering students' computational thinking (CT) levels at Historically Black College and Universities (HBCUs). The sample population for this research includes students enrolled in a first-year engineering course at an HBCU. To support the students' education in cybersecurity-additive manufacturing, virtual reality was used to simulate classroom teaching and assignments. Participants in this study were first taught using the traditional method that allowed them passive viewing of images and videos of objects and spaces. The participants were later taught the same lessons in a Computer Automated Virtual Environment (CAVE) where they could further explore the images and space, they were taught in the traditional class setting. Within the immersive virtual environment, students were observed as they virtually manipulated objects and learned in the CAVE.

Both quantitative and qualitative methods were utilized in this study. Factor Analysis (FA) was used to assess the validity of using CT scales in an HBCU environment, and to help investigate the impact of immersive technology on participants CT skill levels. The results of the FA aligned with previous research findings and provided the research team with a more refined set of CT scales for use in an HBCU environment. Semi-structured student interviews were used to gain insight into students' perceptions and attitudes toward the incorporation of VR into an engineering curriculum, and to further explore the relationship between VR fidelity and scalability of a model that could be used across engineering curriculums. The results of the interviews provided an additional significant degree of validation that the CT scales are suitable to assess engineering students CT skill levels at HBCUs, and that immersive technology such as the CAVE could improve engineering students' ability to train and compete. Furthermore, students exhibited excitement and an eagerness to do more in the CAVE environment.

Keywords: Immersive technology, Engineering education, Virtual Reality, Computer Automated Virtual Environment (CAVE), HBCUs, workforce development

Introduction

In response to the rapid evolution of technology, engineers must swiftly adapt to emerging technologies and methodologies. Computational thinking (CT) has emerged as a crucial problem-solving methodology, offering a structured and analytical approach applicable across various professions. CT is essential for thriving in a technology-driven environment. CT skills foster collaboration, provide adaptability, and instill a mindset crucial for continuous learning in the dynamic field of engineering [1], [2], [3].

To address the limitations of traditional engineering education, immersive virtual environments, exemplified by the Computer Automated Virtual Environment (CAVE), present a groundbreaking platform for enhancing CT skills. The CAVE, employing stereoscopic displays and motion-tracking technology, offers a full-body immersive virtual reality experience, facilitating collaborative problem-solving without the drawbacks associated with conventional virtual reality headsets. However, despite the potential benefits, research on the specific application of CAVE technology to foster computational thinking abilities within engineering curricula, especially in Historically Black Colleges or Universities (HBCUs), remains limited.

This paper explores the integration of CAVE technology into engineering education at an HBCU, addressing the research gap surrounding CAVE utilization for enhancing CT skills. The CAVE's potential to bridge educational shortcomings, particularly in spatial understanding and problem-solving, is examined. Employing a quantitative approach, the study explores the relationship between underlying factors and observed variables within a CT scale survey administered to students exposed to the CAVE. Moreover, a qualitative methodology was employed to investigate students' perceptions and attitudes regarding the integration of CAVE technology. This involved a deep exploration of students' viewpoints, attitudes, and perceptions towards CAVE technology as a platform for enhancing CT skills.

The study aims to offer insights into the potential benefits of integrating CAVE technology in an engineering educational setting for the development of CT skills. The investigations contribute to a deeper understanding of the interplay between the development of CT skills, and students' experiences with the CAVE technology, particularly within the distinctive context of HBCU engineering programs. The study is structured around two guiding research questions that form the framework for the extensive investigation undertaken.

1. Does Korkmaz et al.’s (2017) [4] CT scale effectively measure the underlying construct of CT in HBCU engineering students?
2. To what extent do HBCU engineering students believe that the integration of the CAVE into the curriculum enhances their CT skills relevant to engineering?

The paper is organized as follows: In Section 2, the problem statement is presented. Section 3 offers a background on immersive technology and CT in engineering education. The research design and methodology used in the study are outlined in Section 4. Section 5 is dedicated to discussing the findings of the research, followed by Section 6, which delves into the implications of the results. Finally, Section 7 concludes the paper by summarizing key points and drawing conclusions based on the study's findings.

Problem statement

The World Economic Forum anticipates that over 1 billion individuals will need reskilling by 2030 to meet the demands of an evolving technology-enabled economy. As a response, ongoing research endeavors are focused on enhancing engineering curricula and integrating emerging technology to improve computational thinking skills. The Science and Engineering (S&E) sectors in the United States are pivotal for national security and economic growth, relying heavily on a skilled technical workforce. Despite a significant increase in degrees awarded in S&E fields over the past decade, there remains a disparity in degree attainment for underrepresented groups such as African Americans, Hispanics, American Indians, and Alaskan Natives. This underscores the necessity for targeted efforts to prepare these communities for the expanding S&E labor market. Challenges persist in STEM education, including outdated curriculum, a shortage of qualified STEM teachers, and limited diversity and inclusion, posing potential barriers to the nation's competitiveness in the rapidly evolving global economy [5], [6], [7].

Background

Computational Thinking in Engineering Education

Computational Thinking (CT) has become integral to modern engineering education, evolving from its origins in computer science to shape the skill set crucial for addressing contemporary engineering challenges [8]. CT comprises a collection of thinking and problem-solving skills that find their roots in computer science [9], [10]. A systematic literature review conducted by Kalelioğlu et al. (2016) highlights key descriptors for CT, emphasizing elements such as abstraction, decomposition, problem-solving, and algorithmic thinking [11]. In the realm of engineering, CT plays a pivotal role in dissecting complex problems into manageable smaller parts, requiring engineers to design algorithms and processes for efficient problem-solving.

The ability to formulate clear and logical algorithms is crucial, demanding proficiency in computer programming languages commonly used in engineering, such as Python, Java, MATLAB, or others relevant to the discipline. Additionally, CT serves as a foundational skill for data analysis and modeling across various engineering disciplines. Its widespread adoption in STEM education institutions, as evidenced by the incorporation of Next Generation Science Standards (NGSS), reflects a positive trajectory in developing CT abilities and meeting the demands for skilled technical workers [12].

The implementation of CT in engineering education necessitates a shift towards student-centered learning strategies to mirror the complexities of real-world problem-solving. This transition involves active learning, project-based learning, problem-based learning, and immersive experiences in coding, computational modeling, simulations, and robotics [8], [13]. These diverse strategies empower students to visualize, analyze, and establish meaningful connections, fostering the skills and mindset essential for effective navigation of the intricate challenges within the field of modern engineering. Assessment of CT skills in engineering education involves a comprehensive examination of problem-solving abilities, algorithmic thinking proficiency, critical thinking, collaboration and communication, and creativity as seen in Figure 1. Utilizing various assessment methods, such as the CT scale developed by Korkmaz et al.'s (2017) [4], ensures a thorough understanding of students' CT skill development.

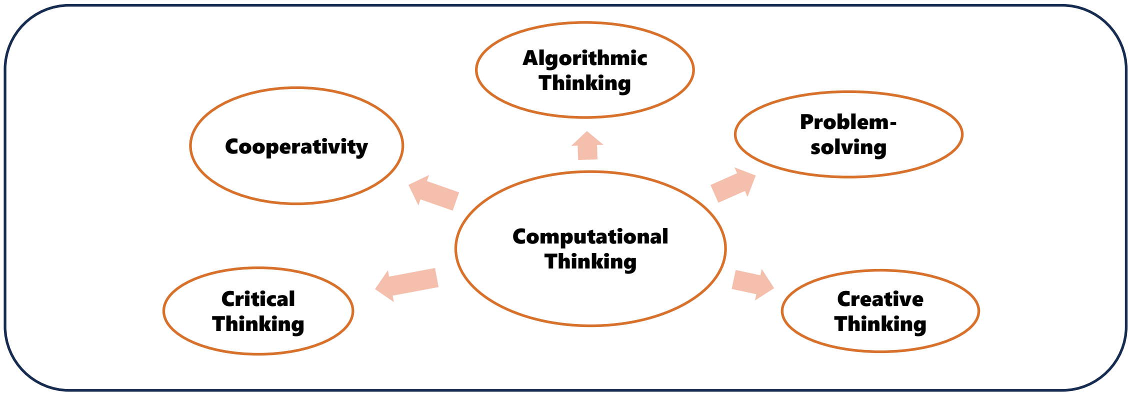

Figure 1. Factors of Computational Thinking Scale by Korkmaz et al.'s (2017) [4].

Creativity: The ability to think innovatively and generate original ideas within the VR environment. In engineering, creativity involves the application of imaginative solutions, design thinking, and the exploration of novel approaches to problem-solving [4].
Algorithmic Thinking: The ability to conceptualize, design, and implement algorithms or step-by-step procedures. It entails a systematic approach to problem-solving, often involving computational logic and structured methodologies [4].
Critical Thinking: The skill to objectively evaluate and analyze information, scenarios, or problems. Critical thinking in engineering involves assessing the reliability of data, identifying patterns, and making informed decisions [4].
Cooperativity: The ability to work effectively with others. This encompasses communicating ideas, sharing information, and collaborating on tasks, fostering a sense of teamwork and collective problem-solving [4].
Problem-Solving*:* The capacity to analyze and resolve complex issues or challenges. This involves the application of knowledge, logical reasoning, and adaptability to devise effective solutions [4].

Immersive Engineering

Engineers often deal with optimizing systems and processes to enhance efficiency and performance. CT aids in analyzing and improving these processes through the application of algorithmic and systematic approaches. As emerging technologies like immersive technology, artificial intelligence, machine learning, and the Internet of Things become integral to engineering, immersive engineering provides a solid foundation for understanding and leveraging these technologies in enhancing computational thinking.

Immersive technology, encompassing virtual reality (VR), augmented reality (AR), and mixed reality (MR), is transforming engineering by creating digitally immersive experiences that bridge the gap between the physical and virtual environment. Recent studies have explored design elements and instructional approaches for effective integration of immersive technology in engineering education. Learning theories, particularly the cognitive theory of multimedia learning and experiential learning grounded in cognitivism and constructivism, provide conceptual frameworks to understand knowledge creation and transfer in immersive-based engineering education [14], [15], [16], [17].

VR technologies, such as the CAVE and Head-Mounted Display (HMD) devices like Oculus Quest®, Apple Vision Pro®, and HTC Vive®, offer unique interactive and immersive experiences in engineering education. Visualization, immersion, and interactivity are the cornerstones of VR, allowing users to observe, immerse themselves fully, and manipulate the virtual environment [18].

Computer Automated Virtual Environment (CAVE) in Engineering Education and Workforce Development.

The Computer Automated Virtual Environment (CAVE), developed in 1992, is a room-sized, fully immersive VR experience distinguished by its stereoscopic displays, computer graphics, and motion tracking technology as seen in Figure 2 . This innovative technology utilizes projectors or LED panels to illuminate virtual images within the CAVE, providing users with an immersive platform for analysis, collaboration, exploration, and decision-making [19].

Figure 2. Computer Automated Virtual Environment (CAVE).

The CAVE offers a revolutionary approach to learning by rendering abstract engineering concepts such as algorithms, data structures, system modeling, signal processing, thermodynamics, optimization, and simulations into immersive 3D environments [20], [21], [22], [23], [24]. Through interactive visualizations, students actively engage with and manipulate these concepts in real-time, creating a dynamic and captivating educational and training experience. Moreover, this capability is crucial in the context of prototyping, where learners can simulate scenarios, such as building robots in virtual factories or optimizing traffic flows in simulated cities. The practical, gamified experiences not only enhance CT, but also serve as powerful motivators for learners, helping them develop problem-solving skills that are essential for engineering careers [25], [26].

The comparison between a CAVE and HMDs is summarized in Table 1. CAVEs provide a more immersive and spatial experience, enabling users to walk and interact naturally within the virtual environment, making them advantageous for collaborative learning and group projects. In contrast, HMDs, although immersive, may have limitations in physical movement and may require networked solutions for collaboration. While HMDs are generally more cost-effective and portable, suitable for individual use and smaller classrooms, CAVEs involve a higher cost but offer a unique, room-sized experience. HMDs are versatile for various applications, including individual learning experiences and virtual field trips, whereas CAVEs are deemed ideal for larger-scale collaborative projects, design reviews, and simulations that benefit from a room-sized environment.

Feature	**HMD**	**CAVE**
Form	Individual Wearable	Room-Sized Environment
Interaction	Personal Interaction, Handheld Controllers	Spatial Interaction, Physical Movement
Mobility	Portable	Stationary
Cost	Varied Costs, Flexible Pricing	Higher Initial Investment, Specialized Setup
Collaboration	Individual or networked	Shared Environment, Multiple Users Simultaneously
User Experience	Immersive, Individualized	Immersive, Spatial, Natural Interaction
Application	Various, Individual Learning, Projects	Collaborative Learning, Group Projects, Simulations
Advantages	Portability, Varied Cost Options	Spatial Interaction, Room-Sized Experience
Challenges	Limited Spatial Interaction, Networked Collaboration for Group Activities may be needed	Higher Initial Investment, Fixed Location

Table 1. CAVE and HMD comparison.

For instance, Halabi (2020), used a problem-based learning approach to incorporate the CAVE environment into teaching 3D prototyping to improve communication and problem-solving skills and ultimately enhance the learning process. Study participants used CAVE to visualize and collaborate on prototypes. Based on the study findings, CAVE environments enhanced higher-order cognitive skills by allowing students to collaborate in a team and with experts outside the classroom [27]. In another example Iowa State University developed a VR software application by utilizing G-code files from a CAD software to simulate the AM process in a CAVE environment. The VR module aimed to help students become familiar with AM procedures and gain hand-on practical experience when students visualize and interact with 3D printer components in immersive VR environment [28].

CAVE's potential in engineering education, bolstered by AI tools, is set to expand. As accessibility increases, CAVE-based learning could revolutionize the field. Yet, there's a gap in understanding its impact at HBCUs, especially in enhancing computational thinking (CT) skills. This study aimed to fill this void by examining how CAVE tech could boost CT skills in HBCU engineering programs. The findings promise insights for curriculum design and teaching methods, crucial for fostering a diverse cohort of tech professionals ready for today's challenges.

Methodology

Research Design

The research employed both quantitative and qualitative methodologies to address distinct research questions. The quantitative aspect focused on investigating the relationship between underlying factors and observed variables in the CT scale survey, utilizing a survey design influenced by Korkmaz et al.'s (2017) prior study [4]. Factor analysis provided a robust framework for construct validation and reliability assessment, offering a comprehensive examination of CT skills within the specific educational setting of engineering students.

In response to research question 2, the qualitative aspect utilized a cohort observational study to delve into participants' perceptions, attitudes, and behaviors regarding the integration of immersive technology in the educational curriculum, specifically for developing CT skills. The qualitative study involved non-participant direct classroom observations and focus group interviews, offering a comprehensive understanding of class dynamics, student engagement, and behavior during exposure to the CAVE.

The research design, as outlined in

Table *2*, involved distinct analyses for quantitative and qualitative data. Quantitative data underwent statistical analysis, while qualitative data were systematically coded and organized into thematic categories. Following the separate analyses, we utilized data triangulation approach to identify points of convergence between quantitative and qualitative results, while also pinpointing any instances of divergence or contradictions. This side-by-side comparison significantly enriched our comprehension of the research topic.

Research Design	**Quantitative**	**Qualitative**
Research Method	Survey	Cohort observational study
Participants	301 participants from an HBCU	44 students enrolled in first year engineering class in an HBCU
Sampling	Purposeful Sampling (based on enrollment in a freshman engineering class)	
Data Collection	Survey (CT scale)	Non-participant direct classroom Observations and Focus-group interviews
Data analysis	Factor analysis, Reliability Test	Thematic coding

Table 2. Research Design and Methodology Summary.

Participant and Research Setting

A purposeful sampling method was used to select participants from a Freshmen Engineering class at an HBCU. The purpose of this sampling approach was to identify participants who would be most likely to understand the central theme of the research. The quantitative aspect included *N* = 301 engineering students, while a cohort observational study involved *N* = 44 first-year engineering students. The combination of both designs ensured a comprehensive exploration of the research topic, capturing diverse perspectives and insights.

Computer Automated Virtual Environment (CAVE) Setting

The Freshmen Engineering class focused on deepening students' grasp of engineering concepts, including visualization, design, and additive manufacturing (AM) cybersecurity. Through a student-centered approach, the class utilized immersive learning via the CAVE spaces. Students engaged with pre-recorded videos before entering the CAVE environment, where the instructor emphasized safety guidelines. Within the CAVE, students explored 3D VR models, working in groups to foster collaboration and innovation. They used joystick controllers to interact with the models, enhancing spatial reasoning. Additionally, they had access to the institution's 3D printing lab. Post-CAVE, students completed reflective essays, presentations, or portfolios, ensuring comprehensive assessment of their learning. The overview of cave setting is illustrated in **Error! Reference source not found.**.

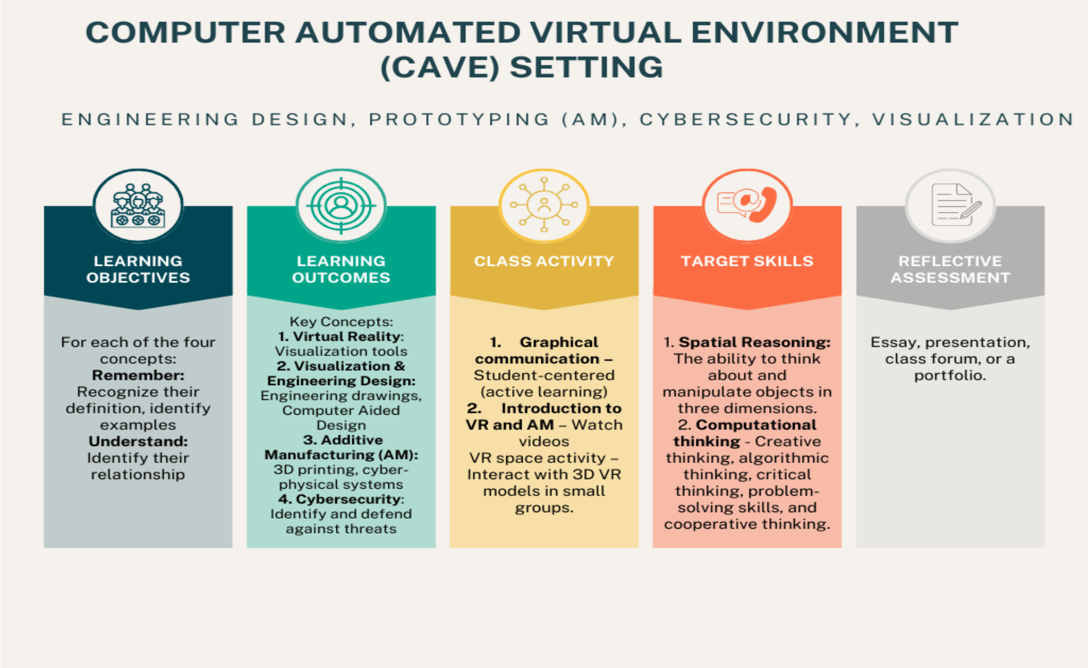

Figure 3. The CAVE learning setting.

Data Collection

After obtaining approval from the institutional review board (IRB), ethical protocols were followed, securing written consent from each participant through their endorsement of an informed consent form. By implementing this process, participants were able to make informed decisions about their participation, emphasizing their right to withdraw at any time. CT scales were then administered to students prior to exposure to the CAVE at the beginning of the semester. Following the CAVE exposure, focus group interviews and non-participant direct classroom observation provided valuable information regarding participants' behaviors, interactions, and engagement with the CAVE. Participants were administered the CT scale once again at the end of the semester so that a longitudinal assessment could be made of the impact of immersive technology on their CT skills.

The research utilized the CT Scales, which is a well-established measurement tool introduced by Korkmaz et al.'s (2017) and published in the journal Computers in Human Behavior [4]. Comprising a five-point Likert scale, Table 4 shows the 29 observed variables grouped into five latent.

1.	Creativity
CR1	I like the people who are sure of most of their decisions
CR2	I like the people who are realistic and neutral
CR3	I believe that I can solve most of the problems I face if I have sufficient amount of time and if I show effort
CR4	I have a belief that I can solve the problems possible to occur when I encounter with a new situation
CR5	I trust I can apply the plan while making it to solve a problem of mine
CR6	Dreaming causes my most important project to come to light
CR7	I trust my intuitions and feelings of "trueness" and "wrongness" when I approach the solution of a problem
CR8	When I encounter with a problem, I stop before proceeding to another subject and think over that problem
2.	Algorithmic Thinking
AT9	I can immediately establish the equity that will give the solution of a problem
AT10	I think that I have a special interest in the mathematical processes
AT11	I think that I learn better the instructions made with the help of mathematical symbols and concepts
AT12	I believe that I can easily catch the relation between the figures
AT13	I can mathematically express the solution ways of the problems I face in the daily life
AT14	I can digitize a mathematical problem expressed verbally
3.	Cooperativity
CO15	I like experiencing cooperative learning together with my group friends
CO16	In the cooperative learning, I think that I attain/will attain more successful results because I am working in a group
CO17	I like solving problems related to group project together with my friends in cooperative learning
CO18	More ideas occur in cooperative learning
4.	Critical Thinking
CRT19	I am good at preparing regular plans regarding the solution of the complex problems
CRT20	It is fun to try to solve the complex problems
CRT21	I am willing to learn challenging things
CRT22	I am proud of being able to think with a great precision
CRT23	I make use of a systematic method while comparing the options at my hand and while reaching a decision
5.	Problem Solving
PS24	I have problems in the demonstration of the solution of a problem in my mind
PS25	I have problems in the issue of where and how I should use the variables such as X and Y in the solution of a problem
PS26	I cannot apply the solution the ways I plan respectively and gradually
PS27	I cannot produce so many options while thinking of the possible solution ways regarding a problem
PS28	I cannot develop my own ideas in the environment of cooperative learning
PS29	It tires me to try to learn something together with my group friends in cooperative learning

Table 3. Observed variables in the computational thinking scale by Korkmaz et al.'s (2017) [4].

The qualitative data were gathered through non-participant direct classroom observations and focus-group interviews. The observations played a crucial role in providing valuable insights into participants' behaviors, interactions, and engagement with the CAVE. The researcher adopted a non-participant approach during these observations, diligently recording comprehensive field notes that covered various aspects, including the classroom setting, participant engagement, attitudes, and behaviors. To supplement the qualitative data, five focus group interviews were conducted, each structured to include 5-17 participants.

Observation sessions spanned three distinct cohorts from the fall of 2022 to the spring of 2023. Cohort 1 participated in a single focus group session, involving 17 participants. In contrast, Cohort 2 engaged in multiple focus group sessions, including Focus Group 2 with 8 participants, Focus Group 3 with 7 participants, and Focus Group 4 with 5 participants. Finally, Cohort 3 took part in a single focus group session, consisting of 7 participants. Each observation, following a designated protocol, lasted approximately 60 minutes. These focus-group interviews occurred immediately after participants' exposure to the CAVE, offering a collective platform for participants to discuss their attitudes, perceptions, and experiences within the CAVE.

During these focus-group interviews, participants were presented with structured questions to elicit their viewpoints and experiences regarding their encounters with the immersive learning environment. Each focus group interview session spanned approximately fifteen minutes, contingent upon the depth of responses provided by the participants. These interviews were recorded using an iPhone and transcribed for in-depth examination to facilitate subsequent analysis.

Data Analysis

Data collected from non-participant direct classroom observations, focus-group interviews, and CT scale surveys were analyzed to address the research questions. The study formulated a null hypothesis positing no relationship between the 29 observed variables and the five underlying factor constructs of the CT scale, which represent various facets of computational thinking. The alternative hypothesis proposed a relationship between the observed variables and the underlying factor constructs. The quantitative data analysis procedure is summarized in Figure 4Figure *4*.

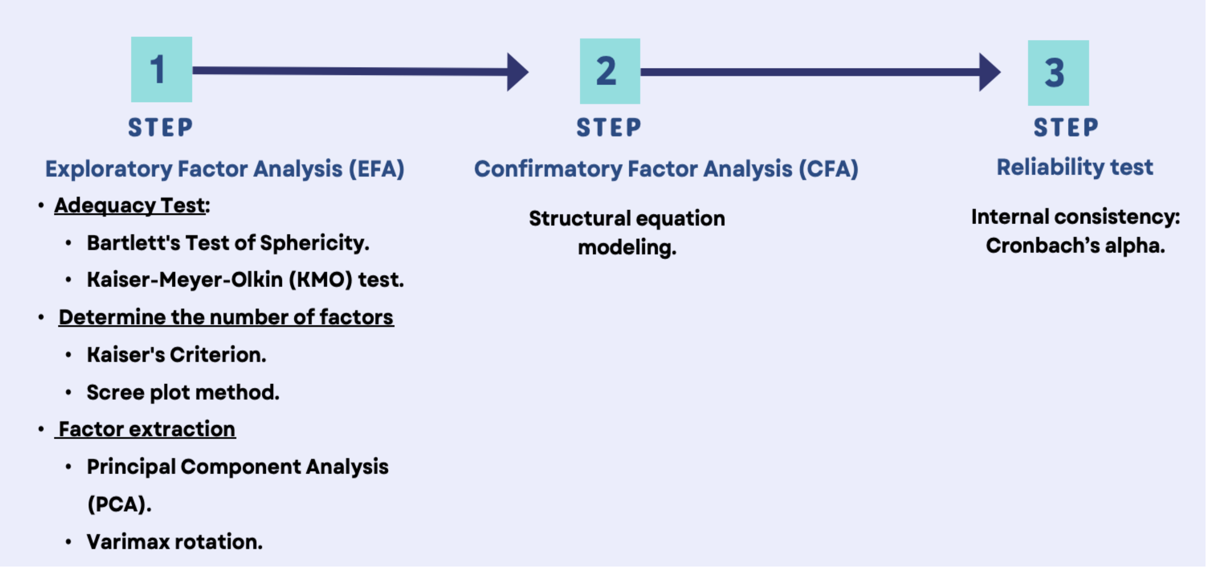

Figure 4. Quantitative data analysis procedure.

Factor Analysis, a statistical technique prevalent in the social sciences and psychology, was employed to identify latent factors explaining patterns of correlations in observed variables. The primary goal of factor analysis is to reduce the dimensionality of data by identifying latent factors capturing shared variance among observed variables. Factors represents characteristics or behaviors that are challenging to measure directly, such as skills and intelligence. This method includes both exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) to identify and verify the structure of underlying unobserved variables [29], [30].

In this study, EFA facilitated the identification of hidden patterns and structures within the data, elucidating relationships between various factors and observed variables. The study employed several steps and tests in the EFA process, including the Adequacy Test (Bartlett's Test of Sphericity, Kaiser-Meyer-Olkin (KMO) test), determining the number of factors (Kaiser's Criterion, Scree plot method), and factor extraction using Principal Component Analysis (PCA) with Varimax rotation.

Confirmatory Factor Analysis (CFA) was employed in this study to validate the relationship between factors and observed variables. The aim was to determine the extent to which each observed variable measured its corresponding factor, testing the hypothesis of no relationship between observed variables and the underlying factor constructs. The structural equation model in CFA visually represented the theoretical model, aiding in model evaluation. Reliability assessment was conducted through Cronbach's alpha. This crucial step established the reliability of the CT scale by gauging their internal consistency. Higher Cronbach's alpha values, often exceeding the 0.7 threshold, indicated robust internal consistency. This study utilized software packages such as SPSS® (Statistical Package for the Social Sciences, Python®, and R for data analysis.

This study utilized thematic coding analysis, following Braun and Clarke's (2006) [31] approach, for qualitative data interpretation from sources such as interview transcripts and survey responses. Thematic analysis, known for its adaptability, revealed valuable insights into participants' perspectives, opinions, experiences, and values [31]. The data analysis procedure, illustrated in Figure 5, involved identifying recurring common themes using MAXQDA software, allowing for the organization of interview transcripts into overarching themes.

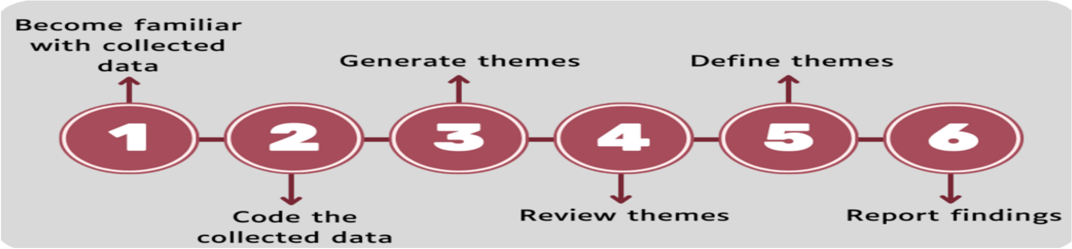

Figure 5. Flowchart of data analysis.

Findings

The quantitative research study, marked by meticulous sampling, comprehensive adequacy assessment, and strategic application of factor analysis methodologies, rejected the null hypothesis. This signifies a relationship between the 29 observed variables and the five underlying factor constructs within the CT scale. Participants' confidence in the efficacy of immersive technology for hands-on, practical learning implies its potential to bridge the gap between theoretical knowledge and practical application, enhancing students' preparedness for real-world challenges in STEM fields. The technology's ability to simulate real-world scenarios provides valuable experiential learning opportunities, deepening students' understanding of engineering concepts and fostering CT skills. The summary of the research findings is presented in Table 4.

Research Question	Data collection	Data analysis	Findings
Does Korkmaz et al.'s (2017) CT scale effectively measure the underlying construct of CT in HBCU engineering students?	Survey – CT scale	Factor analysis and reliability test.	• Reject the null hypothesis. • CT scale is a valid and reliable scale.
To what extent do HBCU engineering students believe that the integration of the CAVE into the curriculum enhances their CT skills relevant to engineering?	• Non-participant direct classroom observation. • Focus-group interview.	Thematic coding	• High level of engagement • Motivation and interest. • Improve learning experience. • Enhance spatial reasoning. • Valuable tool in developing CT skills. • Health and sensitivity concerns.

Table 4. Summary of the research findings.

This aligns with industry demands, suggesting that graduates with immersive technology-enhanced CT skills are better positioned to meet industry expectations and excel in STEM-related careers. Additionally, students' recognition of immersive technology as an efficient and cost-effective tool underscores its potential to reduce the need for resource-intensive activities, such as field trips, leading to cost savings for educational institutions without compromising educational quality. Valid reservations expressed by students regarding issues like control sensitivity dizziness and eye strain underscore the importance of selecting and developing solutions that minimize these discomforts.

The study, responding to research question 1 through factor analysis, utilized a sample of $N = 301$ engineering students from an HBCU enrolled in the Freshmen Engineering class. In the first survey administration, responses were collected from $n = 207$ participants, whereas the second administration yielded responses from $n = 97$ participants. The robust response from participants, with 87% freshmen in the initial administration and 79% in the second, ensured a diverse representation. The meticulous assessment of the dataset's factorability using Bartlett's test and the Kaiser-Meyer-Olkin (KMO) test yielded statistically significant results. Bartlett's Test, with a p-value of $p < 0.0001$, and a KMO value of 0.909 categorized as "excellent," confirmed the dataset's suitability for factor analysis, setting the stage for meaningful exploration.

Proceeding to the Exploratory Factor Analysis (EFA), the study aimed to unveil the inherent factor structure within the CT scale using Principal Component Analysis (PCA). The pivotal steps of determining the number of factors through eigenvalues and extracting these factors based on their loadings were employed. The Kaiser criterion and the Scree Plot, both leveraging eigenvalues, informed the identification of five factors to retain. The Scree Plot, with its "elbow" point indicating the optimal number of factors, played a crucial role as shown in Figure *6*. This outcome sets the foundation for subsequent analysis concentrating on these five factors, unraveling the latent variables governing the structural dynamics of the dataset.

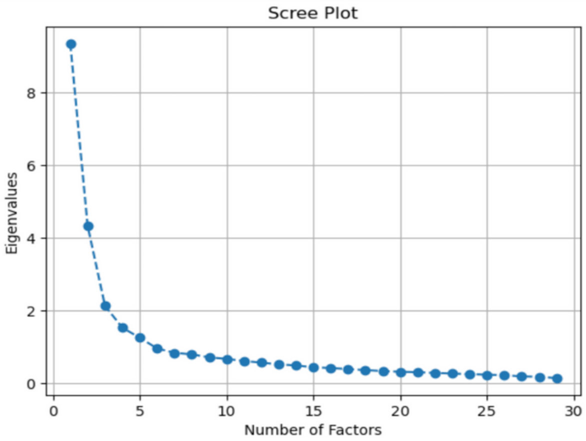

Figure 6. Scree Plot to determine number of factors.

The study initially identified five factors through EFA and subsequently employed PCA and varimax rotation to extract them, enhancing the clarity and interpretability of the factor structure. This meticulous process effectively revealed latent factors that comprehensively accounted for the observed variance, offering profound insights into the underlying CT skills among students. These EFA findings formed the basis for the CFA structural model, designed to validate and confirm relationships between the latent factors and observed variables. Rigorous evaluation using various fit indices, such as the Chi-Square (χ^2) value, Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), Standardized Root Mean Square Residual (SRMR), and Root Mean Square Error of Approximation (RMSEA), collectively indicated an acceptable fit for the model as seen in

Table 5. This validation underscored that the factors derived from the data were well-supported and aligned with the proposed theoretical framework.

The CT scale reliability was further affirmed using Cronbach's alpha, resulting in a high coefficient of 0.913, surpassing the widely accepted threshold of 0.7. This robust internal consistency indicated that the variables within each factor consistently captured the intended latent trait or concept, reinforcing the credibility of the factors and emphasizing their utility in subsequent analyses and interpretations.

Model fit					
Test for Exact Fit		***Chi-Square (χ^2)***	***df***	***p***	
		1072	367	<.001	
Fit Measures					
				RMSEA 90% CI	
CFI	**TLI**	**SRMR**	**RMSEA**	**Lower**	**Upper**
0.861	0.846	0.0730	0.0799	0.0744	0.0855

Table 5. Confirmatory Factor Analysis (CFA) model fit.

Despite the theoretical expectations, the quantitative results unveiled that not all observed variables exhibited strong factor loadings on a latent factor, deviating from the anticipated outcomes aligned with Korkmaz's study as seen in Table 6. This deviation emphasizes the importance of considering the distinct sample population and the unique research setting, demonstrating the nuanced nature of computational thinking skills among the surveyed engineering students.

Factors	**Korkmaz et al.'s (2017) [4] study finding**	**Study Findings**
Creativity (CR):	CR1, CR2, CR3, CR4, CR5, CR6, CR7, CR8	CR3, CR4, CR5, CR6, AT9
Algorithmic Thinking (AT):	AT9, AT10, AT11, AT12, AT13, AT14	AT10, AT11, AT12, AT13, AT14, CRT19, CRT20, CRT23
Cooperativity (CO)	CO15, CO16, CO17, CO18	CO15, CO16, CO17, CO18
Critical Thinking (CRT)	CRT19, CRT20, CRT21, CRT22, CRT23	CR1, CR2, CR7, CR8, CRT21, CRT22
Problem Solving (PS)	PS24, PS25, PS26, PS27, PS28, PS29	PS24, PS25, PS26, PS27, PS28, PS29

Table 6. Comparison between study findings and Korkmaz et al.'s (2017) [4] study finding.

The observation findings reveal a high level of student engagement during the CAVE sessions, marked by active participation, collaboration, and immersion in the virtual environment. Students demonstrated enthusiasm through their interactions, creating a positive and conducive learning atmosphere. Their motivation and keen interest in tackling challenging engineering concepts within the CAVE setting were evident, fostering a dynamic learning environment. Positive body language cues, such as asking questions, contributing creative ideas, and collaborating, were consistently observed across all sessions, indicating sustained engagement and a prolonged attention span.

In the thematic coding analysis process, codes were assigned to units extracted from interviews based on their relevance to the research questions. These codes encompassed various aspects of how students perceive immersive technology as a tool for developing CT, covering elements like realism, immersion, critical thinking, creativity, problem-solving, cooperativity, visualization, cost-efficiency, active learning, sensitivity, dizziness, and eye strain. The clarity of these identified codes facilitated the researcher in recognizing and capturing specific data segments related to each code. Distinct patterns of meaning within the coded units were then identified, leading to the creation of overarching themes. These themes, namely spatial reasoning, CT, fostering the learning experience, and concerns, are presented in Table 7, capturing the essential patterns and insights derived from the interview data analysis.

Theme	**Code**	**Excerpt**
Computational Thinking	Creativity, Critical Thinking, Problem-solving, cooperativity	*"The stuffs that we do in class like AutoCAD and stuff like that, we were able to like put it into like real life basically."* *"I would say I am a hands-on learner. So, for me to learn, I need to see things and actually do it myself. So, I feel like if I learn how to, you know, put something together in virtual reality I can do it in real life."*
Spatial Reasoning	Realism, Immersive, And Visualization	*"So far, it's different... it's like more realistic and it feels more real... Its real-life stuff."*

		"It can give us perspective on what we need to do to improve what we are working on."
Foster Learning	cost-efficiency, active learning,	*"I mean it help in putting on real life situation without actually spending more. That's how it will help because you can learn, You can make mistakes without messing anything up or, you know, damaging anything that costs a lot of money. You can make those mistakes early, so when you finally do get into the field its going to be perfect."*
Concerns	Control sensitivity, Dizziness, eye strain	*"The only thing is probably a big strain on the eyes so after a while for me I took it off a couple of time because I was like getting a little headache."* *"I was the one with I guess the master headset and perspective. I controlled what everyone else was looking at the way I was looking at it. The only thing I wish was better is the sensitivity because if I go left it will go an inch left instead of the whole 90 degrees."*

Table 7. Summary of Thematic Coding Result.

The study highlights immersive technology's crucial role in developing problem-solving, algorithmic thinking, creativity, cooperativity, and critical thinking skills among HBCU engineering students, particularly within the computational thinking theme. The CAVE, as a safe and practical learning environment, facilitates hands-on experiences that align with students' preferences, promoting interactive learning and experimentation. Regarding spatial reasoning, immersive technology, exemplified by the CAVE, creates realistic scenarios, enhancing understanding through 3D visualization and intuitive interaction. However, concerns such as user comfort and technology refinement need addressing for optimal learning experiences.

Both quantitative and qualitative data emphasize immersive technology's positive impact on computational thinking skills, but nuanced differences exist. While qualitative data address concerns like dizziness and control precision, these are not explicitly reflected in quantitative findings, suggesting the need for comprehensive consideration of immersive technology's drawbacks.

Discussion and Implications

The study findings underscore the importance of integrating immersive technology into HBCUs' engineering education to enhance Computational Thinking (CT) skills, bridging the workforce skills gap in technology-driven industries. While immersive technology positively impacts CT skills, user experience and ongoing technology development must be carefully considered. Identifying specific CT dimensions influenced by immersive technology provides valuable guidance for STEM curriculum development. By targeting problem-solving, algorithmic thinking, creativity, cooperativity, and critical thinking, educators can enhance STEM programs. In addressing the potential challenges and limitations associated with integrating immersive technology into engineering education at Historically Black Colleges and Universities (HBCUs), several key points deserve attention:

Access Barriers: Ensuring equitable access to immersive technology for all students, regardless of their socioeconomic background, poses a significant challenge. Financial constraints at HBCUs may impede investment in costly VR/AR equipment and software licenses. Moreover, students from underprivileged communities may lack access to high-speed internet or compatible devices necessary for engaging with virtual environments. Overcoming these barriers necessitates strategic collaboration with industry partners, government agencies, and philanthropic organizations to secure funding and resources.

Technological Dependencies: Immersive technology heavily relies on hardware and software infrastructure, which are susceptible to technical issues, compatibility concerns, and rapid obsolescence. HBCUs must consider the long-term sustainability of their immersive technology initiatives, encompassing ongoing maintenance costs, software updates, and hardware upgrades. Dependence on external vendors or technology providers poses risks, including service disruptions and vendor lock-in. Developing contingency plans and alternative strategies is essential to mitigate these technological dependencies and ensure uninterrupted educational content delivery.

Pedagogical Integration: Integrating immersive technology into existing STEM curriculum mandates meticulous planning and faculty training. Many educators may lack proficiency in utilizing VR/AR tools for instructional purposes, leading to implementation hurdles and resistance to change. Investing in faculty development programs, workshops, and resources is critical to supporting instructors in crafting immersive learning experiences aligned with learning objectives and cultivating critical thinking skills. Furthermore, fostering faculty collaboration and embracing interdisciplinary approaches can enhance immersive technology integration across various disciplines within the engineering curriculum.

Inclusive Design: While immersive technology holds promise for creating captivating and interactive learning environments, it is imperative to ensure inclusivity and accessibility for students with diverse backgrounds, abilities, and learning styles. Design considerations such as user interface accessibility, multilingual support, and representation of diverse perspectives can enhance the inclusivity of virtual experiences. Prioritizing inclusive design principles and engaging students in the co-design process are essential steps in addressing potential biases and cultural sensitivities.

By acknowledging and tackling these challenges and limitations, HBCUs can formulate more resilient strategies for integrating immersive technology into engineering education, fostering equity, accessibility, and innovation in STEM learning environments. Establishing comprehensive health and safety protocols and fostering collaboration with technology developers are vital measures for creating a safe and inclusive learning environment. Future research endeavors should explore the causal relationship between virtual reality (VR) environments and CT development through experimental quantitative methodologies.

Conclusion

The transformative impact of immersive technology in engineering education is underscored by its ability to bridge geographical gaps, providing a collaborative platform for engineers and students alike. This not only accelerates the learning process but also contributes to a more holistic and dynamic approach to engineering education. The immersive and interactive nature of virtual environments not only optimizes design cycles but also ensures that decision-making within virtual scenarios becomes a practical and trainable skill. The evolving landscape of engineering education positions immersive technology as key contributors to fostering innovation, problem-solving, and overall competence among students and professionals in the field.

The findings of this research hold multifaceted implications that extend beyond the immediate context. They present valuable opportunities for enriching the learning experience and refining curriculum design, fostering a more inclusive environment within STEM disciplines. By recognizing and addressing the unique challenges and strengths of students at (HBCUs, educators can create inclusive learning environments where all students have the chance to excel in technology-related fields. The thematic analysis revealed students' recognition of immersive technology's potential to enhance CT skills. Students perceived immersive technology as a platform that allows them to gain practical experience, make mistakes, and learn from them in a safe virtual environment. These perceptions highlight the transformative role of immersive technology in bridging the gap between theoretical knowledge and practical application, ultimately preparing students for success in STEM fields.

The significance of this research lies in its capacity to inform targeted initiatives for educational institutions, policymakers, and industry stakeholders. By showcasing the effectiveness of immersive technology in fostering CT skills and creating inclusive learning environments, the study provides actionable insights to empower a new generation of diverse and highly skilled STEM professionals. The study's broader implications for STEM education emphasize that the integration of immersive technology can serve as a catalyst for inclusion and developing CT skills within the field, thereby contributing to the development of a skilled and diverse technical workforce.

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