Leveraging Game-Based Learning for Enhanced Knowledge Retention and Collaborative Learning Among Novice Computer Science Students

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Abstract
As novice students start learning the concepts of computer science, they struggle to master the content immediately. Even when they have eventually gained some understanding of the subject matter, students tend to have low knowledge retention, especially as the classroom lessons progress to other chapters. This causes fragmented understanding and poor academic performance. Additionally, the lack of peer cohesion and collaborative engagement hinders the exchange of ideas and subsequently results in limited problem-solving strategies. The literature review strengthens the role of gamification in improving engagement and academic performances and that student engagement and interest are key factors in enhancing learning outcomes. Technology is highlighted as a valuable tool for creating authentic learning environments, diversifying learning experiences, and promoting active learning. This study aims to develop an interactive learning tool that integrates education with play, enhancing conceptual understanding and student engagement while encouraging peer collaboration and underpinning the constructivist framework. The game-based learning model deployed in this study is called 'Tech Traverse', modified from the Snake and Ladder game and the concept of scoresheet adapted from the chess game. A phenomenological qualitative study was conducted where participants answered open-ended questions anonymously via Google Forms. The qualitative data was then analysed thematically to identify common trends, insights, and areas for enhancement in the game design. Four major themes emerged from the data analysis: Learning Experiences, Engagement and Enjoyment, Game Structure and Mechanics, and Collaboration and Teamwork. Study findings state that Tech Traverse has improved information recalling and retention, teamwork, and engagement.

Keywords: game-based learning, novice programmers, collaborative engagement

Introduction

Background of Study

Learning programming presents a significant challenge for novices, particularly in logical thinking and abstraction. Programming is a high-level cognitive activity that demands the ability to manipulate interrelated abstractions and apply logical-verbal reasoning. Many students struggle with immediate content mastery, and even when they grasp fundamental concepts, knowledge retention remains low as lessons progress. This results in fragmented understanding, affecting their ability to apply learned concepts in problem-solving tasks. Additionally, a lack of peer collaboration and interactive learning environments limits knowledge sharing and teamwork, further hindering problem-solving development. The literature highlights gamification as a promising approach to increase motivation, engagement, and learning performance as well as to lower learning barriers (Kucak & Kucak, 2022; Marín et al., 2018; Rojas-López et al., 2019). By incorporating the game elements into education, gamification boosts interaction and creates an effective students-centred learning environment that fosters collaboration, knowledge retention and problem-solving skills. To address these issues and to leverage the game-based learning approach, this study introduces Tech Traverse, a game-based learning tool designed to bridge the gap between conceptual learning and practical application. Inspired by Snakes and Ladders and incorporating scorekeeping mechanics from the chess game, Tech Traverse integrates challenges, rewards, and setbacks to reinforce computational thinking while promoting collaborative engagement. By implementing Tech Traverse within a student-centred, constructivist framework, this study aims to explore how game-based learning can enhance conceptual understanding, problem-solving abilities, and teamwork among novice programming students. Given that student-centred learning has been encouraged in educational institutions to improve student accountability, student engagement, and active learning, Tech Traverse can be implemented to meet the demands of the knowledge and skills learners are expected to obtain. The approach allows students to collaborate, providing them more time to engage in the classroom and thus improving knowledge retention.

Problem Statements

In learning programming languages, students lack peer cohesion and collaborative engagement as teachers spend a substantial amount of time in direct instruction (Peters & Pears, 2013). Consequently, the limited exchange of ideas and problem-solving strategies affects knowledge-building and hinders the development of teamwork and communication skills. Gamification has been found to increase engagement and motivation, and it is increasingly being recognised as an approach for encouraging user involvement, drive, and enjoyment in non-gaming environments. In education, it can foster an engaging learning environment that, when combined with promising instructional approaches, improves the overall student learning experience (Ahmad et al., 2020). However, despite its benefits, many programming courses lack structured gamified approaches that promote concept mastery and peer collaboration. Existing models focus primarily on motivation rather than systematic improvements in retention and problem-solving (Zhan et al., 2022). Tech Traverse has been built to encourage peer interaction through collaborative gameplay, prompting students to work together, share insights, and create a supportive community.

Poor knowledge retention remains another significant challenge among novice programming students, hindering their ability to develop problem-solving skills in computer science (Cheah,

2020). While they may grasp syntax theoretically, they struggle to apply concepts effectively, leading to weak analytical thinking and inefficient solutions. This issue is further compounded by varying levels of prior knowledge, making it difficult for students to achieve conceptual mastery and long-term retention. Foundational knowledge in programming is cumulative. As a result, failure to effectively integrate and retain knowledge jeopardises pupils' long-term academic success. Existing direct instructional methods focus more on content delivery rather than reinforcing retention through active engagement. Gamification in education promotes long-term retention through practical application (Brull et al., 2017; Putz & Treiblmaier, 2019; Smirani & Yamani, 2024). While gamification has been acknowledged as a method to improve student involvement, few studies have examined how well non-digital games work to guarantee greater retention of information. Tech Traverse has been designed to promote continuous revisiting of key ideas, helping students to build a stronger cognitive connection and improve retention.

Research Questions

1. What is the role of Tech Traverse in improving constructive communication and collaboration between peers?
2. How does the implementation of Tech Traverse contribute to strengthening programming knowledge retention among novice programming students?

Research Objectives

Main Objective:

- To relate the implementation of Tech Traverse and the knowledge retention and collaborative learning among the Malaysian Matriculation Programme computer science students

Specific Objectives:

1. To explore the role of Tech Traverse in improving constructive communication and collaboration between peers
2. To discover the contribution of Tech Traverse in strengthening programming knowledge retention among novice programming students
3. To understand the role of Tech Traverse in reducing the stress faced by novice programming students when learning computer programming

Literature Review

Gamification in Programming Education

Gamification is a design method incorporating game elements and frameworks into non-game situations, such as education. Gamification in education tries to use the motivational power of games in educational processes, encouraging students to continue in the face of adversity (Stott & Neustaedter, 2013). By leveraging mechanics like points, challenges, leaderboards, and rewards to encourage participation and persistence, gamification significantly affects students' motivation and academic achievement. Studies have revealed that gamification creates a positive learning atmosphere, contributing to students' interest in learning. Furthermore, gamification promotes active learning by moving the emphasis away from passive instruction and towards an adventurous and immersive learning process. Rewards and progress tracking give students a sense of accomplishment and purpose,

encouraging them to persevere in adversity. Specifically, gamification has been shown to enhance students' programming skills and academic performance (Abdul Rahman et al., 2018; Smirani & Yamani, 2024; Yun et al., 2020). Gamification promotes collaborative learning by fostering peer engagement, knowledge sharing, and teamwork, all of which are required for problem-solving in programming education. The combination of quick feedback and adaptive challenges enables students to reflect on their failures and alter their learning tactics, resulting in greater conceptual understanding.

Collaborative Learning

According to Laal and Ghodsi (2012), Collaborative learning (CL) is a method of teaching and learning in which groups of students work together to solve a problem, accomplish a task, or create a product. This technique emphasises learners being responsible for one another and their learning, so the success of one student encourages others to be successful. The core principle of collaborative learning is centred on consensus building through cooperation among group members rather than rivalry. Academically, it promotes deep learning, critical thinking, and problem-solving by engaging students in active conversations and peer interactions, resulting in increased accomplishment and productivity. CL also improves assessment techniques by providing alternate evaluation methods, encouraging self-reflection, and enabling educators to customise instruction based on group dynamics. Overall, CL improves engagement, performance, and resource accessibility, resulting in a comprehensive educational approach that helps students outside the classroom (Nokes-Malach et al., 2015; Qureshi et al., 2023). Collaborative learning (CL) in programming involves students working together to solve coding challenges, debug programs, and build computational thinking skills. Tech Traverse encourages team-based problem solving, where students analyse difficulties, debug mistakes, and make collective judgements. The game promotes active engagement, communication, and a better knowledge of programming ideas through peer conversation, shared techniques, and interactive gameplay.

Knowledge Retention

Knowledge retention is a learner's ability to remember and apply acquired knowledge over time, allowing for more straightforward recall and practical application of concepts. Gamification, interactive pedagogies, and retrieval-based learning have all been demonstrated to improve retention by reinforcing information with engaging and repetitive tasks (Shuxratovna, 2024). Marín et al. (2018), Nokes-Malach et al. (2015) and Rathna Sekhar & Goud (2024) state that collaborative learning, active participation, and repeated practice all help to improve knowledge retention. Discussing and educating others improves comprehension, whereas real-world applications and retrieval practice improve memory. Gamification and interactive methods engage learners while reinforcing topics through repetition. Observational learning, error correction, and explanation within groups help to cement information. Furthermore, technology facilitates personalised learning, allowing students to advance at their own pace and improve retention. Structured feedback, continuous assessments, and peer evaluations further support long-term retention by enabling learners to reflect on their progress and adjust their learning strategies accordingly. Integrating multimodal learning experiences, such as visual, auditory, and kinesthetic activities, reinforces knowledge through multiple pathways, enhancing recall and practical application.

Method

Research Design

Interpretivism is used in this study to gather feedback on learners' experiences using Tech Traverse. The researcher functions as a social actor, analysing the various viewpoints of participants and reflecting on their insights to improve the game's design and implementation. This study takes a mixed-method research approach, with data collected in the form of words and numerical representations. Qualitative research investigates a central phenomenon by asking wide questions and allowing participants to provide detailed viewpoints (Jackson et al., 2007). Because this research aims to understand better learners' engagement, collaboration, and knowledge retention using Tech Traverse, collecting comprehensive, descriptive data is critical to its success. A phenomenological research design was utilised to investigate the lived experiences of novice programming students who engaged with Tech Traverse. This approach ensures that the study accurately captures student experiences while minimising the researcher's preconceived notions. The quantitative component included pre-and post-tests to assess students' knowledge retention before and after using Tech Traverse. This method allows for an objective assessment of learning gains, which supplements the qualitative interview insights. By integrating the two methodologies, the study provides a more complete picture of how Tech Traverse affects student motivation, engagement, and problem-solving abilities. Furthermore, the findings help to improve the game's structure, ensuring its usefulness in teaching novice learners programming fundamentals. This design sheds more light on Tech Traverse's usefulness in improving programming instruction by analysing learners' involvement, motivation, and problem-solving tactics during games. Furthermore, it influences changes to the game's structure, ensuring that it is effectively intended to help novice learners master programming principles.

Design and Development of Tech Traverse

Tech Traverse was developed using a systematic design process with the goal of increasing participation, cooperation, and knowledge retention in programming instruction. Tech Traverse, which is inspired by the Snakes and Ladders board game and incorporates aspects from chess-style scorekeeping, uses game-based learning approaches to make programming ideas more dynamic and accessible to beginning learners.

The game is intended to teach essential programming concepts such as data types, variables, control structures, arrays, and methods. Students participate in team-based gameplay, moving through three zones: Knowledge Boost, Challenge Zone, and Trouble Zone, each with programming-related challenges that involve critical thinking and problem-solving. The game promotes collaborative problem-solving, in which students work collaboratively to predict the output of a given program segment, identify answers for theoretical aspects of Java programming and/or uncover syntax, logic, or runtime issues while strengthening computational thinking skills.

A sequence of task cards is created to efficiently structure learning, each of which contains a programming-related question or challenge. The Knowledge Boost portion contains foundational questions reinforcing fundamental concepts, whilst the Challenge Zone includes problem-solving challenges requiring deeper comprehension. The Trouble Zone delivers obstacles that halt students' progress. It adapts the 'snake' element of the Snake and Ladder game. QR codes are included in select cards to provide just-in-time tips, allowing students to

seek help as needed while encouraging self-directed learning. Each team is allowed to scan the QR code at the back of the task card only twice during the entire game. Figure 1 shows the examples of task cards from each of the zone.

Knowledge Boost

- Players must answer the question on the task card within two minutes
- For each correct answer, the team gets to progress two steps forwards

Challenge Zone

- Players must answer the question on the task card within two minutes
- For each correct answer, the team gets to progress two steps forwards
- For any incorrect answer, the team is required to move one step back

Trouble Zone

- The team is required to move back according to the number of steps indicated on the task card

Figure 1: Examples of Task Card From Each of the Zone

Figure 2: Scoresheet

Tech Traverse

Scoresheet

Turn	Dice Roll	Start Square	Landed Square	Answer	Result	Notes/Reflection

A scorecard is used to track pupils' progress, noting dice rolls, zones visited, responses given, and correctness of answers. This progress-tracking method allows students to reflect on their

learning experiences, emphasising the value of perseverance and revision. The teacher facilitates gameplay through scaffolding. Figure 2 shows the scoresheet used in the game.

Data Collection

This study included 41 of 73 computer science students from Sarawak Matriculation College. The sampling centred on students learning programming for the first time as part of their public test curricula. A purposeful sampling strategy, namely criterion sampling, was used to ensure that participants met specific criteria. These criteria were voluntary engagement in the study, no prior experience studying programming for examination purposes before enrolling in the Matriculation program, and attendance of at least 90% of programming classes during the semester. This method ensured that the chosen participants had a consistent learning background, allowing for more reliable evaluations of their involvement, collaboration, and information retention while utilising Tech Traverse.

The data collection for this study included pre-and post-tests to assess knowledge retention, as well as focus group interviews to assess student collaboration and participation while using Tech Traverse. To collect detailed participant responses, each interview was instantly transcribed, complete with behaviour observations, phonetic transcriptions of dialects, and filler words. (Plummer-D'Amato, 2013) Recommends four to five focus groups for qualitative research. In this study, seven groups of five and one group of eight were recruited. Interviews lasted up to 60 minutes, as suggested by (Gibbs, 1997). Data was collected within four weeks after the gaming session to ensure that responses reflected current and authentic student experiences with the learning tool.

Data Analysis

This study used a mixed-methods approach to investigate students' experiences with Tech Traverse, with a particular emphasis on its effects on information retention, engagement, and collaboration. The statistics were evaluated numerically and qualitatively to provide a thorough understanding of the game's effectiveness. The quantitative analysis used a pre-test and post-test to assess students' knowledge retention after playing the game. Descriptive statistics, such as mean scores and percentage differences, were used to evaluate students' performance before and after the game. The results revealed if the game served to strengthen students' understanding of the subject matter. The qualitative study employed a topic analysis to evaluate students' perceptions of the game-based learning experience. The responses to open-ended questions were sorted and organised into major themes. The analysis followed Braun and Clarke's (2006) six-step process, which included familiarising with the data, developing preliminary codes, identifying themes, reviewing themes, defining themes, and drafting the final report. Direct student quotes were included to back up the findings, which provided valuable insights into their experiences.

Discussion

Thematic analysis results show that Tech Traverse encouraged positive student discussion and collaboration. The game facilitated meaningful interactions that contributed to a shared learning experience by encouraging group discussions, peer learning, and team bonding.

Research Question 1: What is the role of Tech Traverse in improving constructive communication and collaboration between peers?

The study discovered that students actively engaged in talks while striving to tackle game-based challenges. The planned activities encouraged students to express themselves, discuss ideas, and critically evaluate multiple points of view before reaching an accord. One kid said, "Yes, because we discussed the questions and shared our ideas." This collaborative effort increased their understanding of the problem and their ability to communicate their reasoning effectively.

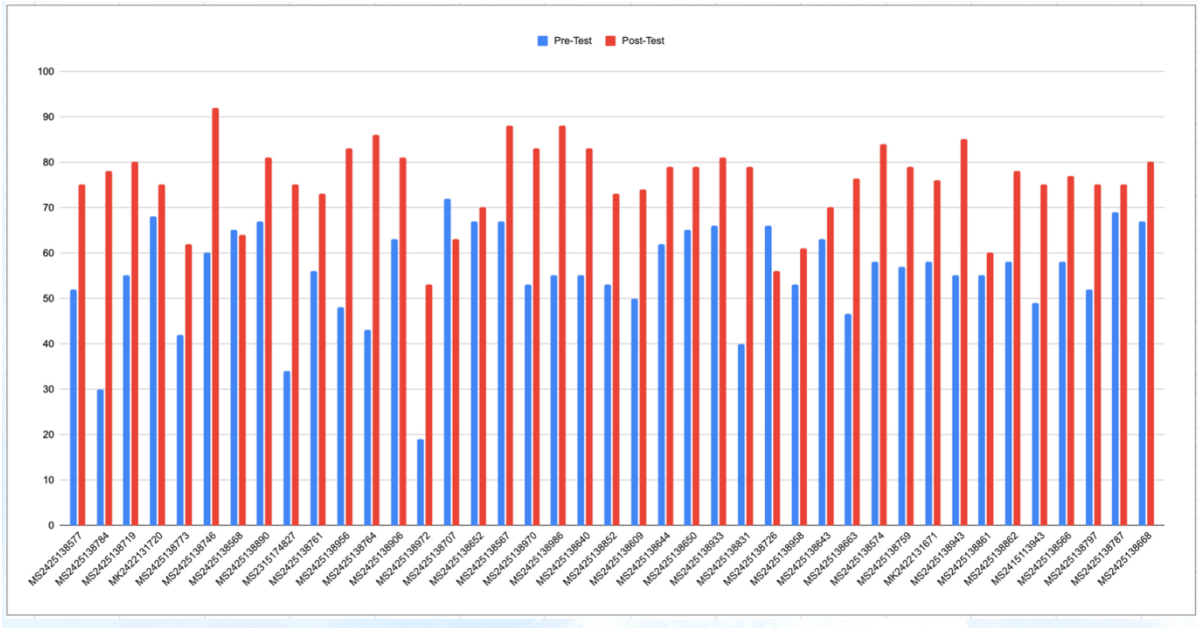
Tech Traverse has allowed peer-to-peer learning and shared understanding, with students assisting one another in comprehending complex concepts. The game environment encouraged spontaneous knowledge-sharing, as seen by students' feedback: "Yes, my peers and I collaborate to answer the question, and everyone contributes their ideas about the answers." This demonstrates that the game fostered a culture of learning from one another, reducing the emphasis on individual achievement and creating a more welcoming learning environment. Students reinforced their own learning by participating in discussions and clarifying topics for their peers, as well as gaining from the perspectives of others.

Aside from knowledge exchange, Tech Traverse promoted interpersonal interactions and team cohesion. Students said that working towards a common goal boosted their sense of belonging and trust in their peers. One participant added, "We work as a team to achieve the same goal. It strengthens the connections of friendship". This implies that the game not only served as an academic tool but also improved students' social growth by allowing them to create meaningful relationships that could last beyond the classroom.

Research Question 2: How does the implementation of Tech Traverse contribute to strengthening programming knowledge retention among novice programming students?

Figure 3 shows the pre-and post-test results.

Figure 3: Pre- and Post-test Results



The examination of pre-test and post-test results, as depicted in the bar chart, shows that Tech Traverse improved programming knowledge retention among novice programming students. The post-test scores are consistently higher than pre-test scores across all but

three participants, indicating that the game-based learning strategy improves students' information retention. The data shows a significant rise in test results from pre-test to post-test, suggesting that students retained more programming principles after utilising Tech Traverse. The majority of students who scored lower on the pre-test demonstrated significant improvement on the post-test. This suggests that the game's interactive and problem-solving aspect helped them learn and remember fundamental programming ideas.

Conclusion

Tech Traverse, a gamified learning approach inspired by Snakes and Ladders, enhances knowledge retention and collaborative learning among novice computer science students by integrating game mechanics, aesthetics, and game-based thinking. The game addresses challenges in programming education, such as low motivation and poor retention. It incorporates Knowledge Boost, Challenge Zone, and Trouble Zone cards to promote critical thinking, while QR codes provide timely hints for self-directed learning. Findings indicate that Tech Traverse fosters peer interaction, teamwork, and a deeper understanding of programming concepts within a student-centered learning environment. By encouraging accountability and constructive communication, it helps students develop essential skills for academic and professional success. While the results are promising, further research is needed to explore its applicability in diverse educational contexts and assess its long-term impact.

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