FOSTERING COMPUTATIONAL THINKING THROUGH GAME-BASED LEARNING IN K-12

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Computational Thinking (CT)

- Analytical thinking approach and problem solving process that breaking problems into small pieces, designing systems for possible solutions, and understanding the relationship among the pieces by drawing fundamental concepts (Wing, 2006; National Research Council, 2010a).

- Wing’s call to action for teaching (2006): 21st century skill, universally applicable attitude not just for computer scientist, but for everyone.

- Two National Academy of Sciences workshops were organized to discuss the cognitive and educational interventions of CT on K-12 curriculum.

- Unanswered questions:
  - How can CT be recognized?
  - What is the best pedagogy for promoting CT among children?
  - Can programming, computers, and CT be legitimately separated? (National Research Council, 2010)

- Focus shifted from theoretical to more practical since 2012.
Game-Based Learning (GBL)

- Implementations of game elements such as core mechanics, challenges, and goals into real-life settings to enhance learning. It aims to reach learning objectives through games.

- GBL as a teaching method seems promising to enhance students’ learning and motivation. Since an increase in implementation of CT pushes schools searching effective teaching methods (Gouws, Bradshaw, and Wentworth, 2013, p. 10-15), many researchers indicate that GBL, especially game design part, seems promising for teaching CT concepts in K-12 settings (Baytak and Land, 2010; Rowe et al., 2017, p. 45).

![Pie chart showing the percentage of video game players in the United States.](chart.png)

The percentage of video game players in the United States

- 82% Players
- 18% Non-Players

Ages between 2 to 17,
Approximately 64 million children

Source: (N.P.D Group, 2009)
Problem Statement and Research Questions

- The bulk of this CS education research is set in the context of undergraduate classrooms; little is known about how applications of game-based learning foster computational thinking in K-12, especially in elementary schools.

- Therefore, the purpose of this study is to obtain a better understanding for educators and researchers by systematically reviewing and synthesizing recent research since 2010 on CT regarding applications of game-based learning (GBL) in K-12.

  - **RQ1**: What range of topics does the current literature cover?
  - **RQ2**: What kind of game-based learning environments and tools have been shown effective in promoting CT?
  - **RQ3**: What are the reported outcomes related to students’ engagement, motivation, and achievement in CT?
  - **RQ4**: How was the CT skills assessed in recent literature?
Methodology

The main data sources include journal articles, conference papers, and doctoral dissertations. The search was conducted in databases that are well-known and well-established in the field of computational thinking and game-based learning: ERIC (Education Resources Information Center), PsycInfo, IJGBL (International Journal of Game-Based Learning), IEEE (Institute of Electrical and Electronics Engineers), and Summon. Besides, Google Scholar was used for additional searches.

<table>
<thead>
<tr>
<th>Inclusion Criteria</th>
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<tr>
<td>K12 education (kindergarten through the 12th grade (1-12))</td>
<td>Other stages of education such as pre-university level, college students, and graduate students.</td>
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<tr>
<td>Empirical studies</td>
<td>Theoretical studies</td>
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<tr>
<td>Studies that provide evidence about students’ learning outcomes</td>
<td>Studies do not provide information about students’ learning outcomes</td>
</tr>
<tr>
<td>Using educational tools or technologies to foster computational thinking development</td>
<td>Studies not mention about any interventions</td>
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Table 1: The selection criteria
Computational Thinking Through Game-Based Learning

- In the literature, different theoretical frameworks are promoted to guide teachers to improve students’ CT skills through GBL.

- Many studies especially focus on block-based coding game designs, follow similar structured frameworks like CPD.

<table>
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<tr>
<th>CPS Components</th>
<th>What Players Have to Do</th>
<th>Game Elements and Design Principles</th>
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<tr>
<td>formulate problems</td>
<td>1. aware of being a problem-solver</td>
<td>core mechanics</td>
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<tr>
<td></td>
<td>2. identify and abstract a problem</td>
<td>1. meta-gaming</td>
</tr>
<tr>
<td>build algorithmic solutions</td>
<td>1. build solutions via programming</td>
<td>2. abstractness fading</td>
</tr>
<tr>
<td></td>
<td>2. program without coding</td>
<td></td>
</tr>
<tr>
<td>test and debug</td>
<td>1. solve the problem</td>
<td>challenges</td>
</tr>
<tr>
<td></td>
<td>2. rethink a more efficient solution</td>
<td>Encapsulation</td>
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*Figure 1 Computational Puzzle Design (CPD) Framework (Source: Jiang et al., 2019, p. 29)*
Computational Thinking Through Game-Based Learning

- In the literature, many researchers develop their own game projects while others prefer to use already developed software such as LEGO Mindstorms, Scratch, and Light Bot.

- However, surprisingly, even though researchers develop their own game designs, still, they tend to use block-based game design methodology (e.g. Howland and Good, 2015, p. 224-240; Leonard et al., 2016; Bauer, Butler, and Popović, 2017, p. 26; Jiang et al., 2019, p. 29).

*Figure 2 Examples of block-based game designs (Dragon Architect and LittleWorld) (Source: Bauer, Butler, and Popovic, 2017)*
Computational Thinking Through Game-Based Learning

- Only a few studies implement hands-on game-based methods and role-playing game designs to develop CT skills and to enhance student communication, reading, and writing skills.

- Jagušt et al. (2018, p. 1-5) developed unplugged game-based activities to teach CT skills.

- Another GBL activity is conducted to explore the relationship between computational thinking and English literature in the K-12 curriculum by Nesiba, Pontelli, and Staley in 2015.
Students’ Engagement, Motivation, and Achievement in CT

- Learning CT skills through GBL, or tangible objects increase students’ motivation and engagement. On the other hand, this kind of studies is insufficient to explain the source of students’ motivation by showing evidence.

- Furthermore, in terms of students’ achievements in CT, most of the studies only put emphasis on decomposition, algorithm design, and abstract thinking (Harrison et al., 2018, p. 134-138; Kazimoglu et al., 2012; Bauer et al., 2017, p. 26). Surprisingly, current studies do not usually mention about pattern recognition and generalization while talking about students’ CT skills.
Assessments and Evaluation Methods in CT Teaching

- In the literature, most of the studies use interviews, pre and post-tests, project portfolio analysis, document-based analysis, design scenarios or the combination of these methods as assessment methods in the interventions of CT (Brennan and Resnick, 2012, p. 25; Bubica and Boljat, 2018; Mioto et al., 2019).

- For Scratch-based: portfolio evaluation, interviews, and design projects

- For Game/Simulation-based: pattern analysis and web-like graphic

*Figure 5 Bloom's taxonomy and CT assessment tools (Source: Gonzales, Leon, and Robles, 2019)*
Most studies have focused on either STEM education, especially in Science education. A few studies only consider all of the STEM subjects in their research methodology.

Most common trends in the studies in terms of block-based environments are Scratch Jr, MIT AppInventor, Game Maker, Code Combats, ColoBot, and LEGO Programs.

From a theoretical perspective, we found that several studies are based on constructionism, constructivism, project-based theory, and active learning theory.

Future studies might want to consider the role of social cognitive theory, information processing theory, and cognitive learning processes on students’ CT abilities.

Most recent addressing the CT assessment has used either student-created, or pre-designed programming artifacts to evaluate students' understanding and use of abstraction, conditional logic, algorithmic thinking, and other CT concepts to solve problems.

The findings of this study also pointed out to the use of gamification as a way to foster students’ computational thinking abilities, engagement and motivation in addition to their academic achievement at early ages.
Selected References


Questions and Comments?