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The Effect of Virtual Reality Gaming on Developing Computational Thinking Skills

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Abstract

In the digital age, where programming prowess is increasingly crucial, the enhancement of Computational Thinking (CT) skills becomes essential. This study ventures into the scarcely explored domain of leveraging game-based learning (GBL) within virtual reality (VR) settings to bolster CT skills. Specifically, it introduces "CT Saber," a VR game inspired by the popular "Beat Saber," tailored to cultivate CT competencies. Employing a Design and Development Research (DDR) methodology across five stages—analysis, design, development, implementation, and evaluation—this investigation assessed the game's impact on 37 computer science students (25 male, 12 female) aged 21-24. A quasi-experimental design with pretest-posttest evaluation was utilized, revealing significant enhancements in CT skills post-intervention ($Z = -4.496$, $p < 0.05$), as analyzed through Wilcoxon Signed-Rank tests. The findings underscore the VR game's efficacy in CT skill development, suggesting a promising direction for integrating VR technologies in programming education.

A. Introduction

Digital technology has become an integral part of our lives, playing a crucial role in solving a myriad of problems. In today's world, virtually all activities involve the use of digital technology, underscoring its pervasive influence on our daily routines. This technology is primarily developed by software engineers or individuals who have programming skills, highlighting the importance of technical expertise in the digital age. One of the skills that bolster programming skills is Computational Thinking (CT) [1]. CT enables individuals to solve problems, design systems, and understand human behavior by drawing on the concepts fundamental to computer science. This skill set is not only vital for software engineers but also even enhances the ability to think logically and systematically for all work backgrounds, making it a critical asset in the development and application of digital technology. Therefore, many researchers stated that CT is believed to be a basic competency that should be developed by twenty-first-century students [2], [3].

CT is described as thought processes involved in formulating problems and the solutions represented in an effective form to be carried out [4]. The term of CT originated from a procedural concept proposed by Papert in 1980[5], then its definition, teaching, learning, and evaluation were discussed by various scholars and researchers [6]. Wing (2006) defined CT as a kind of analytical thinking which includes elements of problem-solving, system design, and understanding human behavior based on the concepts of computer science [7]. Afterwards, Wing (2014) emphasizes that CT is not only about problem-solving, but also problem formulation [8]. Even, Wing (2006) stated that CT is equal to other skills like reading, writing, or arithmetic that should be empowered by all students, not only computer science students. Additionally, the International Society for Technology in Education (ISTE) and Computer Science Teachers Association (CSTA) believe that CT is essential to improve the achievement level of students, preparing them for global competitiveness and blending academics into real life [9].

Educational systems in many countries realized the importance of CT so that they integrated CT or subjects related to programming and computer science into compulsory education or just an additional. However, 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 [10]. Portugal made a policy that computer science and programming are compulsory for all pupils in primary and secondary schools since 2017 [11]. 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 [12] [13]. 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.

Teaching CT can be conducted through several approaches, such as visual block programming [14], tangible programming[15], and games. Visual block programming that potential for teaching CT are App Inventor, Alice, Construct 2, Kodu, Blockly, and the most popular one is Scratch [1]. Game-based learning (GBL) is one of other strategies that many researchers employed for learning CT. GBL refers to a strategy of utilizing games in the educational process to enhance learning activities so that engage and motivate students to actively process educational content and foster development process [16]. GBL allows students to keep learn by interacting with a game and actively thinking while playing without being aware of it, so that it may improve learning motivations, engagement, and problem-solving. Noroozi et al., (2020) address that the GBL environments supposed to aid users in gaining 21st century skills such as problem-solving, decision making, critical thinking, analytical, critical, and argumentation [17].

The games used in the GBL approach can be set up in various platforms and environments, such as computer desktops, web browsers, mobile applications, augmented reality (AR), and virtual reality (VR). One innovative setting that may enhance a student's learning experience in a virtual environment to facilitate the GBL is VR technology [18]. Educause Horizon's report shows that one of the emerging technologies and practices that is believed to have a significant impact on the future of postsecondary teaching and learning is VR [19]. Rogers (2019) also stated that VR is one learning aid for the 21st century that allows users to retain more information and better apply what they have learned after using it [20], [21]. One reason is that VR technologies can generate, visualize, and simulate a virtual environment with 3D objects or artifacts and make users experience a high degree of immersion so that users perceive that they are actually "there" [18]. Hence, it can be beneficial if VR technologies are utilized to foster CT skills through GBL environment settings. However, the strategies to foster CT skills that harness VR in GBL settings are still lacking. The majority of tools used for it are visual block programming with Scratch [1]. This study aims to investigate the effect of a VR game on the CT skills development.

B. Research Method

This study employs a design and development research (DDR) method to achieve the objectives. DDR is the systematic study of design, development, and evaluation processes to establish an empirical basis for creating instructional and non-instructional products, tools, and new or enhanced models that govern their development [22], [23]. This aligns with the professional suggestions in instructional design and technology that facilitate learning and improve performance by creating, using, and managing appropriate instructional and non-instructional interventions.

DDR method can be categorized into two main types: (1) research on products and tools and (2) research on design and development[23]. This study suits the first type, research on products and tools, where the product that will be developed is a software application of VR, which is considered a tool for learning. The entire design and development process can be documented through a model of analysis, design, development, implementation, and evaluation (ADDIE). Figure 1 shows the research design in the ADDIE model.

In the initial phase of the DDR utilizing the ADDIE model, the analysis stage is crucial for laying the foundational framework of the educational intervention. This stage encompasses a comprehensive analysis of needs, where an evaluation is conducted to identify the specific requirements and challenges that the intervention aims to address. Following this, learning objectives are defined, establishing clear, measurable goals that the educational tool intends to achieve in terms of learner outcomes. Furthermore, determining the target audience is another activity conducted in the analysis phase. These steps used to ensure that the development of the educational tool is precisely aligned with the learners' requirements and the educational goals.

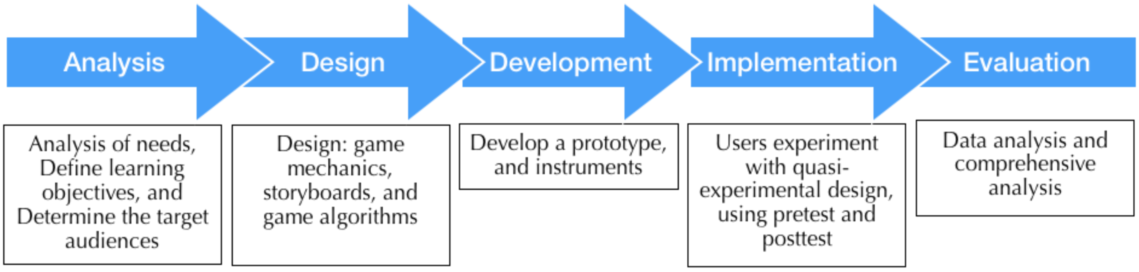


Figure 1. Research design employed

Transitioning to the design phase, attention shifts towards the technical assembly of the educational tool, specifically focusing on GBL interventions using aVR game. In this context, game mechanics are thoughtfully devised to ensure engaging, interactive, and pedagogically sound experiences that effectively facilitate learning objectives. Table 1 shows the design of game mechanics implemented in the developed game. Storyboards are crafted, outlining the visual and narrative flow of the game, thereby serving as a blueprint for the development process. Additionally, the design of game algorithms plays a critical role in this phase, underpinning the logic, decision-making processes, and dynamic elements within the game. These algorithms are essential for creating adaptive learning environments that respond to the learner's actions and progress. Together, these components of the design phase are instrumental in shaping a compelling and educationally effective game-based learning tool, bridging the gap between educational theory and the immersive experience of VR gaming.

Table 1. Design of game mechanics

Game Mechanics	Description
System creates a grid map	The game system creates a grid map that contains obstacles, a heart icon, and the locations of the start and finish points randomly.
System generates cubes	The system generates cubes with random positions and flying towards the player. The generated cubes contain an arrow with a certain direction.
Player makes a route	The game system permits players to make a route from the start to the finish point by slashing a cube. The arrow direction embedded in the cube determines the pathway.
Player slashing a cube	Cubes that are randomly generated by the system can be slashed by players using lightsabers.
Scoring system	Players get a point when slashing a cube. The maximum score for each level is 100.
Double score system	Players get a double point when the route created passes through a heart icon.
Game accomplished	The game is accomplished when a player makes a route from start to finish and then continues to the next level.
Leveling system	The game consists of six levels with different maps and obstacles at each level.

Game Mechanics	Description
Timer system	The timer is set based on the length of the audio clip used as the back sound.
Game over	The game is over in two conditions, time is over or the route created by the player is hitting an obstacle.

The development stage involves the creation of a prototype alongside the necessary instruments for evaluation. This phase is characterized by the actual construction of the educational tool, where theoretical designs and algorithms are transformed into a tangible, interactive product. The development of a prototype is a critical step, allowing for the preliminary testing and refinement of the educational intervention. Concurrently, the development of instruments to measure the effectiveness of the intervention, namely assessment tasks in pretest and posttest forms. The instruments are used to evaluate the intervention's impact on learning outcomes.

In the implementation phase, users are engaged in an experimental setup employing a quasi-experimental design, which includes both pretest and posttest measures to ascertain the intervention's effectiveness. This design allows for the examination of learning outcomes before and after the intervention, providing insights into the educational tool's impact on the target audience's knowledge and skills. Following this, the evaluation phase conducts a comprehensive analysis of the collected data, utilizing statistical methods to assess the extent to which the intervention meets the defined learning objectives. This stage is used to measure the effectiveness of the VR game tool that has been developed and the implemented learning approach, identifying areas for improvement, and informing future iterations of the development process.

Table 2. Demographic information of participants involved

Info		n	%
Gender	Male	25	67.6
	Female	12	42.4
	Total	37	100
Age	19-20	19	51.4
	21-22	16	43.2
	23-24	2	5.4
	Total	37	100
Have ever learned CT?	Yes	31	83.8
	No	6	16.2
	Total	37	100
Have ever used VR devices?	Yes	24	64.9
	No	13	35.1
	Total	37	100

Table 2 shows the demographic information for the participants in this study. The gender distribution of the 37 participants is predominantly male, constituting 67.6% (n=25), while females make up 32.4% (n=12). In terms of age, the majority of participants are between the ages of 19 and 20, accounting for 51.4% (n=19) of the sample. Those aged 21 to 22 represent 43.2% (n=16), and a smaller portion, 5.4% (n=2), are between the ages of 23 and 24. When they asked about CT, a significant majority of participants, 83.8% (n=31), had previously learned about CT, which is the subject matter of the VR game. In contrast, 16.2% (n=6) have not had such an educational experience. Additionally, familiarity with the technology used in the intervention is relatively high; 64.9% (n=24) of the participants have used VR devices before, while 35.1% (n=13) have not, indicating a good level of readiness in terms of engagement with the virtual environment used for the developed VR game.

C. Result and Discussion

1. Game Development Features

The virtual reality (VR) game developed for this research, named "CT Saber," is engineered using the Unity game engine, specifically version 2020.2.7f1. The software development kit (SDK) used was Oculus Integration version 34.0, released in November 2021, then updated regularly when the notification came up. This game is designed to be compatible exclusively with VR devices such as the Oculus or Meta Quest and their variants, leveraging the immersive capabilities of these platforms to facilitate a unique learning experience. The title "CT Saber" amalgamates the concept of Computational Thinking (CT) with an homage to the popular Oculus game, Beat Saber. Inheriting the core game mechanics from Beat Saber, where players slice through floating cubes directed at them, CT Saber introduces a novel educational twist. Beyond the visceral action of slicing cubes, CT Saber compels players to engage in computational thinking by navigating the best possible route to a designated endpoint on a grid map. This requires players to strategize their movements from the starting point, circumventing obstacles to reach the target destination successfully. This integration of computational problem-solving into the gameplay mechanics not only enriches the player's engagement with the game but also fosters the development of critical thinking skills in a fun and interactive environment.

Figure 2 illustrates the gaming environment present within the VR game CT Saber. The development of this environment is grounded in the design of game mechanics outlined in Table 1, such as the system for creating a grid map filled with obstacles, a heart icon, and designated start and finish locations. The appearance of these elements is generated randomly to foster a diverse map variety with each gameplay session. Additionally, the system incorporates a timer to establish a maximum duration within which players are required to complete the given mission. This design strategy not only challenges the players' strategic planning and problem-solving skills, which are essential components of CT, but also introduces an element of urgency to enhance engagement and simulate real-world problem-solving scenarios. Through this intricate combination of randomized map generation and time constraints, CT Saber aims to provide an immersive and intellectually stimulating experience, pushing players to adapt their strategies and decision-making processes continuously.

The VR game CT Saber is structured across six distinct levels, each featuring a unique map design while maintaining consistent gameplay mechanics. As depicted in Figure 3, the game concludes with one of two possible outcomes: accomplished or failed. Figure 3(a) illustrates the scenario in which the player successfully completes the mission, signified by a smiling emoticon, indicating a successful navigation through the game's challenges to reach the intended goal. Conversely, a failed attempt is represented by a sad emoticon, as shown in Figure 3(b), signaling the player's inability to meet the game's goals.

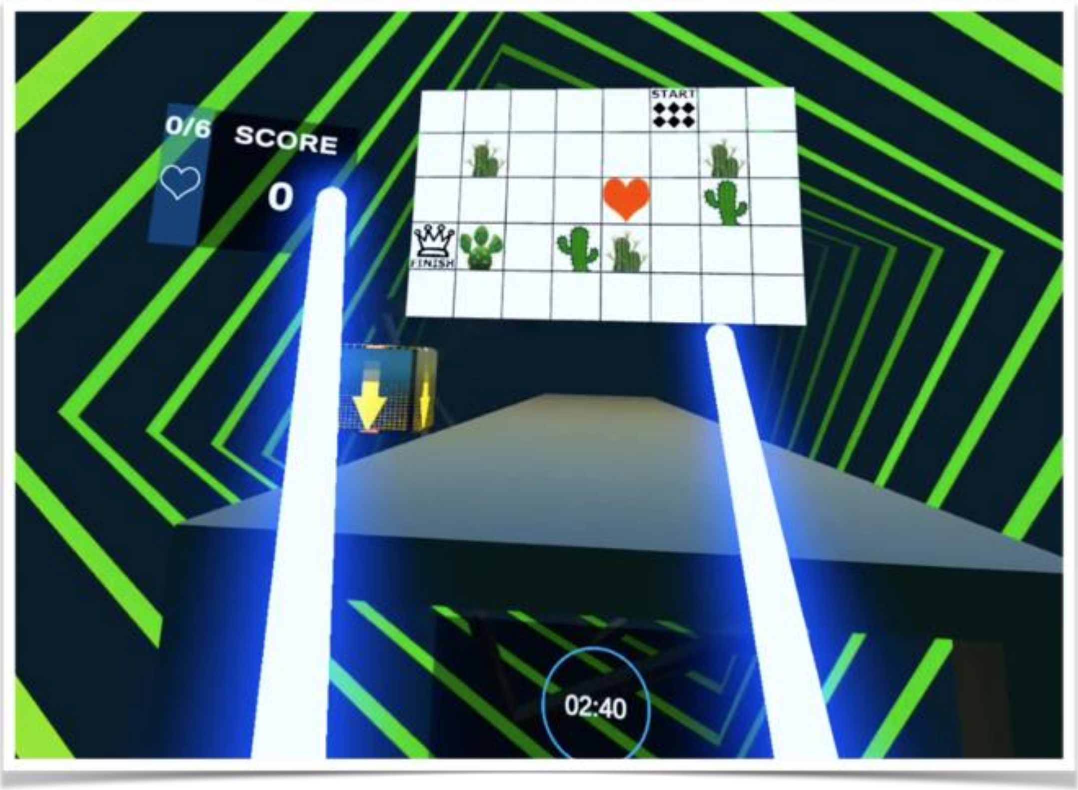
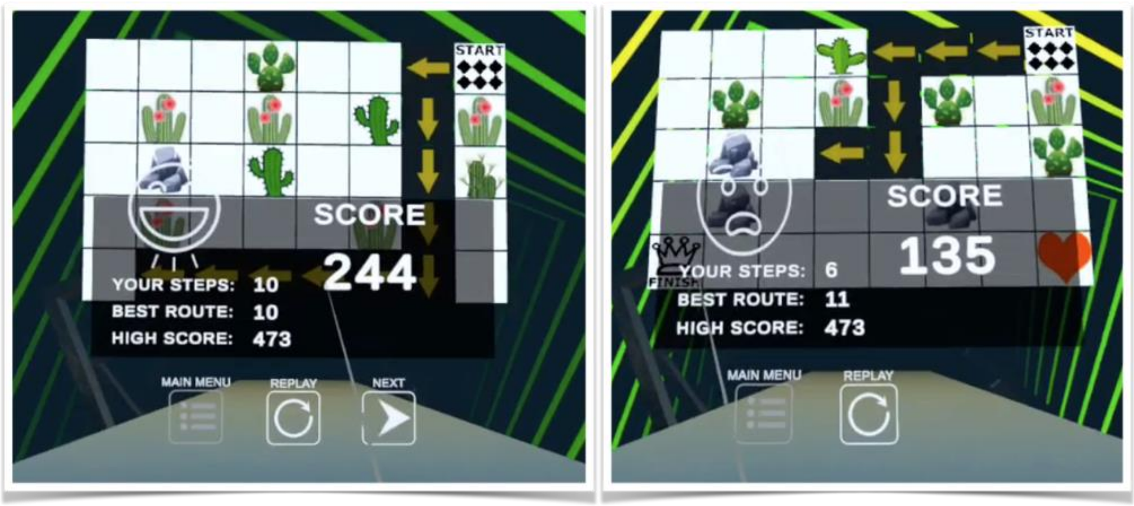


Figure 2. Game environment in the CT Saber

Upon the completion of each game session, a pop-up menu appears, providing a comprehensive summary of the player's performance. This summary includes the score achieved, the number of steps taken, the optimal route that could have been followed, the highest score attained, and various other selectable options. Notably, if the player fails to achieve the level's target, the option to proceed to the next level is withheld. Instead, the player is presented with a choice to either retry the same level or return to the main menu. This mechanism ensures that players are adequately challenged to develop and apply effective strategies, reinforcing the game's educational objective to enhance computational thinking skills through engaging and iterative gameplay experiences.

Among the six existing levels of the game, two quizzes are included, adopted from the Bebras Challenge available on bebras.or.id. These quizzes serve a dual purpose: to embed an evaluative component within the gameplay to assess the players' CT skills and to provide a seamless integration of assessment within the learning trajectory. The positioning of quizzes is deliberately placed after the completion of levels two and four, serving as checkpoints that gauge the progression of CT abilities developed through interaction with the game. By utilizing questions from a recognized platform like the Bebras Challenge, the game ensures that the evaluation of CT capabilities is both standardized and reflective of an internationally benchmarked understanding of these skills. This approach not only enriches the gaming experience with an educational assessment but also aligns the player's in-game progress with tangible learning outcomes in CT.



(a) (b)

Figure 3. The Game ends in two conditions: (a) accomplished, and (b) failed

2. Effectiveness of the Game

The effectiveness of the CT Saber VR game as a tool for learning CT was statistically evaluated using SPSS software. The first step in the data analysis process involved assessing the distribution of the data to determine normality. This preliminary examination is critical as it dictates the appropriate statistical methods for subsequent analysis. If the data were found to be normally distributed, parametric tests could be applied with greater confidence in their assumptions. However, in the presence of non-normal data, alternative non-parametric methods would be warranted.

Table 3 presents the results of normality tests conducted on the scores from a pretest and posttest using the SPSS statistical package. The Kolmogorov-Smirnov and Shapiro-Wilk tests are both utilized to evaluate the distribution of the data against a normal distribution. For the pretest scores, the Kolmogorov-Smirnov statistic is 0.164 with a significance level (p-value) of 0.014, and the Shapiro-Wilk statistic is 0.929 with a significance level of 0.02. In the case of the posttest scores, the Kolmogorov-Smirnov statistic is 0.228 with a significance level effectively at 0, while the Shapiro-Wilk statistic is 0.906 with a significance level of 0.004. The degrees of freedom (df) for both tests are 37, corresponding to the sample size. Both tests' significance levels for pretest and posttest scores are below the common alpha level of 0.05, suggesting that the scores do not follow a normal distribution. The Lilliefors Significance Correction indicates that a correction has been applied to the Kolmogorov-Smirnov test, enhancing its accuracy for small sample sizes. These results imply that non-parametric statistical techniques are more appropriate for further analysis of the CT Saber VR game's effectiveness in learning CT.

Table 3. Normality test

	Categories	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Scores	Pretest	.164	37	.014	.929	37	.020
	Posttest	.228	37	.000	.906	37	.004

a. Lilliefors Significance Correction

Given the non-normal distribution of data, the Wilcoxon Signed-Rank Test was utilized as the non-parametric method for statistical analysis. Table 4 presents the ranked data from the Wilcoxon Signed-Rank Test, showing the distribution of differences between post-test and pretest scores. The table indicates that 2 participants had negative ranks (mean rank = 7.50, sum of ranks = 15.00), signifying that their posttest scores were lower than their pretest scores. Conversely, 28 participants exhibited positive ranks (mean rank = 16.07, sum of ranks = 450.00), indicating higher posttest scores relative to their pretest scores. The presence of 7 ties suggests that for these participants, there was no change between their pretest and posttest scores. The total number of participants included in this analysis is 37.

Table 4. Ranked data from the Wilcoxon signed-rank test

		N	Mean Rank	Sum of Ranks
Posttest - Pretest	Negative Ranks	2[a]	7.50	15.00
	Positive Ranks	28[b]	16.07	450.00
	Ties	7[c]		
	Total	37		

a. Posttest < Pretest
b. Posttest > Pretest
c. Posttest = Pretest

Table 5 details the test statistics from the Wilcoxon Signed-Rank Test applied to the posttest-pretest score differences. A Z-score of -4.496, with an asymptotic significance (2-tailed) of 0, reflects a highly significant difference in scores. The significance level of 0 indicates that the probability of this result occurring by chance is extremely low, thus confirming the presence of a statistically significant change in scores after the intervention. This result was based on the negative ranks, as indicated by the notation 'b' in the table, which signifies that the analysis was influenced by the participants who scored lower on the posttest than on the pretest. The evidence provided by Table 5 supports the conclusion that the intervention, presumably the CT Saber VR game, had a significant impact on the participants' Computational Thinking skills.

Table 5. Wilcoxon signed-rank test results

	Posttest - Pretest
Z	-4.496[b]
Asymp. Sig. (2-tailed)	.000

a. Wilcoxon Signed Ranks Test
b. Based on negative ranks.

3. Discussion

This section discusses the implications and significance of the observed statistical outcomes derived from deploying the CT Saber VR game as an educational tool for fostering CT skills. The Wilcoxon Signed-Rank Test results elucidate a substantial difference in CT competencies as evidenced by pretest and posttest evaluations, indicating the potential efficacy of the VR intervention. This segment examines the data to interpret the impact of the game mechanics and immersive VR environment on the participants' CT abilities. We align our findings with the broader narrative of digital learning, drawing on the theoretical underpinnings of CT education and the empirical evidence from prior research in the field. The focus is to contextualize the significance of these findings in contributing to the evolving landscape of educational technologies and instructional methods, particularly in CT skills development.

The findings from the present study provide evidence for the efficacy of the CT Saber VR game as a pedagogical tool in enhancing CT skills. The statistically significant improvement in post-test scores suggests that immersive virtual reality environments can be conducive to learning and skill development, in line with Mayer's Cognitive Theory of Multimedia Learning, which posits that rich multimedia environments can enhance learning by providing multiple channels for information processing [24].

The implications of these results are multifaceted. Firstly, the study contribute to the burgeoning field of educational technology by supporting the integration of VR gaming as an effective instructional strategy, especially in disciplines that require abstract and systematic thinking. Secondly, these findings hold practical significance for educators and curriculum developers seeking innovative methods to teach complex cognitive skills. The ability of CT Saber to engage learners in an active and experiential learning process showcases the potential of VR to facilitate higher-order thinking skills.

Underlying these implications is the theoretical mechanism supported by the Cognitive Load Theory, which argues that learning is optimized when cognitive resources are efficiently used [25]. The CT Saber game's mechanics, requiring players to strategize and make rapid decisions, may have facilitated cognitive schema formation, thereby fostering CT skills without overloading the learners' cognitive capacities. Furthermore, the constructivist learning theory, which emphasizes learning as an active, constructive process, is echoed in the game's design, which allows learners to construct knowledge through interactive problem-solving tasks, reinforcing the connection between educational theory and the observed outcomes of the study.

While yielding insightful results regarding the efficacy of the CT Saber VR game in fostering CT skills, the present study has limitations. One of the primary constraints is the sample size, which, although adequate for initial explorations, may not fully represent the diverse populations that could benefit from such educational interventions. Additionally, the study’s scope is limited by the singular use of the VR platform, which may not account for the variance in technological familiarity among different demographic groups. This focus on a specific VR device also narrows the generalizability of the findings to similar environments and user experiences.

Further research is suggested to expand the demographic inclusivity of the sample, potentially providing a broader understanding of the CT Saber VR game's impact across various age groups, educational backgrounds, and technological proficiencies. Future studies could also benefit from a longitudinal design, assessing the retention of CT skills over time post-intervention, which was beyond the scope of the current study. Moreover, comparing the VR-based learning approach with traditional or alternative educational methods could yield richer insights into the optimal contexts and conditions for teaching CT concepts. Finally, qualitative data, such as participant feedback and observational notes, would complement the quantitative data, offering a more nuanced perspective on the user experience and the learning process within the VR environment.

D. Conclusion

The investigation into the CT Saber VR game's impact on CT abilities has culminated in several noteworthy conclusions. The statistical analysis, conducted through the Wilcoxon Signed-Rank Test due to the non-normal distribution of the data, has indicated a significant effect of the game on participants' CT skills. This suggests that engaging with the VR environment of CT Saber can effectively enhance certain aspects of CT. The incorporation of elements from the Bebras Challenge into the game's design is particularly promising, as it appears to contribute to the observed improvement in CT abilities. However, it is important to acknowledge the study's limitations, including its sample size and the use of a single type of VR device, which may influence the extent to which these findings can be generalized.

In light of these results, it can be inferred that VR technology has the potential to serve as a valuable tool in the realm of educational interventions aimed at developing CT skills. CT Saber demonstrates the viability of using game-based learning to not only engage learners but also to deliver educational content in a manner that is both effective and enjoyable. Future research should continue to explore this avenue, expanding on the diversity of participants and examining long-term learning outcomes to fully ascertain the educational value of VR in fostering essential 21st-century skills.

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