Play to Learn: Improving Middle School Students' Computational Thinking Through Game-Based Learning

Abstract

Game-based learning shows great potential as a tool for enhancing students' computational thinking abilities. However, these approaches in K-12 settings frequently emphasize the teaching of specific computing concepts and programming skills. This approach often overlooks the broader goal of developing students' computational thinking competency—a set of skills that can be applied across various subjects and aligns with curriculum standards. To address this need, the current study investigated how game-based learning influenced middle school students' learning performance. One hundred sixty-nine students participated in the study, playing the game over a period of 4 weeks. We observed evidence that the gaming experience significantly influenced the development of computational thinking competency, self-efficacy toward computational thinking, and interest in STEM career after gameplay.

Introduction

Game-based learning (GBL) is considered a highly engaging platform for enhancing students' computational thinking (CT) competency. Its effectiveness stems from its ability to alleviate negative perceptions about learning CT (Sun et al., 2020). The interactive environment of GBL promotes students fully immersion, and the problem-solving nature of GBL aligns well with CT skills, which involve cognitive and behavioral processes in problem solving (Dondlinger, 2007; Grover & Pea, 2013; Liu & Jeong, 2022). Research has demonstrated the potential of using GBL to develop students' cognitive and non-cognitive aspects of CT, including concept understanding, skills development, and attitude change (Hooshyar et al., 2020; Hsu et al., 2018; Liu & Jeong, 2022; Zhao & Shute, 2019). This is achieved through immersive game-based problem-solving experiences (Israel-Fishelson & Hershkovitz, 2019).

However, the field faces challenges due to varying definitions and methods used to operationalize, observe, and measure the CT competency development in K-12 settings (e.g., Atmatzidou & Demetriadis, 2016; Liu & Jeong, 2022; Turchi et al., 2019; Zhao & Shute, 2019). There is a notable lack of effective, classroom-applicable methods that teachers may use as part of curriculum requirements (Araujo et al., 2019; Chen et al., 2017). It can hinder the systematic scaling of CT in K-12 across the United States (Acevedo-Borrega et al., 2022). Moreover, many studies emphasize computer programming concepts and skills (e.g., Lai, 2021) due to CT's roots in computer science. While efforts have been made to simplify the complexities of the syntax of programming languages (e.g., Zhao & Shute, 2019), the focus often remains on computing concepts and skills rather than broader CT competency, which students can use across the disciplines. Therefore, there is pressing need for more research on CT competency, which refers to the skills applicable across various learning fields and for systematic problem solving in daily life (Tsai et al., 2021).

Therefore, the current study describes the implementation of GBL in middle school students CT competency that highlights a learning process of creative problem solving with less emphasis on programming. This research is particularly crucial in the field of GBL, to ensure that CT education extends beyond programming to encompass a wider range of problem-solving skills. We focus on the descriptive influence of this educational approach on the development of students' CT competency, self-efficacy toward CT, and interest in STEM career. Specifically, the current study addresses three research questions:

1. Did middle school students' CT competency improve after playing the game?
2. Did middle school students' CT self-efficacy improve after playing the game?
3. Did middle school students' interest in STEM career improve after playing the game?

Literature Review

CT in K-12 Settings

CT has its roots in the work of Seymour Papert (1980), who first explored the connection between programming and cognitive skills. The concept gained renewed attention through Jeanette Wing's (2006) influential characterization of CT as "solving problems, designing systems and understanding human behavior that draws on concepts fundamental to computing" (p. 33). Wing's work, along with subsequent elaborations by Cuny et al. (2010), established CT as thought processes that comprise problem identification and solution formulation, often facilitated by computational methods. This broader definition expanded CT's boundary beyond computer science, positioning it as a fundamental competency that benefits everyone in their daily life (Hooshyar et al., 2020; Zhang & Nouri, 2019).

Despite widespread recognition of its importance, a universally accepted definition of CT remains unclear (Shute et al., 2017; Turchi et al., 2019; Zhang & Nouri, 2019). In the current study, we define CT as a creative problem-solving process with less emphasis on programming (Barr & Stephenson, 2011). It is aligned with the operational definition provided by the International Society for Technology in Education (ISTE) and the Computer Science Teachers Association (CSTA), which argued that CT is associated with, but not limited to, the following characteristics: (1) formulating problems that can be solved with the use of computing devices and tools; (2) organizing and analyzing data logically, (3) representing data abstractly; (4) automating solutions through algorithmic thinking; (5) solving problems efficiently and effectively; and (6) implementing the problem solving process to a wide range of situations and domains (ISTE & CSTA, 2011).

Developing CT through GBL

GBL in education involves embedding instructional content and learning goals within the structure of digital games, utilizing them as pedagogical tools to enhance the learning experience (Gee, 2003; Prensky, 2002). It is considered an effective platform offering students experiential learning opportunities through engagement in meaningful problem-solving processes within interactive contextual simulations (Gee, 2003; Ke, 2016; Prensky, 2002). Numerous studies have demonstrated that GBL can yield both cognitive and non-cognitive benefits, including metacognition, knowledge acquisition, skill development, motivation for content learning, and attitude change (Gee, 2003; Ke& Clark, 2020; Author, 2022,2023; ter Vrugte & de Jong, 2017).

In the realm of CT, researchers have used GBL to develop students' CT, and many reported that GBL was associated with significant improvements in the acquisition of CT-related knowledge, skills, and abilities (Liu & Jeong, 2022; Zhao & Shute, 2019). For instance, Esper et al. (2014) conducted a study with 55 4th grade students using CodeSpells, a 3D immersive video game designed to teach entry-level Java computing concepts. After 8 weeks of 1-hour weekly sessions, students demonstrated the ability to understand and write basic Java code. In addition, Liu and Jeong (2022) examined the effects of learning supports embedded in the game PenguinGo on CT knowledge acquisition among 79 4th-6th grade students. Although there were no significant differences between the treatment group (game with learning supports) and the control group (game with no learning supports), all students showed significant improvement in CT skills in near transfer tasks. However, this improvement did not extend to far transfer tasks.

Assessing the development of CT solely through programming-related concepts and skills may provide an incomplete picture of students' overall CT competency (Hooshyar et al., 2020; Zhang & Nouri, 2019). Recognizing this limitation, the present study aims to address this gap by investigating the effects of GBL on students' CT competency in a broader context.

Methodology

Research Design

To address the research questions, we adopted a one-group pretest-posttest research design to investigate the effects of GBL on students' CT competency, CT self-efficacy, and interest in STEM career.

Participants

We employed the purposeful convenience sampling strategy (Creswell & Poth, 2017) to recruit students in a public junior high school in spring 2024. Among the recruited 169 participants, 101 (59%) students were male, 64 (38%) were female and 4 (3%) did not report. The majority students identified as either Black or African American (54, 32%) or White (36, 21%). Twenty-four (14%) students were in 7th grade, and 145 (86%) were in 8th grade.

Game used

We integrated Minecraft Education, a node-based planning application (i.e., Minecraft Factory Planner: MFP), and a learning management system (i.e., Canvas) to design and develop a GBL system that teachers could use to monitor students' learning (cf. Author, 2021). It is a first-person, three-dimensional, multi-level role-player game that aims to enhance CT competency for middle school students. The primary goal of the game is to construct objects efficiently and successfully to protect a hypothetical planet from the damage caused by an upcoming meteor shower (Author, 2024). The content focuses on two CT concepts and practices: Data and Analysis, Problem Decomposition and Solution Design. These concepts are incorporated into 2 units, each consisting of 7 lessons.

Procedure

The study included three sessions as depicted in Figure 1. In Session 1, participants completed a demographic questionnaire, a pretest assessment of CT competency, a CT self-efficacy survey and a STEM career interest survey. In Session 2, the participants played the game individually for 90 minutes every two days per week during their regular science class. The gameplay lasted 4 consecutive weeks. In Session 3, the participants completed a posttest assessment of CT competency, a CT self-efficacy survey, and a STEM career interest survey. Three researchers and a head teacher facilitated the gameplay for the students.

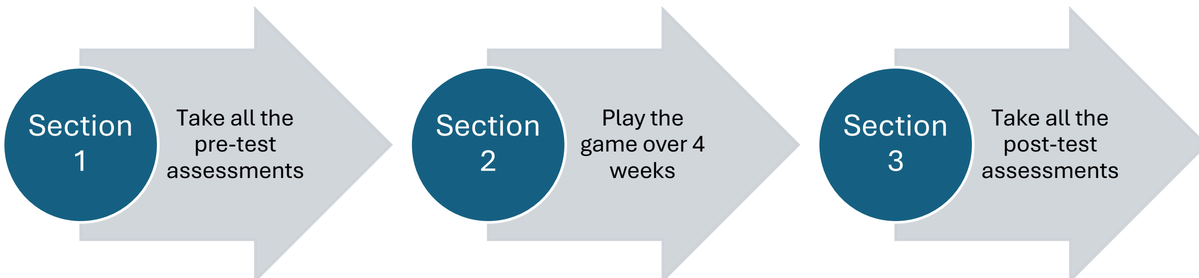

Figure 1. The procedure of research study

Data source and Data Analysis

A demographic questionnaire was administered to collect background information, such as gender, grade, and ethnicity. CT competency was measured using the Interactive Assessments of CT (IACT, Rowe et al., 2021). We adopted the Computational Thinking Self-Efficacy Scale developed and validated by Kukul and Karatas (2019) to measure students' CT self-efficacy. The scale consisted of 18 items in total and the scores represent the average across 18 items. Students responded to each item on a five-point Likert scale. The internal reliability of the test items achieved excellent levels on both the pretest (Cronbach's alpha = .88) and posttest (Cronbach's alpha = .94). In addition, students completed the STEM Career Interest Survey (Kier et al., 2014). The survey includes 44 items. Scores on this measure represent the average across all 44 items. Students responded to each item using a five-point Likert scale. The internal reliability (Cronbach's alpha) of each test item used in the study ranged from .94 to .96 across pretest and posttest, indicating excellent levels of internal consistency. In our analysis, we used a paired samples *t*-test to compare the pretest-posttest outcome scores measured by the CT Competency, the Computational Thinking Self-Efficacy Scale, and the STEM Career Interest Survey. We removed the missing data for the analyses.

Results

Table 1 displays the results of the paired sample *t*-test on pretest-posttest outcome scores for CT competency, CT self-efficacy, and interest in STEM career. The results indicate that the overall difference in students' CT competency was statistically significant, $t(138) = -1.96$, $p = .026$, $d = 0.76$. Furthermore, we observed that students' self-efficacy toward CT significantly increased after the gameplay experience, $t(127) = 2.17$, $p = .016$, $d = 0.75$. In addition, the results reveal statistically significant increases in STEM career interest, $t(120) = -1.749$, $p = .041$, $d = 0.70$.

Table 1
Results on Pretest-Posttest Measures for CT competency, CT self-efficacy, and STEM career interest

Resource	*n*	Result of Paired Samples *t*-test				*t*	*p*
		Pretest		Posttest			
		M	*SD*	*M*	*SD*		
CT competency	139	-.55	0.95	-.43	0.99	-1.97	.026
CT self-efficacy	128	3.38	0.59	3.24	0.66	2.17	.016
STEM career interest	120	3.39	0.58	3.51	0.70	-1.75	.041

Note: the z-score of the CT competency was used in the analysis.

Conclusion

The study adopted a one-group pretest-posttest research design to investigate how GBL influenced middle school students' CT competency, CT self-efficacy, and STEM career interest. We emphasize that CT is a thinking process for creative problem solving, with less emphasis on programming (Barr & Stephenson, 2011; Author, 2024). The results showed that students' CT competency was statistically higher after playing the game. This aligns with prior research studies (Liu & Jeong, 2022; Zhao & Shute, 2019), which reported that GBL positively influenced students' CT development. Furthermore, the results showed that students' overall CT self-efficacy was statistically significantly higher than after playing the game. This is consistent with previous research studies that have reported GBL influences self-efficacy gains (Hu et al., 2022; Author, 2024). Therefore, this study further contributes to the literature by demonstrating that learning CT in a GBL environment could also positively influence students' CT self-efficacy. Finally, statistically significant increases in STEM career interest were observed after playing the game.

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