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STRENGTHENING THE CULTURE OF COMPUTATIONAL THINKING THROUGH VR GAME-BASED LEARNING IN VOCATIONAL HIGH SCHOOLS

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Abstract

Computational Thinking (CT) is an essential competence for students in vocational education to support problem-solving, systematic thinking, and adaptability to workplace demands. However, the development of CT in vocational high schools is often limited to technical instruction and has not been fully integrated into students' learning culture. This study aims to examine the role of Virtual Reality (VR) Game-Based Learning in strengthening the culture of computational thinking among vocational high school students. The study focuses on how VR-based game learning activities foster habitual patterns of logical, systematic, and problem-solving thinking within vocational classroom practices. Using a qualitative descriptive approach through classroom observations, analysis of learning activities, and student reflections, this research explores changes in student engagement, learning interactions, and thinking habits during the implementation of VR Game-Based Learning. The findings indicate that VR-based games create an immersive and contextual learning environment that encourages active participation, collaboration, and sustained engagement, contributing to the formation of a computational thinking culture relevant to vocational learning contexts. This study suggests that VR Game-Based Learning can function as an effective pedagogical practice to support the development of a positive learning culture aligned with the needs of vocational education.

INTRODUCTION

The rapid development of digital technologies has significantly transformed educational practices worldwide, demanding new competencies that extend beyond traditional academic knowledge. In the context of 21st-century education, schools are increasingly expected to cultivate higher-order thinking skills, adaptability, and problem-solving abilities that enable students to navigate complex and technology-driven environments. One of the most prominent competencies highlighted in recent educational discourse is Computational Thinking (CT), which has been recognized as a foundational skill applicable across disciplines and educational levels (Liu et al., 2024; Sukirman et al., 2022). Rather than being limited to computer science or programming, CT represents a way of thinking that emphasizes logical reasoning, decomposition of problems, pattern recognition, abstraction, and algorithmic thinking, all of which are essential for addressing real-world challenges.

In vocational education, particularly in Vocational High Schools, the relevance of computational thinking becomes even more pronounced. Vocational students are prepared to enter professional and industrial environments that increasingly rely on automation, digital systems, and data-driven decision-making. As a result, vocational education is no longer focused solely on procedural or technical skills, but also on developing students' cognitive flexibility and systematic thinking abilities (Maulina & Khusna, 2024). CT supports vocational learners in understanding workflows, diagnosing problems in technical systems, and designing efficient solutions, aligning closely with workplace demands. However, despite its importance, the integration of computational thinking into vocational learning practices remains inconsistent and often fragmented.

Recent studies indicate that CT instruction in schools frequently emphasizes technical mastery rather than the cultivation of a learning culture that supports habitual computational thinking (Liu et al., 2024). In many cases, CT is introduced as an isolated topic or short-term intervention, which limits students' opportunities to internalize computational ways of thinking as part of their daily learning practices (Lathifah et al., 2023). This issue is particularly evident in vocational classrooms, where instructional time is often dominated by competency-based training and task completion, leaving little space for reflective and exploratory thinking processes. Consequently, students may demonstrate short-term gains in CT-related tasks without developing sustained thinking habits that reflect a true computational thinking culture.

The concept of learning culture plays a crucial role in addressing this challenge. Learning culture refers to the shared values, practices, interactions, and habits that shape how learning occurs within a classroom or school environment. In the context of computational thinking, a CT-oriented learning culture emphasizes continuous problem-solving, collaboration, reflection, and experimentation rather than rote procedures. According to contemporary educational research, the development of such a culture requires pedagogical approaches that actively engage students and allow them to experience thinking processes in meaningful and contextualized ways (Videnovik et al., 2023)

One instructional approach that has gained increasing attention for its potential to foster active and meaningful learning is Game-Based Learning (GBL). GBL integrates game elements such as challenges, feedback, goals, and narratives into educational contexts, promoting student motivation and engagement. Recent reviews highlight that game-based learning environments can support higher-order thinking skills by encouraging learners to experiment, fail safely, and iteratively refine their strategies (Videnovik et al., 2023). When applied to computational thinking, GBL allows students to practice decomposition, pattern recognition, and algorithmic reasoning within playful yet structured problem scenarios (Giannakoulas & Xinogalos, 2024).

Beyond traditional digital games, Virtual Reality (VR) has emerged as a powerful extension of game-based learning due to its immersive and interactive characteristics. VR technology enables learners to experience simulated environments that closely resemble real-world contexts, allowing for embodied and experiential learning (Handoko et al., 2024). Recent studies emphasize that VR-based learning environments can enhance students' sense of presence, engagement, and motivation, which are critical factors in sustaining learning cultures (Marougkas et al., 2023). Through immersion, VR allows students to interact with learning content in spatial and contextual ways that are difficult to achieve through conventional classroom instruction.

In vocational education, VR has been increasingly explored as a tool for simulating workplace environments, technical systems, and procedural tasks. These simulations provide students with opportunities to practice skills in safe and controlled settings while developing conceptual understanding. However, recent research suggests that the pedagogical potential of VR extends beyond skill training to include the development of thinking skills such as problem solving, critical thinking, and computational thinking (Faresta et al., 2024; Sukirman et al., 2024). By embedding CT challenges within VR game-based scenarios, educators can encourage students to engage in complex reasoning processes while remaining motivated and actively involved.

Several recent studies have demonstrated the effectiveness of VR-based learning in enhancing computational thinking outcomes. Sukirman et al. (2024), for example, reported that VR gaming environments designed around CT principles significantly improved students' abilities to analyze problems and construct logical solutions. Similarly, low-cost VR learning environments have been shown to promote CT engagement among students by providing accessible and interactive experiences that do not require advanced technological infrastructure (Jasruddin et al., 2025). These findings indicate that VR game-based learning holds promise as an inclusive and scalable pedagogical approach.

Nevertheless, much of the existing research focuses on learning outcomes rather than on the broader cultural dimensions of learning. While improvements in test scores or CT performance are valuable, they do not fully capture how students internalize computational ways of thinking as part of their learning identity. In vocational high schools, where learning is closely tied to professional identity formation, it is essential to understand how instructional innovations influence students’ thinking habits, classroom interactions, and learning behaviors over time (Maulina & Khusna, 2024).

From a cultural perspective, VR game-based learning may contribute to the formation of a computational thinking culture by reshaping classroom dynamics. Immersive VR games often require students to collaborate, communicate, and negotiate solutions, fostering social interaction and shared problem-solving practices. These interactions align with the values of vocational education, which emphasize teamwork, adaptability, and practical problem-solving. Research in educational technology suggests that such interactive environments can shift the role of teachers from information transmitters to facilitators of learning, further reinforcing a learner-centered culture (Marougkas et al., 2023; Rodríguez, 2024).

Moreover, VR game-based learning supports learning by doing, a pedagogical principle strongly associated with vocational education. Through experiential engagement, students are encouraged to explore multiple solution paths, reflect on their actions, and refine their strategies—key processes in computational thinking. Faresta et al. (2024) highlight that immersive technologies can foster reflective thinking by allowing learners to visualize abstract processes and observe the consequences of their decisions in real time. Such experiences can help students develop a deeper understanding of computational concepts and integrate them into their habitual ways of thinking.

Despite these promising findings, there remains a significant research gap regarding the role of VR game-based learning in shaping computational thinking culture specifically within vocational high school contexts. Existing studies often address VR, CT, or vocational education separately, with limited attention to how these elements interact to influence learning culture. Additionally, many studies are conducted in higher education or general secondary education settings, leaving vocational high schools underrepresented in the literature (Liu et al., 2024; Videnovik et al., 2023).

Given the mission of vocational education to prepare students for complex and evolving work environments, it is crucial to explore pedagogical approaches that not only develop technical competencies but also foster sustainable thinking habits. Strengthening a culture of computational thinking requires instructional practices that are engaging, contextualized, and aligned with students’ professional aspirations. VR game-based learning offers a promising avenue for achieving this goal by integrating immersive technology with pedagogical strategies that emphasize active learning and reflection.

Therefore, this study aims to investigate how VR Game-Based Learning can contribute to the strengthening of a culture of computational thinking among vocational high school students. Rather than focusing solely on cognitive outcomes, this research examines learning practices, classroom interactions, and students’ thinking habits during the implementation of VR-based game learning activities. By adopting a qualitative and practice-oriented perspective, this study seeks to provide insights into how immersive technologies can support the development of positive learning cultures in vocational education. The findings are expected to contribute to the growing body of literature on educational innovation while offering practical implications for teachers and schools seeking to integrate computational thinking into vocational learning environments in meaningful and sustainable ways.

METHODS

This study employed a qualitative descriptive research design to examine how the implementation of VR Game-Based Learning strengthens the culture of computational thinking in vocational high school settings. A qualitative approach was chosen to capture students' learning behaviors, thinking habits, and classroom interactions, which are central to understanding learning culture beyond measurable outcomes.

The research was conducted at **SMK Negeri 5 Surakarta**, involving three classes of students from the Software and Game Development (**Pengembangan Perangkat Lunak dan Gim**) program. These students were selected using purposive sampling due to the relevance of their field of study to computational thinking and digital learning practices. The study was carried out during regular instructional sessions in 2nd semester in the year of 2025.

The learning intervention involved the implementation of VR Game-Based Learning activities designed to engage students in problem-solving scenarios that reflect core elements of computational thinking, such as logical reasoning, decomposition, and decision-making. The activities were integrated into classroom instruction and conducted over several learning sessions, allowing students to experience repeated exposure to computational thinking practices within an immersive virtual environment.

Data were collected through classroom observations, student reflections, teacher interviews, and learning artifacts. Classroom observations focused on students' engagement, collaboration, and problem-solving behaviors during VR-based activities. Student reflections were used to capture learners' perceptions of their thinking processes, while teacher interviews provided insights into changes in classroom dynamics and learning culture. Learning artifacts, including task records and reflection notes, supported the triangulation of data.

Data analysis was conducted using thematic analysis, in which qualitative data were coded and grouped into themes related to computational thinking culture, such as systematic problem-solving, collaboration, engagement, and reflective thinking. To ensure trustworthiness, data triangulation and member checking with the teacher were employed. Ethical considerations were observed by obtaining informed consent, ensuring voluntary participation, and maintaining participant anonymity throughout the study.

RESULTS AND DISSCUSSION

RESULTS

Implementation of VR Game-based Learning Activities

The research activities began with the implementation of VR Game-Based Learning in three classes of the Software and Game Development (Pengembangan Perangkat Lunak dan Gim) program. Prior to the core activities, students were introduced to the learning objectives, basic concepts of computational thinking, and instructions for using the VR equipment. This initial phase aimed to ensure that students understood both the purpose of the activity and the rules of interaction within the virtual environment.

Figure 1. The implementation of VR Game-based learning for Vocational Student

During the core learning activities, students participated in VR-based game scenarios that required them to solve problems through logical reasoning, step-by-step planning, and decision-making. Due to the limited number of VR devices, students took turns using the equipment, while others observed, discussed strategies, and provided feedback. Classroom documentation shows students actively engaging with the VR environment, collaborating with peers, and demonstrating high levels of focus during the learning process.

The implementation phase was conducted over several learning sessions, allowing students to repeatedly engage with VR game-based tasks. This repetition enabled students to become more familiar with the learning approach and gradually adapt their thinking strategies when facing increasingly complex challenges.

Increased Student Engagement during Learning Activities

Observations during the implementation revealed a significant increase in student engagement compared to conventional classroom instruction. Students showed enthusiasm, curiosity, and sustained attention throughout the VR-based sessions. Even students who were not directly using the VR equipment remained involved by observing gameplay, discussing possible solutions, and anticipating outcomes.


Figure 2. Students' active engagement

Photographic documentation on Fig. 2 illustrates students' active participation, including their focus while using VR devices and their involvement in peer discussions. Student reflections further indicated that the immersive nature of VR made learning activities more interesting and motivating. This heightened engagement contributed positively to the classroom learning atmosphere and supported the formation of an active learning culture.

Development of Systematic Problem-solving practices

During VR game-based learning activities, students demonstrated increasingly systematic approaches to problem solving. Observations showed that students began to analyze problems by identifying objectives, breaking tasks into smaller steps, and testing solutions sequentially. When an approach failed, students revised their strategies rather than repeating the same actions.

These behaviors reflect core components of computational thinking, particularly decomposition and algorithmic reasoning. Student reflections revealed that learners became more aware of the importance of planning and logical sequencing. Repeated exposure to problem-solving scenarios in the VR environment encouraged students to adopt structured thinking habits that extended beyond the game context.

This observation is further supported by the results of structured classroom observations and in-game performance indicators, as summarized in Table 1. The findings show that students achieved high observation scores in problem identification, task decomposition, and sequential strategy execution, with average ratings above 4.3 on a five-point scale. The highest score was observed in strategy revision (4.6), indicating that students consistently adjusted their approaches after unsuccessful attempts rather than persisting with ineffective strategies.

Table 1. Observation and Game Performance results on Systematic Problem-solving practices

No	Indicator	Observation Description	Average Score/Level
1	Problem Identification	Students were able to recognize goals and constraints in VR game scenarios before taking action	High (4.4 / 5)
2	Task Decomposition	Students broke complex challenges into smaller, manageable steps during gameplay	High (4.3 / 5)
3	Sequential Strategy Execution	Students applied step-by-step actions rather than random trial-and-error	High (4.5 / 5)
4	Strategy Revision	Students modified their approach after failure instead of repeating the same actions	High (4.6 / 5)
5	Game Level Completion Accuracy	Percentage of tasks completed with correct sequence and logic	82%
6	Error Reduction Across Attempts	Decrease in errors between first and final attempts within a session	Moderate–High (≈30% reduction)

In addition, game performance data revealed that approximately 82% of VR game tasks were completed with correct logical sequences, while errors decreased by an estimated 30% across repeated attempts within the same learning session. These results suggest that students increasingly relied on systematic reasoning instead of trial-and-error approaches. The combination of observational and performance-based evidence indicates that VR game-based learning effectively supported the development of structured problem-solving practices aligned with computational thinking principles.

Strengthened peer interaction and collaboration learning

The research activities also fostered collaborative learning among students. Although VR gameplay was often individual, peer interaction was consistently observed before, during, and after the activities. Students exchanged ideas, suggested alternative strategies, and collectively reflected on problem-solving outcomes.

Figure 3. Student engagement through active disscussion

Photographs from the classroom sessions show students engaging in group discussions while waiting for their turn with the VR equipment. This collaborative behavior contributed to the development of a shared computational thinking culture, where reasoning and problem-solving were practiced collectively. Teacher interviews supported this observation, noting increased student participation and communication during VR-based learning sessions.

Increased Persistence and Positive Attitudes Towards Errors

Another key result observed during the research activities was an increase in students' persistence and willingness to learn from mistakes. The VR game environment allowed students to experience failure without negative consequences, encouraging them to try alternative solutions. Students were observed making multiple attempts to solve challenges, adjusting their strategies based on feedback from the virtual system.

Student reflections indicated that they perceived errors as part of the learning process rather than as failures. This shift in attitude supported a more resilient and growth-oriented learning culture, which is essential for developing sustainable computational thinking habits in vocational education.

Emergence of Reflective Thinking through Post-Activity Discussions

Following each VR game-based learning session, students participated in guided reflection activities. During these discussions, students explained their reasoning, identified challenges they encountered, and evaluated the effectiveness of their problem-solving strategies. These reflection sessions encouraged students to articulate their thinking processes and connect their experiences in the virtual environment to broader learning concepts.

Teacher feedback indicated that students became more confident in expressing their ideas and reasoning over time. The emergence of reflective thinking suggests that VR game-based learning not only supported active engagement but also facilitated deeper cognitive processing and internalization of computational thinking practices.

DISSCUSSION

This study aimed to explore how VR Game-Based Learning contributes to strengthening a computational thinking culture among vocational high school students. The findings indicate that the integration of VR-based learning activities does not merely function as a technological enhancement, but also plays a meaningful role in shaping students' thinking habits, learning behaviors, and attitudes toward problem solving. The discussion below interprets these findings in relation to existing theories and recent studies on computational thinking, game-based learning, and immersive learning environments.

VR Game-Based Learning as a Medium for Cultivating Computational Thinking Culture

The results demonstrate that VR Game-Based Learning effectively supported the development of systematic problem-solving practices, which are central to computational thinking. Students consistently engaged in identifying problems, decomposing tasks, executing sequential strategies, and revising their approaches based on feedback. These behaviors align closely with established computational thinking frameworks that emphasize decomposition, algorithmic thinking, and iterative problem solving.

Unlike traditional instructional methods that often emphasize correct answers, the VR game environment encouraged students to focus on the process of thinking. The immersive and interactive nature of VR required students to actively engage with problems rather than passively receive information. This finding supports the notion that computational thinking is best developed through experiential learning environments where learners are repeatedly exposed to authentic problem-solving situations.

From a cultural perspective, the repeated engagement with VR-based challenges contributed to the formation of habitual ways of thinking. Computational thinking was not treated as an isolated skill but became embedded in students' learning routines. This supports the idea that learning culture is shaped not only by curriculum content, but also by the learning environments and pedagogical practices experienced by students.

Systematic Problem Solving Beyond Trial-and-Error

One notable finding of this study is the shift from random trial-and-error behaviors toward more structured and reflective problem-solving strategies. Observation data and game performance indicators showed that students increasingly revised their strategies after failure rather than repeating ineffective actions. This behavior reflects the development of metacognitive awareness, where students monitor and evaluate their own thinking processes.

In the context of vocational education, this finding is particularly significant. Students in the Software and Game Development program are expected to develop logical reasoning and debugging skills, which require persistence and systematic analysis. The VR game-based learning environment provided a safe space for students to experiment, fail, and improve without fear of negative evaluation. As a result, errors were reframed as part of the learning process rather than as indicators of incompetence.

This aligns with recent research suggesting that game-based and immersive learning environments support iterative learning processes and promote resilience in problem solving. The reduction of errors across repeated attempts observed in this study further indicates that students internalized structured thinking strategies through continued interaction with the VR environment.

Individual Learning and the Internalization of Computational Thinking

Although game-based learning is often associated with collaboration, this study demonstrates that individual VR learning activities can also effectively foster computational thinking. By engaging individually with VR game scenarios, students were required to rely on their own reasoning, decision-making, and reflection. This individual engagement appears to support deeper internalization of computational thinking processes.

The findings suggest that individual VR-based learning encourages students to take ownership of their thinking strategies. Reflection activities conducted after gameplay further reinforced this internalization, as students articulated their reasoning and evaluated the effectiveness of their approaches. This process aligns with constructivist learning theories, which emphasize that knowledge is actively constructed through personal experience and reflection.

In vocational school settings, where individual competency development is essential, this approach offers a valuable pedagogical alternative. VR Game-Based Learning enables students to practice problem solving independently while still benefiting from immersive and engaging learning experiences.

Implications for Learning Culture in Vocational High Schools

The findings of this study highlight the potential of VR Game-Based Learning to influence learning culture beyond short-term engagement. Increased persistence, systematic reasoning, and reflective thinking indicate a shift toward a learning culture that values process, logic, and continuous improvement. Such a culture is highly relevant to vocational education, particularly in fields related to software development and digital technology.

Teachers play a crucial role in facilitating this cultural shift. The structured implementation of VR activities, combined with guided reflection, helped students connect their gameplay experiences to broader learning objectives. This suggests that technology alone is insufficient; pedagogical design and teacher facilitation remain central to fostering meaningful learning cultures.

Limitations and Future Research Directions

Despite its contributions, this study has several limitations. The research was conducted in a single vocational high school with a limited number of classes, which may affect the generalizability of the findings. In addition, the study relied primarily on observational and descriptive data rather than experimental or longitudinal designs.

Future research could explore the long-term impact of VR Game-Based Learning on computational thinking development, compare individual and collaborative VR learning models, or examine its effectiveness across different vocational disciplines. Quantitative studies involving pre- and post-tests may also provide deeper insights into learning outcomes.

SIMPULAN

This study concludes that VR Game-Based Learning plays a meaningful role in strengthening a computational thinking culture among vocational high school students, particularly in the Software and Game Development program at SMK Negeri 5 Surakarta. The findings indicate that the integration of VR-based learning activities supports the development of systematic problem-solving practices, persistence, engagement, and reflective thinking, which are core components of computational thinking.

The immersive nature of VR game-based environments encourages students to actively engage with learning tasks and to approach problems through structured and logical strategies. Rather than relying on trial-and-error, students demonstrated increased awareness of planning, step-by-step execution, and strategy revision when facing challenges. These behaviors suggest that computational thinking was not only practiced as a skill but also internalized as a habitual way of thinking within the learning process.

From a cultural perspective, the repeated implementation of VR Game-Based Learning contributed to the formation of positive learning habits that emphasize process, logic, and continuous improvement. This indicates that computational thinking can be effectively embedded into vocational learning culture when supported by appropriate pedagogical design and reflective activities.

Despite these positive outcomes, this study is limited to a specific vocational school context and relies on qualitative observational data. Therefore, future research is recommended to explore the long-term impact of VR Game-Based Learning on computational thinking development, to involve larger and more diverse samples, and to incorporate quantitative or mixed-method approaches for deeper analysis.

Overall, this study highlights the potential of VR Game-Based Learning as an innovative instructional approach to support computational thinking culture in vocational high schools, aligning learning practices with the cognitive and professional demands of digital-era education.

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