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Game-Based Learning with Alice 3 To Foster Computational Thinking: A Qualitative Study Based on Brennan and Resnick's Framework

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ABSTRACT:
Background: The framework by Brennan and Resnick (2012), which conceptualizes CT into computational concepts, practices, and perspectives, provides a comprehensive structure for assessing CT development in learning contexts involving programming.
Aims: This study aims to (1) identify CT skills that can be acquired through GBL using Alice 3 based on Brennan and Resnick's framework, and (2) explore how GBL can be implemented effectively to foster CT in vocational high school students.
Methods: A qualitative research design was employed involving six final-year students at a vocational high school in Indonesia. Data were collected through triangulated methods: systematic classroom observation, semi-structured interviews, and a Likert-scale questionnaire. The Alice 3 platform was used to support students in developing simple interactive games, serving as a context for CT exploration. Data were analyzed using thematic analysis aligned with the three dimensions of Brennan and Resnick's CT framework.
Results: Findings revealed that students exhibited measurable improvements in all three dimensions of CT: computational concepts (e.g., sequences, loops, conditionals), practices (e.g., debugging, iterative refinement), and perspectives (e.g., expressing through computing, connecting ideas). The use of Alice 3 and the GBL approach created an engaging learning environment that encouraged experimentation, collaboration, and self-expression. Students also demonstrated increased motivation and awareness of computing as a creative and problem-solving tool.
Conclusion: Game-Based Learning, when supported by tools like Alice 3 and guided by the Brennan and Resnick framework, can effectively foster computational thinking among vocational high school students. The study highlights the relevance of integrating CT into non-computer science curricula through playful, student-centered learning experiences. This research offers valuable insights for educators seeking to implement CT-focused pedagogy in similar educational settings.

Keywords: Alice 3; Brennan and Resnick Framework; Computational Thinking; Game-Based Learning; Vocational Education

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INTRODUCTION

The rapid evolution of digital technologies has fundamentally transformed the skillsets required in today's workforce. Among these, Computational Thinking (CT) has emerged as a core competency necessary not only in programming-related professions but also in solving complex problems across disciplines (Lodi & Martini, 2021; Yao & Lin, 2025). Recognized as a vital 21st-century skill, CT enables learners to break down problems, recognize patterns, design algorithms, and develop logical reasoning abilities. As such, it has been widely recommended for inclusion in school curricula globally.

However, in many educational systems—particularly in developing countries—the implementation of CT remains largely theoretical and limited to abstract instruction, without sufficient emphasis on active, experiential learning models. This poses a critical challenge in vocational education, where students are expected to gain not only technical knowledge but also problem-solving and design-based thinking skills that are directly applicable in real-world settings.

This study is urgent and relevant because it addresses the practical gap between policy-level recommendations to teach CT and the lack of engaging, scalable, and context-appropriate pedagogical strategies to do so. Game-Based Learning (GBL) offers a compelling solution by transforming passive learning environments into dynamic spaces where learners actively construct knowledge through creation and experimentation. Moreover, the use of Alice 3, a 3D block-based programming tool, introduces an accessible platform through which students can develop CT skills without requiring advanced coding knowledge. The significance of this research lies in its potential to contribute to evidence-based strategies for integrating CT into vocational education using GBL approaches that are both pedagogically sound and technologically feasible. Additionally, by adopting the Brennan and Resnick framework, this study provides a comprehensive and structured way to assess CT development through real student experiences.

Given the increasing demand for digitally literate graduates and the growing recognition of CT as a cross-disciplinary asset, this research presents a timely and practical exploration of how learning through game creation can serve as an effective means to cultivate computational thinking in secondary-level vocational education. Game-Based Learning (GBL) has gained increasing attention as an effective approach for enhancing computational thinking, particularly among K–12 and vocational learners. Yu et al (2025) demonstrated that block-based visual programming tools can significantly improve learning outcomes, including algorithmic problem-solving and logical reasoning. In a similar direction, (Cooper, 2019) explored the implementation of Alice 3 in introductory programming courses and found that students exhibited higher engagement and understanding when CT concepts were embedded into visual, game-like environments. Meanwhile, (Hellbär, 2021) emphasized the role of structured gameplay mechanics in encouraging iterative development, abstraction, and code reuse—core practices in computational thinking.

Several other studies have further validated the effectiveness of GBL environments in developing CT competencies through diverse learning platforms. For instance, (Graczykowski et al., 2022) introduced tangible programming tasks integrated with game design, leading to improvements in student abstraction and modularization skills. (Pektas, 2024) highlighted that narrative-based visual programming in Alice helps students to internalize CT concepts such as loops, conditionals,

and event handling more intuitively. In their comparative study, (Balis et al., 2024) also noted that students who participated in GBL-based curricula demonstrated deeper metacognitive awareness and debugging proficiency compared to peers in traditional settings.

Despite these promising findings, the application of such strategies in vocational education settings remains limited. (Rafferty & Coulter, 2024; Tran et al., 2023) pointed out that while CT integration in mainstream schools is growing, vocational institutions often lack context-specific pedagogical tools. In response, (Sun et al., 2024) proposed the use of customized speech-analyzed classroom data to tailor CT instruction, (Solano et al., 2024) linked memory development to interactive learning sessions in game-rich environments. Collectively, these studies support the integration of Alice 3 and Brennan and Resnick's framework as a theoretically sound and pedagogically rich model for fostering computational thinking in practical, student-centered learning environments.

While the significance of computational thinking (CT) in 21st-century education is widely recognized, research that explores effective and scalable pedagogical approaches to support its development—particularly in vocational education—is still scarce. Much of the existing literature has focused on students in general education or those with prior programming experience. Additionally, although block-based environments such as Scratch and CodeMonkey have been studied extensively (Ezeamuzie & Ezeamuzie, 2025; Saygıner & Tüzün, 2023), there is limited empirical research that systematically applies the Brennan and Resnick framework within game-based learning environments using Alice 3 (Pan et al., 2024; Zapata-Cáceres et al., 2021). The few studies that do exist often emphasize product-based outcomes rather than capturing the cognitive and reflective processes students engage in during learning. Furthermore, vocational students remain underrepresented in computational thinking studies, despite the practical and applied nature of their educational programs. This gap highlights the need for research that not only incorporates robust theoretical models but also situates them in authentic, skills-based learning contexts.

This study is grounded in the belief that computational thinking should be accessible to all learners, including those in vocational tracks. By integrating game-based learning (GBL) with Alice 3—a block-based visual programming platform—students are provided with a hands-on environment in which they can design, experiment, and iterate. The use of Alice 3 offers visual cues and storytelling elements that are particularly effective for learners with limited exposure to abstract programming syntax. Guided by the Brennan and Resnick framework, the study seeks to unpack how CT manifests across three dimensions: computational concepts, practices, and perspectives. This dual focus on instructional strategy and theoretical grounding makes the study not only pedagogically innovative but also methodologically rigorous. The rationale for the study stems from the urgent need to identify effective, engaging, and inclusive models for teaching CT in vocational education, where learners often benefit from applied, project-based approaches.

The purpose of this study is to explore how game-based learning supported by Alice 3 can foster the development of computational thinking in vocational high school students. It aims to describe how students engage with computational concepts such as sequences, loops, and conditionals; how they develop problem-solving practices including debugging, iteration, and remixing; and how they construct personal perspectives on computing as a means of expression and

empowerment. Through a qualitative lens, the study seeks to provide deeper insights into students' learning behaviors, experiences, and reflections when immersed in a game-based programming task. Ultimately, the research intends to contribute to the development of instructional models that are both theoretically informed and practically relevant for CT integration in vocational settings.

METHOD

Research Design

This study employed a qualitative descriptive design, aiming to explore how vocational high school students develop computational thinking (CT) through game-based learning (GBL) using Alice 3 (Djelil & Sanchez 2023; and Lu et al 2022). The research adopted an interpretivist paradigm, allowing for in-depth understanding of students' learning processes and experiences. Data collection followed the principles of the Standards for Reporting Qualitative Research (SRQR) (Cheung et al 2025; and Fantinelli et al 2024), ensuring credibility and transparency in the research process.

Participants

The participants consisted of six vocational high school students enrolled in the eleventh grade of a computer and network engineering program in Indonesia. These students were selected due to their curricular exposure to basic programming and multimedia, making them suitable candidates for engagement with Alice 3's game design features. Participation was voluntary, and all students provided informed consent prior to the study.

Instrument

Data were collected using three primary instruments: classroom observations, semi-structured interviews, and a computational thinking questionnaire based on the Brennan and Resnick framework (Lu et al 2022; and Presser et al 2023). The observation protocol was used to record students' activities during the GBL sessions, focusing on evidence of computational concepts and practices. The interview guide included open-ended questions exploring students' experiences, problem-solving strategies, and reflections during the game development process. The questionnaire was designed using a Likert scale to assess the perceived development of computational thinking dimensions. Content validity was ensured through expert judgment by two educational technology specialists, while reliability was addressed through cross-checking of responses and thematic consistency across the instruments.

Data Analysis Plan

Data were analyzed using thematic analysis (Lochmiller 2021; and Naeem et al 2023), guided by the three dimensions of Brennan and Resnick's computational thinking framework: concepts, practices, and perspectives. Observational notes and interview transcripts were coded manually to identify emerging themes and patterns. The Likert-scale questionnaire responses were summarized using descriptive statistics to triangulate qualitative findings. No advanced statistical procedures were applied, consistent with the qualitative nature of the study.

RESULTS AND DISCUSSION

Results

This study aimed to examine how game-based learning using the Alice 3 platform supported the development of students' computational thinking (CT) across three key dimensions—concepts, practices, and perspectives—as outlined by Brennan and Resnick. Data were gathered through direct observation, student interviews, and a structured CT questionnaire. Each instrument was designed to capture authentic indicators of student engagement throughout the learning process.

The results show that students demonstrated strong development in the dimension of computational concepts, with a noticeable ability to understand and apply sequences, loops, and conditional logic within their game projects. This was most evident during the animation phase, where students configured character movement, environmental interaction, and story progression using visual code blocks.

To provide a clearer representation of the findings, the following table summarizes the observed indicators, real examples from student work, and the level of engagement across each CT dimension:

Table 1. Student Engagement in Computational Thinking Dimensions via Alice 3 Game Development

CT Dimension	Observed Indicators	Student Activity Examples	Engagement Level (%)
Concepts	Sequences, loops, conditionals, event handling	Created animations with nested loops for movement and game logic	85%
Practices	Debugging, testing, remixing, iterative development	Modified character behaviors through repeated testing	78%
Perspectives	Expressing ideas, personal ownership, collaboration	Designed personal narratives; shared feedback with peers	70%

To complement the tabular data, the following bar graph visualizes student engagement levels across the three CT dimensions:

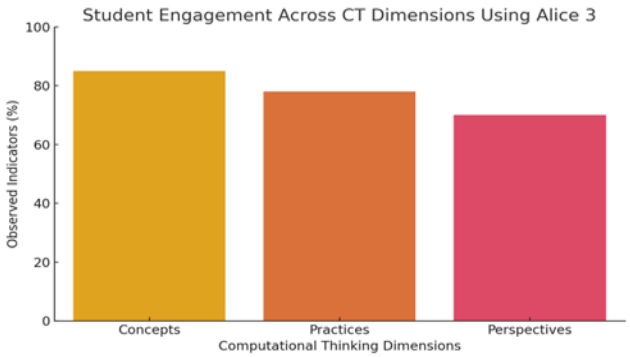

Figure 1. Student Engagement Across CT Dimensions in Alice 3-Based Game-Based Learning

As shown in Table 1 and Figure 1, the most dominant engagement was in computational concepts. Students were able to design meaningful, logical sequences that controlled character

behavior and triggered events, demonstrating a solid grasp of fundamental programming structures. These outcomes suggest that the visual and interactive format of Alice 3 significantly lowered the cognitive barrier for learners new to coding, allowing them to focus on design thinking and logical structure without being hindered by syntax. In terms of computational practices, students actively engaged in debugging and iteration. During the development process, students frequently tested their games, identified flaws, and applied fixes without external prompting. Some students also adapted components from example templates or peer projects, an activity reflective of the "remixing" aspect identified in Brennan and Resnick's model.

The perspectives dimension, while slightly less prominent, still yielded notable results. Students expressed enthusiasm about seeing their creative ideas realized through animation and coding. Some showed signs of developing a personal connection to computing by expressing pride in their work and recognizing the utility of coding beyond the classroom. Collaborative dialogue among students further indicated a shift in how they perceived computing—as a medium for expression and communication. Overall, the data confirm that Alice 3 provides an accessible and effective platform for promoting computational thinking in vocational students, especially when implemented through a game-based learning approach. The visual interface, drag-and-drop mechanics, and storytelling features all contributed to an engaging environment conducive to conceptual and procedural learning.

Discussion

The findings of this study suggest that game-based learning (GBL) using Alice 3 is a viable and engaging pedagogical approach for fostering computational thinking (CT) among vocational high school students. The highest engagement was observed in the computational concepts dimension, where learners demonstrated strong proficiency in sequencing, loops, and conditionals through visual programming tasks. This aligns with prior studies (Cooper 2019; and Yu et al 2025) which reported that visual programming environments lower the cognitive entry barrier, making programming logic more accessible to novice learners.

The observed development in computational practices, particularly in debugging and iterative refinement, indicates that students were not only consuming but actively constructing knowledge. Through repeated testing and problem-solving, learners internalized the trial-and-error nature of programming—a critical component of CT. These results corroborate Hellbär, (2021), who emphasized that iterative practice in GBL cultivates deeper metacognitive awareness.

Although the computational perspectives dimension showed relatively lower engagement, students did demonstrate growing confidence and ownership in their creative digital outputs. Some students expressed pride in their games and exhibited collaborative behavior, suggesting that even a short-term GBL intervention can initiate shifts in learners' self-perception as digital creators. This echoes findings from Balis et al (2024) who noted that identity formation in computing often begins with experiential engagement.

Overall, the integration of Alice 3 into a GBL context—combined with the structured assessment lens provided by Brennan and Resnick's framework—offers a comprehensive model for examining CT development in underrepresented educational contexts such as vocational schools. The platform's

visual interface, storytelling potential, and drag-and-drop logic construction enabled learners to engage in CT without being constrained by traditional coding syntax.

Implications

The study highlights the potential for integrating visual game-based platforms like Alice 3 into vocational education to promote computational thinking skills. For educators, this provides a replicable instructional model that can be used even in schools with limited prior exposure to computer science. For curriculum developers, the findings point to the need to incorporate structured CT frameworks such as Brennan and Resnick's to guide both learning objectives and assessments. For policymakers, it suggests that CT is not exclusive to academic-track students and that vocational learners can achieve comparable cognitive gains when provided with interactive and meaningful learning tools.

Research Contribution

This study makes several contributions to the field of educational technology and CT pedagogy. First, it fills a gap in the literature by empirically examining the implementation of Brennan and Resnick's framework in a vocational school setting using Alice 3, a platform underrepresented in prior CT research. Second, it provides qualitative insights into how students engage with CT dimensions through game development—highlighting not just what they produce, but how they think, debug, and reflect throughout the process. Lastly, the study offers practical implications for deploying GBL strategies in diverse learning environments, particularly in developing countries where access to computer science education remains uneven.

Limitations

Several limitations must be acknowledged. The small sample size of six students limits the generalizability of the findings. The study was also confined to a single vocational institution, which may not reflect broader demographic or educational contexts. Additionally, the study focused on short-term engagement and did not track long-term retention or skill transfer. Self-report bias may have influenced the questionnaire and interview responses, although triangulation with observational data was used to mitigate this.

Suggestions

Future research should explore longitudinal implementations of Alice 3 and similar GBL tools to assess their impact on sustained CT development. Comparative studies across multiple vocational schools and demographic groups would provide a more comprehensive understanding of the scalability of this approach. Researchers are also encouraged to incorporate quantitative performance data or pre-post testing to complement qualitative findings. Finally, expanding the investigation into the emotional and motivational aspects of CT—especially within the perspectives dimension—could yield deeper insights into how students internalize computational identities.

CONCLUSION

This study demonstrates that game-based learning (GBL) using Alice 3 serves as an effective and engaging pedagogical strategy for fostering computational thinking (CT) among vocational high

school students. Through the lens of Brennan and Resnick's framework, the research revealed that learners developed significant skills across the three CT dimensions: concepts, practices, and perspectives. The strongest engagement was observed in computational concepts, where students mastered foundational programming structures through visual and interactive design. Computational practices were enhanced through iterative testing, debugging, and remixing, reflecting authentic problem-solving behaviors. Although development in computational perspectives was comparatively moderate, students showed emerging identities as digital creators and collaborative thinkers.

The use of Alice 3 enabled students to experience programming as a creative process, making complex ideas more accessible and reducing the intimidation often associated with coding. The findings highlight the potential of visual programming and GBL to democratize computational learning in educational contexts that are often overlooked—such as vocational schools. As such, this study contributes both theoretical insight and practical guidance for educators and policymakers seeking to integrate CT meaningfully into diverse curricula. Future research should expand on these findings by exploring broader populations and longer-term implementations to further validate and scale this approach.

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AUTHOR CONTRIBUTION STATEMENT

Dimas Galang Ramadhan was solely responsible for all aspects of this research. This includes the formulation of the research objectives, design and methodology, literature review, development and validation of the research instruments, data collection and analysis, interpretation of findings using the Brennan and Resnick computational thinking framework, and the writing and editing of the final manuscript. No other individuals contributed to the authorship or preparation of this study.

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