A FRAMEWORK OF IMMERSIVE VIRTUAL REALITY GAME BASED LEARNING TO FOSTER COMPUTATIONAL THINKING SKILLS

SUKIRMAN

UNIVERSITI PENDIDIKAN SULTAN IDRIS

2025

A FRAMEWORK OF IMMERSIVE VIRTUAL REALITY GAME BASED LEARNING TO FOSTER COMPUTATIONAL THINKING SKILLS

SUKIRMAN

THESIS PRESENTED TO QUALIFY FOR DOCTOR OF PHILSOPHY

FACULTY OF COMPUTING AND META-TECHNOLOGY
UNIVERSITI PENDIDIKAN SULTAN IDRIS

2025

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ACKNOWLEDGEMENTS

First and foremost, I would like to express my sincere gratitude to my supervisor, Dr. Laili Farhana binti Md Ibharim, for her continuous support, guidance, and invaluable advice throughout the research and writing of this thesis. Her guidance and encouragement have been instrumental in completing this work. I would also like to extend my heartfelt thanks to my co-supervisor, Prof. Madya Dr. Che Soh bin Said, and my external co-supervisor Prof. Dr. Budi Murtiyasa M.Kom, for their insightful comments, constructive criticism, and dedicated time to review my work. I am grateful to Universiti Pendidikan Sultan Idris (UPSI) for providing the necessary resources and facilities to conduct my research. I am also grateful for the financial support from Universitas Muhammadiyah Surakarta (UMS), which made this research possible. I am deeply indebted to my colleagues and fellow researchers at Informatics Engineering Education, Faculty of Teacher Training and Education UMS, for their collaboration, technical assistance, and stimulating discussions that enriched my research. I would like to acknowledge the contributions of my study's participants, whose cooperation and input were vital to this research. I want to give special thanks to my family, my wife and son, my parents, and my siblings, for their unwavering support, patience, and love throughout my academic journey. Their belief in me kept me motivated even during the toughest times. Lastly, I am grateful to my friends and colleagues, for their constant encouragement and moral support and for always being there when I needed them. Thank you all for being a part of this journey.

ABSTRACT

Digital games and virtual reality (VR) technologies are promising interactive learning tools for fostering computational thinking (CT) skills. However, robust and systematic frameworks for designing and implementing game-based learning experiences within VR environments are lacking, particularly for the development of CT skills. The research objectives are to: 1) develop an immersive virtual reality game-based learning (IVR GBL) framework to foster CT skills, 2) integrate the framework into a VR game, and 3) validate its usability and effectiveness in the context of the CT skills development. The framework was applied in the development of a VR game entitled "*CT Saber*", designed to facilitate CT learning. The study employed a Design and development research (DDR) methodology, encompassing systematic literature analysis, expert reviews, and a quasi-experimental design. Nine experts in educational technology (digital games and VR) and CT validated the framework. The study involved 107 undergraduate students in a Computer Science Education program, representing a population of approximately 300 students in a higher learning institution in Indonesia. The usability testing using the USE questionnaire involved 36 participants, while 71 participated in the quasi-experimental design (treatment = 37; control = 34). Analytical methods included non-parametric statistical testing (*Wilcoxon signed-rank*) to examine effectiveness, and PLS-SEM to assess the relationships between VR game features (*interactivity, playability, presence, immersion, enjoyment*) and CT skills (*decomposition, pattern recognition, abstraction, algorithm design*). Findings revealed a high usability score (74.25 out of 100) and a statistically significant improvement in CT skills following the intervention ($Z = -4.496$, $p < 0.05$). Through PLS-SEM analysis, *enjoyment* was identified as a significant mediator in developing CT skills, particularly *decomposition, pattern recognition*, and *algorithm design*. These findings support the theoretical validity and practical effectiveness of the IVR GBL framework and offer empirical design guidelines in advancing the CT skills development through immersive VR learning environments.

KERANGKA PEMBELAJARAN BERASASKAN PERMAINAN REALITI MAYA IMERSIF UNTUK MEMUPUK KEMAHIRAN PEMIKIRAN KOMPUTASIONAL

ABSTRAK

Permainan digital dan teknologi realiti maya (VR) merupakan alat pembelajaran interaktif yang berpotensi memupuk kemahiran pemikiran komputasional (CT). Walau bagaimanapun, masih kurang kerangka yang mantap dan sistematik untuk mereka bentuk serta melaksanakan pengalaman pembelajaran berasaskan permainan dalam persekitaran VR, khususnya bagi pembangunan kemahiran CT. Objektif kajian ini adalah: 1) membangunkan kerangka pembelajaran berasaskan permainan realiti maya imersif (IVR GBL) bagi memupuk kemahiran CT, 2) menyepadukan kerangka tersebut ke dalam permainan VR, dan 3) menilai kebolehgunaan dan keberkesanannya dalam konteks pembangunan kemahiran CT. Kerangka kerja ini diaplikasikan dalam pembangunan permainan VR bertajuk "*CT Saber*", direka khas untuk menyokong pembelajaran CT dalam persekitaran maya imersif. Kajian ini menggunakan pendekatan reka bentuk dan pembangunan penyelidikan (DDR) yang merangkumi kaedah analisis literatur sistematik, tinjauan pakar, dan reka bentuk kuasi-eksperimen. Kerangka kerja telah disahkan oleh sembilan orang pakar dalam bidang teknologi pendidikan (permainan digital dan VR) dan CT. Penyelidikan melibatkan seramai 107 orang pelajar dalam program Pendidikan Sains Komputer daripada populasi sekitar 300 pelajar di sebuah institusi pengajian tinggi di Indonesia. Seramai 36 pelajar terlibat dalam ujian kebolehgunaan menggunakan soal selidik *USE*, manakala 71 pelajar terlibat dalam kajian kuasi-eksperimen (rawatan = 37; kawalan = 34). Kaedah analisis merangkumi ujian statistik non-parametrik (*Wilcoxon signed-rank*) bagi menilai keberkesanan, serta analisis PLS-SEM untuk menguji hubungan antara ciri permainan VR (*interactivity, playability, presence, immersion, enjoyment*) dengan pembangunan kemahiran CT (*decomposition, pattern recognition, abstraction, algorithm design*). Dapatan kajian menunjukkan skor kebolehgunaan yang tinggi (74.25 daripada 100) dan peningkatan signifikan dalam kemahiran CT ($Z = -4.496, p < 0.05$). Analisis PLS-SEM turut menunjukkan bahawa *enjoyment* memainkan peranan sebagai perantara yang signifikan dalam mempengaruhi pembangunan kemahiran CT, terutamanya *decomposition*, *pattern recognition*, dan *algorithm design*. Dapatan kajian ini menyokong kesahan teori dan keberkesanan praktikal kerangka IVR GBL serta menyediakan panduan reka bentuk empirikal dalam membangunkan kemahiran CT melalui persekitaran pembelajaran VR imersif.

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LIST OF ABBREVIATIONS

ADDIE	Analysis, Design, Development, and Implementation
ANOVA	Analysis of Variance
AR	Augmented Reality
AVE	Average Variance Extracted
BBC	British Broadcasting Corporation
CA	Cronbach's Alpha
CR	Composite Reliability
CS	Computer Science
CSTA	Computer Science Teachers Association
CT	Computational Thinking
DBL	Designed-Based Learning
DBR	Design-Based Research
DDR	Design and Development Research
ERIC	Education Resources Information Center
EVE	Educational Virtual Environment
GBL	Game-Based Learning
GIVRLE	Game-Based Immersive Virtual Reality Learning Environment
HCI	Human-Computer Interaction
HMD	Head-Mounted Display
ICT	Information Communication Technology

IDE	Integrated Development Environment
ISTE	International Society for Technology in Education
IVE	Immersive Virtual Environment
IVLE	Immersive Virtual Learning Environment
IVR	Immersive Virtual Reality
IVR GBL	Immersive Virtual Reality Game-Based Learning
LCD	Liquid Crystal Display
LMS	Learning Management System
MAE	Mean Absolute Error
MUVE	Multiuser Virtual Environment
OS	Operating System
PBL	Problem-based Learning
PjBL	Project-Based Learning
PLS	Partial Least Square
PLS-SEM	Partial Least Square Structural Equation Modeling
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RAM	Random Access Memory
RMSE	Root Mean Square Error
SDK	Software Development Kit
SEM	Structural Equation Modeling
SLR	Systematic Literature Review
SPSS	Statistical Program for Social Science
SUS	System Usability Scale
UI	User Interface

USA	United States of America
USE	Usefulness, Satisfaction, and Ease of use
UX	User Experience
VIF	Variance Inflation Factor
VLE	Virtual Learning Environment
VR	Virtual Reality
VRGACT	Virtual Reality Game Application for CT
VRLE	Virtual Reality Learning Environment

APPENDIX LIST

CHAPTER 1

INTRODUCTION

1.1 Introduction

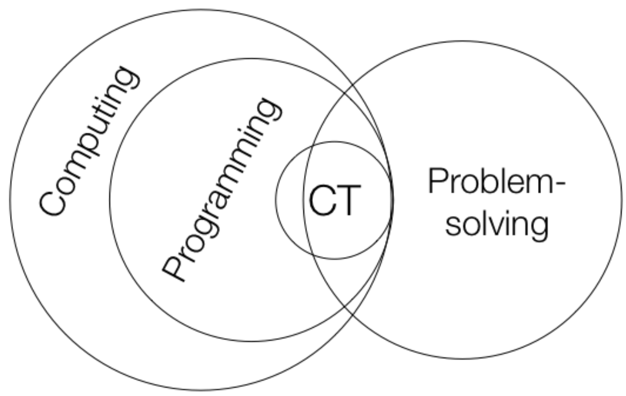
Digital technology has become a fundamental component of our daily lives, serving as a critical tool for executing various essential activities. This pervasive integration of technology is largely driven by the innovation and development efforts of software engineers and other professionals who possess advanced programming skills. A pivotal skill that underpins these programming capabilities is Computational Thinking (CT), which is increasingly recognized as an essential competency for students in the digital age. Scholars have emphasized the importance of CT in educational curricula, arguing that it equips students with the creative thinking abilities required by programmers to effectively handle errors and challenging situations (Jou et al., 2023; Nouri et al., 2020; Zhang & Nouri, 2019). Moreover, CT extends beyond mere programming; it encompasses a set of sophisticated problem-solving strategies that are applicable across a broad range of fields, from digital humanities to computational finance and economics (Hooshyar et al., 2021). By fostering these skills, CT helps students develop the ability to approach and solve complex problems in a systematic and logical manner, making it an indispensable part of modern education.

CT is described as a set of thought processes inspired by Computer Science (CS) to formulate problems and their solutions in a form that information processing agents can effectively execute (Wing, 2006). Through interacting with the agents (e.g., robotics, electronic toys, artifacts in the programming environment like *Scratch*, *Blockly*, or related), students may consider steps and use technical skills to manipulate the machine (agents) to resolve problems. CT allows pupils to cultivate and enhance their innovative thinking and problem-solving skills in dealing with complex problems (Cheng et al., 2023). Therefore, Wing (2006) argued that CT is a fundamental skill that should be learned by everyone like reading, writing, and arithmetic, not only for CS learners. Because CT is not merely about CS, but it is a combination of thinking skills that are crucial for handling complex problems like theoretical (mathematical) thinking, engineering thinking, and scientific thinking (Chou, 2019). Students who learn CT may benefit from the principles, concepts, and approaches commonly applied to computer science.

In the realm of CS itself like computing, programming, coding, and problem-solving, CT is considered as the fundamental core connected to the matters, as illustrated in Figure 1.1 (Zhang & Nouri, 2019). Computing is a big concept that covers programming and CT, while problem solving is slice of them that can be found in various areas. Programming and coding are often interchangeable in the colloquial use although in fact, both of them are different. Coding is pointed as the writing of computer programming code, while programming is more than just write a code. It is because programming involves complex tasks of understanding a problem, designing, coding, and maintenance, so that coding is considered to be a subtask of programming. However, some people more interested using the term of "*coding*" than programming since it contains a hint of secret code and achievement in cracking the code. In the programming and problem-solving scopes, CT takes a role as the approach in handling a problem by breaking it down algorithmically into simple enough steps that would be easily understood. Hence, CT may support programming abilities, computing, and problem solving skills (Fronza et al., 2019).

Figure 1.1

CT position amongst prevalent topics



CT and programming can mutually support the development of each other (Tikva & Tambouris, 2021). Learn how to coding could help students to develop their CT skills (Zhang et al., 2023), while learning CT can support programming abilities (Lee et al., 2023). However, programming is not the only way for learning CT. Many tools or strategies can be employed for learning CT, for example by playing video game

(W. Zhao & Shute, 2019), learning how to develop a game or software application (Stamatios, 2022), using a controllable robot (Angeli & Valanides, 2019), and employing mathematics activities (Soboleva et al., 2021). Even, learning CT can be conducted without information and communication technologies or often called as unplugged (Fanchamps et al., 2023). Besides, many pedagogy approaches can be utilized to teach CT, such as problem-based learning, project-based learning, inquiry learning, discussion, design-based learning, peer-tutoring, and game-based learning (Alajlan et al., 2023).

Game-based learning (GBL) is one of the strategies that many researchers employ to learn CT. GBL refers to a strategy of utilizing games in the educational process to enhance learning activities, engaging and motivating students to actively process educational content and foster developmental processes (Trajkovik et al., 2018). GBL allows students to continue learning by interacting with a game and actively thinking while playing without being aware of it, which can improve learning motivation, engagement, and problem-solving skills (Hwang et al., 2014). One reason is that GBL includes challenges that can sustain students' motivation, concentration, and engagement over time in the learning process, impacting the classroom atmosphere (Wang & Tahir, 2020). Hence, it is understandable that GBL is adopted as a strategy to aid students in learning various subjects. Moreover, Noroozi et al., (2020) argue that GBL environments are supposed to help users acquire 21st-century skills such as problem-solving, decision-making, critical thinking, analytical skills, and argumentation. Additionally, recent research indicates that GBL is not only effective in enhancing specific skills but also in fostering collaborative skills, which are essential in today's workplace (Azhar et al., 2022).

The games used in the GBL approach can be implemented on various platforms and environments, including computer desktops, web browsers, mobile applications, augmented reality (AR), and virtual reality (VR). An innovative setting that may significantly enhance a student's learning experience in a virtual environment is VR technology (Radianti et al., 2020). According to Educause Horizon's report, VR is one of the emerging technologies and practices believed to have a significant impact on the future of postsecondary teaching and learning (M. Brown et al., 2020). Rogers (2019) also stated that VR is an important learning aid for the digital age, allowing users to retain more information and better apply what they have learned (Krokos et al., 2019). One reason for this is that VR technologies can generate, visualize, and simulate a virtual environment with 3D objects or artefacts, creating a high degree of immersion, so users perceive that they are actually "*there*" (Radianti et al., 2020). This subjective experience of being in one place instead of physically situated in another is referred to as "*presence*". Additionally, VR supports interactivity, enabling users to modify the environment in real time. Many advantages can be obtained by users or learners who use VR head-mounted displays (HMD), such as acquiring better cognitive, affective, and psychomotor skills, being more engaged, and spending more time on learning tasks (Jensen & Konradsen, 2018). Hence, utilizing VR technologies can be beneficial in fostering CT skills through GBL environment settings.

GBL in a VR environment offers several unique benefits and advantages. Firstly, the immersive nature of VR creates an engaging and interactive learning experience that can significantly enhance motivation and interest in the subject matter. Studies have shown that immersion in a VR environment leads to higher retention rates and a deeper understanding of complex concepts (Parong & Mayer, 2018a).

Furthermore, the interactive elements of GBL in VR settings allow for immediate feedback and adaptation, which can cater to individual learning paces and styles, making the learning process more personalized and effective (Merchant et al., 2014). Additionally, VR environments can simulate real-world scenarios and experiments that might be too dangerous, expensive, or impractical to perform in a traditional classroom setting. This capability allows students to explore and learn from realistic simulations, fostering critical thinking and problem-solving skills (Makransky & Petersen, 2019). The multisensory experiences provided by VR can also enhance memory and recall by engaging multiple senses simultaneously, thus reinforcing learning through visual, auditory, and kinesthetic inputs (Asad et al., 2021).

Moreover, VR-based GBL leverages the integration of game elements and VR features to create an immersive and interactive learning environment. Game elements, such as playability and interactivity, combined with VR features like presence and immersion, contribute to an enjoyable learning experience. This sense of enjoyment is essential for maintaining learners' motivation and focus during problem-solving activities (Johnson-Glenberg, 2018). The synergy between these components provides learners with the opportunity to develop CT skills, such as decomposition, pattern recognition, abstraction, and algorithm design, through hands-on and immersive experiences. In conclusion, integrating VR technologies with GBL offers substantial educational benefits by utilizing the strengths of enjoyment-driven experiences to enhance skill development and learning outcomes. These advantages underscore the transformative potential of VR in modern education, particularly in fostering critical skills for the digital age.

This chapter presents an introduction to the research including background, problem statement, objectives, research questions, hypothesis, conceptual framework, the scope of the study, and operational definitions. The chapter describes the general overview how important of the research to be conducted and why the strategy is selected to answer the research questions. This is essential since it can aid in mapping the recent issues and problems so that it will be easier to formulate the problems and find out the solutions.

1.2 Research Background

According to the International Society for Technology in Education (ISTE), an organization in teaching technology in the classroom, Computational Thinker is one of the standards that should be empowered by students of digital age learners (ISTE, 2019). Wing (2006) argued that CT is not only for computer science students, but it is a fundamental skill that should be understood by everyone like reading, writing, and arithmetic. Wing emphasized that CT involves solving problems in a way that can be operationalized with computers, rather than thinking like a computer. Previously Papert (1980) proposed a concept similar to CT skills, namely procedural thinking, which should be instilled in children's minds. He believed that programming and thinking skills are related and facilitate procedural thinking across multiple disciplines.

Wing (2006) defined that CT involves "*solving problems, designing systems, and understanding human behavior, by drawing the concepts fundamental to computer science*" (p.33). This definition was later refined to "*thought processes involved in* *formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent*" (Cuny et al., 2010). Generally, CT can be simplified into four major facets: decomposition, pattern recognition, abstraction, and algorithm design (Cachero et al., 2020). The decomposition refers to breaking down problems, data, or processes into smaller and manageable parts. The pattern recognition is observing patterns, trends, and data regularity, and then the abstraction means identifying general principles that result in these patterns. Meanwhile, the algorithm design means developing the step-by-step instructions for solving this and similar problems. CT offers a way of solving problems that focus on conceptualization and thought processes rather than syntactically (W. Zhao & Shute, 2019). Applying CT to high-level skills such as problem-solving, creativity, and critical thinking will improve the capacity for innovation (Kukul & Karataş, 2019).

Educational systems in many countries are beginning to recognize the importance of CT, integrating CT or subjects related to programming and computer science into compulsory education or just an additional. The name used is various due to the term of CT have not well-established, such as "*digital competence*" in Sweden, "*computing*" in England, or "*computer science*" in the USA (Heintz et al., 2016). Portugal made a policy that computer science and programming are compulsory for all pupils in primary and secondary schools since 2017 (João et al., 2019). Indonesia ministry of education and culture (Kemdikbud) has issued a regulation to apply computer science in middle school with the name of "*Informatika*" with the core is CT (Kemdikbud, 2019). It means that the CT has internationally acknowledged and must be adopted to prepare a better generation. Because the facts showed that this 21st

century society is massively computerized and a country with better computer science has a more advanced level.

Methods for teaching CT can be conducted through several approaches, including visual block programming, tangible programming, and games. Visual block programming tools, such as *App Inventor, Alice, Construct 2, Kodu, Blockly*, and the most popular one, *Scratch*, have shown significant potential in teaching CT concepts effectively (Zhang & Nouri, 2019). These tools utilize a drag-and-drop interface that allows learners to create programs by assembling blocks that represent different programming constructs, making the learning process more intuitive and less intimidating for beginners (Rose et al., 2017). Tangible programming, on the other hand, involves physical objects or manipulatives to represent programming concepts, providing a hands-on learning experience that can be particularly beneficial for young learners (Wang et al., 2011). This approach helps students to understand abstract computational concepts through concrete, physical interactions.

Games have emerged as a powerful medium for teaching CT because they engage students in problem-solving and logical thinking interactively and enjoyably (Lee et al., 2014). Educational games designed for CT instruction often incorporate puzzles and challenges that require players to apply computational principles to progress, thereby reinforcing their learning through practice and repetition. Additionally, playing digital games has been identified as another promising approach to fostering CT skills (Zhao & Shute, 2019). These games can have cognitive and attitudinal impacts that support the development of CT skills. When combined with collaborative GBL, the CT learning process is further enhanced, as students can interact with game artefacts, actively think while playing, and receive immediate feedback on their actions (Turchi et al., 2019). This immediate feedback allows users to explore and learn from the challenges provided, encouraging them to find suitable solutions. Furthermore, games are generally effective tools for improving learning achievements, motivation, and problem-solving skills (Hung et al., 2014), making the GBL environment an engaging and dynamic space for CT skill development.

Several elements that should be considered to engage users in GBL are enjoyment, playfulness, and interactivity (Prensky, 2001). Interactivity plays a crucial role in enhancing engagement in GBL by allowing users to participate actively in the learning process rather than being passive recipients of information. Interactive elements, such as decision-making opportunities, and real-time feedback, create a dynamic learning experience that can adapt to the needs and actions of the learner. This active engagement not only makes learning more enjoyable but also reinforces understanding and retention of the material. Therefore, engagement is an important factor that should be taken into account since it also has a positive impact on learning outcomes (Hamari et al., 2016).

Additionally, challenges in the game significantly influence the learning process, but the development of these challenges should consider the players' skill levels. It is important to implement adaptive learning mechanisms that assess and respond to individual skill levels. This can be achieved through initial skill assessments and continuous monitoring of player performance. Challenges should be neither too easy nor too difficult, they should be designed to stretch the player's abilities just beyond their current competence (Shroff et al., 2019). This balance ensures that players remain engaged and motivated, experiencing a sense of accomplishment as they progress. Appropriately designed challenges can help players become "immersed" in the virtual environment created. The higher the challenge, the greater the sense of immersion, which indirectly enhances engagement (Hamari et al., 2016).

Immersion in GBL refers to the state in which players are deeply engaged and absorbed in the game, often losing awareness of their surroundings due to the compelling nature of the game environment (Brown & Cairns, 2004). This immersive experience can be significantly enhanced in VR environments, where advanced technological capabilities create highly interactive and sensory-rich settings that simulate real-world experiences, leading to a greater sense of presence and involvement (Slater & Wilbur, 1997). The use of VR headsets and hand controllers allows students to interact with 3D objects and navigate through virtual spaces as if they were physically present, thereby fostering a strong sense of presence (Dalgarno & Lee, 2010). VR technologies provide a level of immersion that positively impacts learning outcomes. Studies have demonstrated that students in VR environments exhibit improved retention rates, deeper understanding of complex concepts, and higher levels of engagement compared to traditional learning methods (Parong & Mayer, 2018a; Schrader & Bastiaens, 2012; Selzer et al., 2019).

VR technologies enhance immersion through realistic visualizations and interactive features that make users feel as though they are in an actual setting. This sense of presence—where users experience a "*suspension of disbelief*" and feel as though they are truly in the virtual world—motivates and commits learners to the learning process (Lombard & Ditton, 1997; Monahan et al., 2008; Shapira et al., 2016).

The concept of presence in VR fosters an "*I am here*" feeling, which actively engages learners and positively influences their motivation and interest to interact with the game or simulation (Moreno & Mayer, 2002).

In educational contexts, VR technologies have been shown to enhance students' academic performance and motivation (Alhalabi, 2016; Mestre et al., 2011), improve behavior and cognitive function (Shema-Shiratzky et al., 2019), and develop social and adaptation skills (Ip et al., 2018). VR-based learning environments (VRLEs) offer unprecedented learning experiences within safe and controlled settings, easily simulating a variety of real-world situations (Mikropoulos & Natsis, 2011). These capabilities make VR a powerful tool in modern education, providing immersive and engaging learning experiences that traditional methods cannot match.

Based on the elucidation above that VR technology and the GBL approach offer numerous advantages of interactive and immersive learning strategies, this research aims to investigate the usability and effectiveness of GBL in a VR environment concerning the learning of CT skills. The combination of the GBL strategy within a VR environment is selected due to its capability to provide users with novel experiences. VR technologies offer a unique visualization context that enhances the perception of volumetric details, which cannot be achieved with conventional computer monitors (El Beheiry et al., 2019). Furthermore, the Educause Horizon report indicates that the adoption of VR technologies in education is increasing as VR becomes more affordable (Alexander et al., 2019).

Before investigating the effectiveness of the combined GBL and VR approach, usability testing will be conducted on the developed VR game to ensure it meets the necessary usability standards and provides an engaging user experience. This research is expected to contribute to broader knowledge across various fields. The use of VR in CT learning can enhance student engagement through more immersive and interactive experiences, which can boost motivation and learning outcomes (Parong & Mayer, 2018a). This study will employ a mixed-methods approach to evaluate how the integration of GBL and VR affects various aspects of learning. Thus, this research aims to provide meaningful insights into the effective implementation of VR technology in education and its potential for developing CT skills in students.

1.3 Problem Statements

CT is recognized as an essential skill for students at all educational levels in this digital technology era (Nouri et al., 2020; Ogegbo & Ramnarain, 2022; Zhang et al., 2023). CT is also acknowledged as a fundamental core for formulating and analyzing complex problems and developing robust solutions (Cuny et al., 2010; Shute et al., 2017). As emphasized by Wing (2006), CT is not merely a skill for computer science professionals but a universal competency akin to reading, writing, and arithmetic. For prospective programmers and pre-service teachers of programming, CT should be introduced early to build a solid foundation for CT beyond mere coding (Kazimoglu et al., 2012). Nowadays, educational systems worldwide have begun integrating CT into their curricula, recognizing its importance in equipping learners with critical problem-solving, analytical, and creative thinking abilities. Despite these efforts, there remains a pressing need to explore innovative and engaging methods to effectively impart CT skills, particularly to address diverse learning needs and challenges in modern educational contexts.

The lack of CT skills can lead to significant consequences for learners. Firstly, students may struggle with breaking down complex problems into manageable components and developing effective solutions, a skill critical for tackling challenges in both academic and real-world contexts (Bull et al., 2020). Secondly, limited CT skills often translate into weaker critical thinking and innovation abilities, reducing learners' capacity to approach problems creatively and adapt to rapidly evolving technological environments (Ogegbo & Ramnarain, 2022). Lastly, without strong CT skills, learners may face fewer career opportunities in high-demand fields such as computer science, engineering, and data science (Bakala et al., 2021), where these skills are fundamental.

The teaching of CT, however, faces significant challenges. Traditional pedagogical approaches often rely on didactic methods, which tend to foster passive learning environments and fail to motivate students to engage actively with complex problem-solving tasks. While strategies such as visual and block-based programming, (Chou, 2019; Marcelino et al., 2018), tangible programming (Gardeli & Vosinakis, 2019; Jin et al., 2018), collaborative projects have demonstrated some success, these methods frequently lack the interactivity and immersion necessary to sustain students' motivation and interest (Fronza et al., 2019; Leonard et al., 2016). Whereas immersive virtual learning environment (IVLE) has been shown to positively impact learning processes (Jia & Qi, 2023; Shi et al., 2022). Consequently, learners may struggle to develop a deep understanding of CT concepts or apply them effectively in real-world scenarios.

Existing research and tools in CT education, including GBL and VR, reveal a gap in leveraging immersive environments to enhance learning outcomes. While previous studies have demonstrated the potential of VR to increase engagement and provide realistic simulations, many implementations fall short in achieving a fully immersive and interactive experience (Zhang & Nouri, 2019). For instance, low-end VR technologies, like Google Cardboard, often limit interactivity (Agbo et al., 2023), while higher-end VR applications frequently prioritize visual appeal over educational effectiveness (Selzer et al., 2019). Moreover, the integration of GBL and VR remains underexplored, particularly in the context of fostering core CT skills such as decomposition, pattern recognition, abstraction, and algorithm design. This highlights the need for a structured framework that combines the immersive and interactive potential of VR with the engaging and pedagogical advantages of GBL to enhance CT skills effectively.

To address these challenges, this research specifically focuses on developing, integrating, and validating a comprehensive framework for Immersive Virtual Reality Game-Based Learning (IVR GBL) to foster CT skills. This framework will serve as a systematic guide for designing, implementing, and evaluating IVR GBL environments, emphasizing key elements such as interactivity, immersion, and educational effectiveness. This study seeks to contribute significantly to the academic and practical understanding of how IVR GBL can be leveraged to develop CT skills by validating this framework through usability testing and comparative analysis with conventional methods. The findings are expected to provide researchers and educators with a robust foundation for adopting IVR GBL as an innovative approach to teaching CT in diverse educational contexts.

1.4 Research Objectives

Based on the background explained and the aforementioned problem statements, the objectives of this study are:

i. To develop a framework for fostering CT skills through an IVR GBL approach.
ii. To integrate the developed framework into a VR game for learning CT skills.
iii. To validate the integrated framework through usability assessment, experimental evaluation, and statistical analysis of its impact on students' CT skills.

1.5 Research Questions

Research questions in this study can be formulated as follows:

i. What are the essential elements for developing a framework to foster CT skills through an IVR GBL approach?
ii. How can the developed framework be integrated into a VR game?
iii. What is the impact of the IVR GBL framework on students' CT skills?

1.6 Research Hypothesis

The study proposes a framework of IVR GBL for learning CT skills using a VR game. The research hypotheses of the study are:

H_0: H0: The IVR GBL framework does not significantly improve students' CT skills.

H_a: Ha: The IVR GBL framework significantly improves students' CT skills.

Table 1.1 summarizes the research objectives, research questions, hypotheses, methodology, expected results, and contributions to provide a clear visual overview of the study. This summary shows a clear and concise visual representation of the research structure to help readers understand its purpose and direction.

Table 1.1

Summary of research objectives, research questions, hypotheses, methodology, expected results, and contributions

Research problem	Research Objectives	Research Questions	Hypotheses	Methodology	Expected results	Contributions
How to develop a framework to foster Computational Thinking (CT) Skills through an IVR GBL approach?	To develop a framework for fostering CT skills through an IVR GBL approach.	What are the essential elements for developing a framework to foster CT skills through an IVR GBL approach?		Systematic Literature Review (SLR) using Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). Expert review for framework validation.	A conceptual framework of IVR GBL for learning CT skills. A validated framework ready for integration into a VR game.	Providing a theoretical foundation for designing IVR GBL to support CT skills. A framework that can be used as a guideline for designing IVR GBL.
	To integrate the developed framework into a VR game for learning CT skills.	How can the developed framework be integrated into a VR game?		Game Development (Prototype based on validated framework).	A VR game integrating the IVR GBL framework.	A practical implementation of the IVR GBL framework in an interactive learning environment.

Research problem	Research Objectives	Research Questions	Hypotheses	Methodology	Expected results	Contributions
	To validate the integrated framework through usability assessment, experimental evaluation, and statistical analysis of its impact on students' CT skills.	What is the impact of the IVR GBL framework on students' CT skills?	H_0: The IVR GBL framework does not significantly improve students' CT skills. H_a: The IVR GBL framework significantly improves students' CT skills.	Usability Testing using USE Questionnaire. Quasi-experimental design (pretest-posttest with control and treatment groups) and followed by statistical analysis.	Usability testing data for improvement. Empirical validation of the IVR GBL framework through experimental findings, usability data, and statistical analysis of pre-test & post-test results.	Insights into the effectiveness of IVR GBL features for improving user engagement and CT skills. Evidence-based validation of the IVR GBL framework for fostering CT skills.

1.7 Scope of the Study

To make the research is more focus on the research objectives and research problems, the scope of the study is delimited to the following:

i. The study focuses on the development and validation of a framework for IVR GBL to foster CT skills. The framework integrates theoretical and practical insights, emphasizing game elements and VR features such as playability, interactivity, enjoyment, immersion, and presence. Additionally, the CT skills components in this study are decomposition, pattern recognition, abstraction, dan algorithm design.

ii. The participants in this study are undergraduate students of computer science education with prior exposure to programming courses. This ensures that the participants have a foundational understanding of CT concepts.

iii. The VR game developed as part of the framework targets specific CT skill components, including decomposition, pattern recognition, abstraction, and algorithm design.

iv. The VR game is created using the Unity game engine and deployed on Oculus/Meta Quest 2 devices to ensure an immersive experience. Other VR platforms are excluded from the scope.

v. The findings of this study are specific to the IVR GBL environment and may require adaptation when applied to different educational contexts, age groups, or technological platforms.

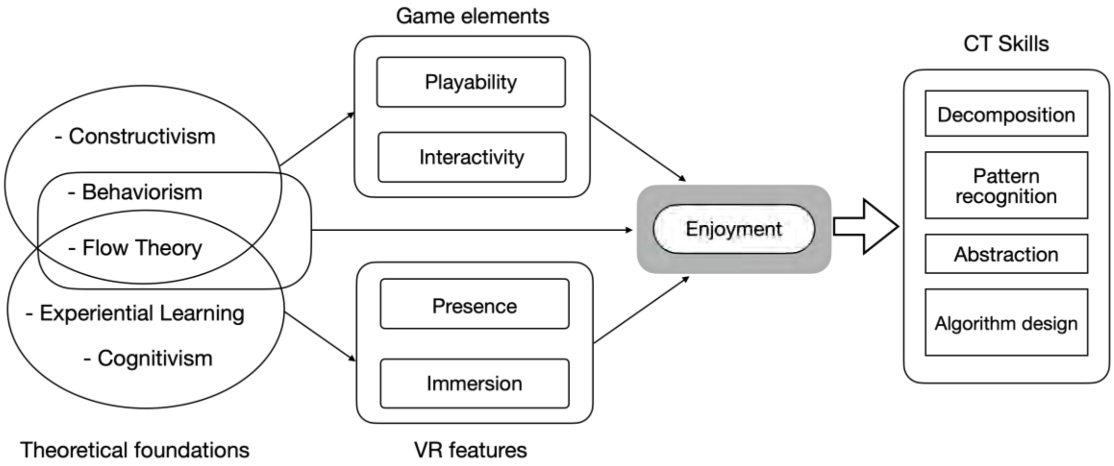
1.8 Conceptual Framework

This study aims to develop, integrate, and validate an IVR GBL framework for fostering computational thinking (CT) skills. The framework serves as a systematic guide to bridge the gap in integrating immersive VR and GBL approaches to enhance CT skills. It also lays the foundation for designing and implementing innovative educational solutions that actively engage learners and address the challenges posed by conventional teaching methods.

Figure 1.2 presents the conceptual framework of the study, providing an initial outline guiding the research process, connecting the theoretical foundations, the elements of the IVR GBL framework, and the targeted CT skills. It not only establishes the theoretical foundation of the study but also demonstrates how the integration of specific design elements in VR environments can effectively support CT skill development. The framework is dynamic, serving as the basis for refinement through empirical testing and validation, with the final framework to be presented in the results chapter.

Figure 1.2

Conceptual framework of the study



Based on the conceptual framework, the study is grounded in five key learning theories, namely Constructivism, Behaviorism, Flow Theory, Experiential Learning, and Cognitivism. Constructivism emphasizes active learning through exploration and interaction (Vygotsky & Cole, 1978; Wu, et al., 2012), forming the foundation for game elements such as playability and interactivity, which encourage learners to actively engage with the game while constructing their knowledge. Behaviorism, with its focus on reinforcement through feedback, supports the design of game elements by ensuring that learners receive timely feedback, enhancing their learning behaviors (Gunnars, 2021). Flow Theory underpins enjoyment by emphasizing the importance of balancing challenge and skill to create an optimal state of engagement (Atombo et al., 2017), fostering motivation and sustained focus. Experiential Learning highlights the importance of hands-on, contextualized experiences, making it integral to developing VR features such as presence and immersion, which provide realistic and meaningful learning environments (Li et al., 2022). Lastly, Cognitivism emphasizes the role of mental processes, such as information processing and schema building, in learning, supporting the design of VR features to ensure they are cognitively engaging and facilitate understanding (Brieger et al., 2020).

In the conceptual framework, the independent variables are categorized into game elements and VR features. Game elements, which include playability and interactivity, focus on the usability, allowing learners to immerse themselves in problem-solving tasks. VR features, consisting of presence and immersion, enhance learners' connection with and involvement in the virtual environment, enabling focused and immersive experiences. The combination of game elements and VR features creates enjoyment, which acts as a mediating variable. Enjoyment, grounded in Flow Theory and Behaviorism, represents learners' emotional response to the learning experience, bridging the independent variables with the targeted CT skills. It plays a pivotal role in maintaining motivation and engagement, which are essential for effective learning.

The ultimate goal of this framework is to develop key components of CT skills, namely decomposition, pattern recognition, abstraction, and algorithm design. These skills are fostered through the interplay of theoretical foundations, game elements, VR features, and enjoyment. Decomposition involves breaking down complex problems into manageable parts, while pattern recognition enables learners to identify patterns and connections within data. Abstraction helps filter out irrelevant details to focus on essential information, and algorithm design facilitates the creation of step-by-step problem-solving solutions. This framework not only provides a theoretical and practical structure for the design of IVR GBL but also highlights how learning theories, when applied effectively, can transform virtual environments into impactful educational tools that enhance CT skills.

1.9 Operational Definition

The operational definition section details the terms and variables used in this study. This section provides definitions to ensure a common understanding of key concepts and terminologies integral to the research. Several key terminologies and variables covered in the study are explained comprehensively, encompassing both general and specific aspects pertinent to the research objectives.

a. Computational Thinking (CT)

Computational thinking (CT) is the thought process involved in formulating problems and their solutions in a manner that can be effectively executed by an information-processing agent (Cuny et al., 2010). CT is also defined as the process involving "*solving problems, designing systems, and understanding human behavior by drawing on the concepts fundamental to computer science*" (Wing, 2006). Later, Wing (2014) redefined CT as a thinking process that includes the formulation of problems in a way that a computer can effectively process and the expression of solutions.

In the context of this study, CT is a critical skill set that the VR game aims to develop in learners. Through the immersive and interactive environment provided by the *CT Saber* VR game, learners engage in activities that enhance their ability to decompose complex problems, recognize patterns, abstract key information, and design algorithms. These CT skills are essential for solving real-world problems and are integral to the educational objectives of the game.

b. Computational Thinking Skills

Computational thinking (CT) skills refer to managing a set of problem-solving cognitive processes as follows (BBC Bitesize, 2015; Cachero et al., 2020):

(1) *Decomposition*: The ability to break down data, processes, or problems into smaller, manageable parts.

(2) *Pattern Recognition*: The ability to recognize patterns, trends, or similarities among the decomposed problems.

(3) *Abstraction*: The ability to filter out or ignore the characteristics of patterns that are not needed, focusing on essential specific details.

(4) *Algorithm Design*: The ability to develop a step-by-step procedure to accomplish tasks.

CT skills in the context of this study are integral to the framework used in the CT Saber game. Decomposition is applied as users tackle the challenge of finding the best path from the starting point to the endpoint, breaking the overall task into smaller, more manageable parts. Pattern recognition comes into play as users identify directional patterns while creating routes, aiding in efficient decision-making. Abstraction involves selecting which directions within the cubes to slash and which to ignore and focusing on crucial cubes with the best direction. Algorithm design is implemented when users plan the sequence of routes to take, effectively creating a structured approach to achieving their goals. By integrating these CT skills into the gameplay, the study aims to demonstrate how the IVR GBL can enhance learners' CT abilities.

c. Game-Based Learning (GBL)

Game-based learning (GBL) is a strategy to enhance learning activities and the educational environment by utilizing games to engage and motivate learners (Trajkovik et al., 2018). GBL is an active learning strategy that can be implemented in both formal and informal settings, including the teaching and learning of CT skills. In the context of this study, GBL is integrated into the IVR GBL approach through the *CT Saber* VR game, which leverages the engaging and interactive nature of games to foster CT skills. By immersing learners in a VR environment, the game aims to make learning more enjoyable and effective, thereby enhancing their ability to decompose problems in the game challenge, recognize patterns, abstract key information, and design algorithms.

d. Game Elements

Game elements are factors or variables that contribute to the overall gaming experience. These elements are designed to engage players, create challenges, and provide entertainment. In this study, the game elements are positioned as independent variables and include the following:

(1) *Playability*: The ability of a game to provide environments that allow users to play and learn simultaneously. It defines the degree to which a game is fun to play and user-friendly, with an emphasis on the interaction style and plot quality of the game (Foraker, 2020). In the context of *CT Saber*, playability ensures that

the game is both engaging and educational, facilitating an enjoyable learning experience.

(2) *Interactivity*: The ability of a game to respond and provide appropriate feedback to users while playing, which engages the players (Leonard et al., 2020). Interactivity facilitates a two-way communication process between players (as learners) and the game's features. This dynamic interaction is crucial for maintaining engagement and enhancing the learning process in the *CT Saber* VR game.

e. Virtual Reality Features

Virtual reality (VR) features are unique aspects that contribute to the VR environment and enhance the user's experience, making it more engaging, realistic, and enjoyable. The VR features considered in this study include:

(1) *Presence*: The concept of being perceptually present in a virtual environment created by a VR application, to the extent that it feels as if the medium is not there (Selzer et al., 2019). This feature makes virtually designed objects in the VR application appear more real, allowing users to engage in embodied interactions with virtual objects (Leonard et al., 2020). In the context of CT Saber, presence ensures that learners feel immersed in the virtual world, enhancing their engagement and focus.

(2) *Immersion*: The users' perception of being physically present in a non-physical world, such as a digital environment. This perception is generated by visual

displays, sounds, and other stimuli surrounding the users (Berns et al., 2019). Similar to the previous research, immersion in this study is achieved through visual and auditory stimuli, creating a compelling and realistic learning environment that captivates users and supports the learning process.

f. Enjoyment

Enjoyment is operationally defined as the emotional response of users to their experience while interacting with the IVR GBL environment. Enjoyment reflects the extent to which users find a pleasurable and satisfying environment that makes players enjoy the experience (Giannakos, 2013). It is a mediating variable that bridges the relationship between game elements, VR features, and the development of CT skills. Enjoyment in this study is measured through learners' subjective perceptions of their experience with the IVR GBL environment.

g. Virtual Reality Game Application for learning CT

Virtual Reality Game Application for Learning Computational Thinking (VRGACT) is a term that encapsulates the tool and environment for learning CT by integrating game elements and VR features. The application is named "*CT Saber*" where "*CT*" stands for computational thinking. The CT Saber VR game application can only be installed on Oculus Quest 2 and its variants, including Oculus Quest, Meta Quest 2, and Meta Quest Pro. This specific platform compatibility ensures that users can fully experience the immersive and interactive features designed to enhance CT skills through engaging gameplay.

h. Immersive Virtual Reality Game-Based Learning (IVR GBL)

Immersive Virtual Reality Game-Based Learning (IVR GBL) is an educational approach that combines immersive VR technology with GBL principles to create a highly engaging and interactive learning environment. Previous research showed that IVR GBL can significantly enhance learners' motivation, engagement, and overall learning experience by immersing them in a virtual world where they can interact with educational content through gameplay (Bazargani et al., 2021; Silva et al., 2017). This approach leverages the strengths of both virtual reality and GBL to provide a more effective and enjoyable learning experience.

In the context of this study, IVR GBL is implemented through the VR game "*CT Saber*" designed specifically for learning CT skills. The CT Saber game integrates educational content related to CT skills with immersive VR features and engaging game mechanics. By using CT Saber, learners can practice and develop skills such as decomposition, pattern recognition, abstraction, and algorithm design in a virtual environment that is both interactive and immersive. This approach ensures that learners are actively engaged in the learning process, making it easier to absorb and apply complex concepts in computational thinking.

i. Usability

Usability refers to the extent to which a specific product can be used by specific users to achieve specific goals with effectiveness, efficiency, and satisfaction in a specified context of use. Nielsen (1992) explains that usability encompasses several components, including learnability, efficiency, memorability, errors, and satisfaction. According to the international standard ISO 9241, usability is defined similarly, emphasizing effectiveness, efficiency, and satisfaction (Hariyanto et al., 2020). In the context of this study, the usability is to what extent the CT Saber VR game can be used for learning CT skills. The game should be intuitive for learners to quickly understand its functionality (learnability), efficient in enabling task completion (efficiency), and memorable for easy recall after non-use (memorability). Additionally, the game should minimize errors by providing clear instructions and feedback and ensure that learners find the experience enjoyable and satisfying (satisfaction).

j. Conventional Learning Methods

The conventional learning method in this study refers to the way instructors deliver lectures in a classroom setting, where the primary mode of instruction is through direct, face-to-face interaction. The instructor presents the course material on CT and provides explanations of the topic. Furthermore, course materials and resources are uploaded to a Learning Management System (LMS), allowing students to access lecture notes, readings, assignments, and other instructional content at their convenience. This method provides a structured and organized learning environment, but it may result in passive learning, where students receive information without significant interaction or engagement with the material.

In contrast, IVR GBL represents a more dynamic and interactive learning approach. Specifically, IVR GBL utilizes the CT Saber VR game to teach CT. Through the use of VR technology, learners are immersed in a simulated environment where they can actively engage with educational content. The CT Saber game incorporates game mechanics and VR features to create an engaging and motivating learning experience, promoting active participation and hands-on practice of CT skills such as decomposition, pattern recognition, abstraction, and algorithm design.

j. Effectiveness

Effectiveness is operationally defined as the extent to which the IVR GBL framework achieves its intended purpose of enhancing CT skills. Effectiveness is measured through the improvement in learners' CT skills after engaging with the IVR GBL environment, compared to conventional teaching methods. It is evaluated based on the performance of learning outcomes in pretest and posttest assessments.

1.10 Limitation of the Study

This study, while offering valuable insights into the integration of immersive VR and GBL to foster CT skills, is subject to several limitations:

a. *Technological Scope*: The VR game, *CT Saber*, is exclusively developed for deployment on the Oculus/Meta Quest devices. The VR game is developed using the Unity game engine with the Oculus Integration framework. This reliance on specific hardware and software may restrict its adoption in educational institutions with limited resources or alternative hardware setups. The VR game can only be installed on the Oculus Quest 2 and its variants, like Oculus Quest, Meta Quest 2, and Meta Quest Pro.

b. *Participant diversity*: The participants in this study are restricted to college-level computer science education students with prior programming knowledge. This focus limits the generalizability of the findings to other educational levels, disciplines, or learners with no programming background. Future studies could broaden the participant base to include K-12 students or non-computer science majors.

c. *Content adaptability*: The learning materials in the *CT Saber* VR game are adapted from the *Bebras Challenge*, which may not encompass the full range of CT skills or contextual applications. While effective for specific skill areas, this approach might not align with diverse educational standards or curricula across different regions.

d. *Evaluation periods*: The study primarily evaluates short-term outcomes, such as usability and immediate CT skill improvement, without exploring long-term impacts like skill retention, transferability, or real-world application. Further research is needed to assess these aspects over extended periods.

e. *Self-reported metrics*: Some aspects of the study, including enjoyment and perceived usability, rely on self-reported data. This approach may introduce biases stemming from subjective perceptions or external influences.

f. *General educational comparisons*: While this study contrasts the IVR GBL approach with conventional teaching methods, it does not benchmark its performance against other innovative methods like augmented reality, blended learning, or adaptive learning technologies.

1.11 Summary

This chapter provides a comprehensive introduction to the research, emphasizing the significance of CT as an essential skill for the modern digital age. CT is recognized for its foundational role in problem-solving, systematic thinking, and fostering innovation across disciplines beyond computer science. The chapter outlines the challenges of conventional teaching methods, which often fail to actively engage learners, and presents IVR GBL as a promising approach to address these gaps.

The research proposes the development, integration, and validation of a framework for IVR GBL aimed at enhancing CT skills. This framework combines theoretical insights from constructivism, behaviorism, flow theory, experiential learning, and cognitivism, with practical elements such as game mechanics and VR features to create an immersive and interactive learning environment. The framework's implementation is demonstrated through the development of a VR game, "*CT Saber*", specifically designed to foster CT skills like decomposition, pattern recognition, abstraction, and algorithm design.

The chapter articulates the study's research objectives, which include developing the IVR GBL framework, integrating it into the VR game, and validating its usability and effectiveness. The corresponding research questions and hypotheses guide the investigation, focusing on the framework's essential elements, its integration, and its impact on CT skills. The conceptual framework presented in this chapter provides a structured representation of the relationships among game elements, VR features, enjoyment as a mediator, and the targeted CT skills.

The study's scope, defined in this chapter, delimits its focus to college-level computer science education students with prior programming knowledge, the use of Oculus/Meta Quest VR devices, and specific CT skill components derived from the *Bebras Challenge*. The chapter also identifies limitations, including technological constraints, participant diversity, and the short-term nature of evaluations.

In conclusion, this research aims to contribute significantly to the field of educational technology by demonstrating how IVR GBL can foster CT skills through an immersive approach. The findings are expected to provide practical insights for educators and researchers, advancing the integration of advanced technologies like VR in education. This study holds the potential to transform traditional pedagogical strategies, offering innovative tools for developing digital age skills.