A Classification of Computational Thinking Model Based on Computational Thinking Abilities in Game-Based Learning Activities

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Abstract: This article reports a structural classification taxonomy on computational thinking abilities among tertiary students in game-based learning activities focusing on the playing games approach. The computational thinking abilities among tertiary students involves with the two main constructs which are solving problem creatively and making decision in game-based learning activity for their learning purposes. This study described the fundamental issue of applying computational thinking to tertiary students in university setting towards nurturing 21st Century skills. The issues were then analysed using attributes embedded in three different areas which are the computational thinking, game-based learning activities, and the 21st Century skills. A case study with ten students was used as the qualitative research design, and subsequently through interview protocol and observations. From the case study conducted, a taxonomy of computational thinking for enhancing 21st Century skills in game-based learning (playing games) approach was developed to classifying computational thinking with student’s experiences in game-based learning activity. It is believed that this research can helps educators and curriculum decision makers in identify the appropriate computing activities for tertiary students in university.

Keywords: Computational thinking, game-based learning, learning by playing games, 21st Century skills, taxonomy.

1. Introduction

Firstly, games are increasingly being used in education to improve academic achievement, motivation, and classroom dynamics (Ahmad & Abdullasim, 2019). Games are not only used to teach young school children, but also used to improve the quality of academic performance among tertiary students in university level (Hoe, 2019; Farber, 2015).

The ability to use games as teaching tools requires two-pronged approach: Playing Games and Making Games. Playing games naturally create a compelling complex problem space or world, which players come to understand through self-directed exploration. They are scaffolded to deliver better results in producing better human (Gill, 2018; Nijholt, 2014) i.e. improved hand-eye coordination, producing better surgeons, overcome dyslexia, whole-body-interaction, slowing the aging process, ease pain, making new social connections, making faster decisions, reduce stress, less likely to bully, and address autism (Gilbert, 2016). Whatever complex, challenging, and ambitious games are, does playing games can improve cognitive skills and ability or even improving human intelligence especially in the field of computing.

By understanding how the gamers play and act towards the gameplay activity, game developers can understand gamers thoroughly before or while designing new games. As mentioned, playing games requires problem solving skills, thinking about low level logic, spending hours fixing errors and bugs in programs, and being obsessed with aesthetics, gameplay, game mechanics, performance, playability, and all kinds of details (Yatim, 2019; Salen et.al., 2014; Tullis & Albert, 2008). This study focuses on the playing game approach instead of making games approach.

Secondly, number of educational programming tools provide programming styles that are apparently far more attractive to teenagers by using visual representation compared to other conventional programming (Ibharim, 2016; Yatim, 2009; Papert, 1980). Visual languages are also said to be one of the benefits to make programming easier and more accessible to teenagers, although not all aspects lead to visual representations. It is believed that the styles of programming used by teenagers are depending on the teenagers themselves such as their experience, age and learning motivation. The important factor is that the tools provide a gradually transition from a simple visual programming representation to a more high-level abstract programming language (Kafai, 2016; Yatim, 2009).

Without a well-developed playing ability, a person may encounter serious problems affecting one’s academic pursuit or career. Therefore, this research will embark a deep understanding on gamer’s experiences in playing games to narrow any gap exists between playing experiences and learning topics in computing field.
Thirdly, computational thinking and programming skills has become target domains of learning among tertiary students for this current generation. There is a need for educators to find connections between current teaching practice and computational thinking activities (Sidek & Yatim, 2020; Sondakh, 2018; Tsarava, Moeller, & Ninaus, 2018; Ministry of Education, 2016). One specific context for analyzing tertiary student’s computational thinking activities are used which is the game play context. This context was chosen concerning with the tertiary student’s understanding of rules that they constructed by playing games (Asrani & Yassin, 2020; Wong, Yatim, Tan & Yap, 2019; Gary, 2016; Field, Pantic & Kafai, 2015; Wing, 2008). More interestingly, what kind of computational activity (game-based learning) is most suitable for tertiary students, and why?

Without well-developed computational thinking activities, a person may encounter serious problems affecting one’s academic pursuit or career. Therefore, this research will embark a deep understanding on a student’s experiences in computational thinking activities to narrow any gap exists between learning experiences and computational thinking in computing field. As in the status of the body of knowledge in game-based learning field, this research will fulfil that gap as stated in the literature.

2. Objectives

1. To investigate the fundamental issue of applying computational thinking to tertiary students in university setting towards nurturing 21st Century skills;
2. To analyze the attributes embedded in computational thinking which are more appropriate for the tertiary students; and
3. To classifying computational thinking with student’s experiences in game-based learning activity.

3. Research Method

This research used a qualitative research design, and subsequently through a case study. The selection of this method due to its nature and often no clearly defined research problem, and questions may arise during the period of the study. For example, researchers may notice unusual behavior and ask, “What is happening?” or “Why”? The whole process of study was divided into five phases, as depicts in a flow chart in Figure 1:

**Figure 1.** A flow chart of research activities

**Phase 1: Need Analysis and Meta-Analysis**
This phase focuses on the requirements gathering of information related to computational thinking, game-based learning activity, and 21st Century skills needed for tertiary students. This phase provides specific information for the three areas in order to capture, document, communicate, and manage requirements. For computational thinking, four main concepts of computational thinking, i.e. (1) decomposition, (2) pattern recognition, (3) abstraction, and (4) algorithms (Ministry of Education, 2016), as shown in Table 1:

<table>
<thead>
<tr>
<th>COMPUTATIONAL THINKING</th>
<th>EVENT</th>
<th>PLAYER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decomposition</td>
<td>A way of thinking about problems, algorithms, processes and systems in terms of their parts. The separate parts can then be understood, solved, developed and evaluated separately. This makes complex problems easier to solve and large systems easier to design.</td>
<td></td>
</tr>
<tr>
<td>Pattern Recognition</td>
<td>Involves finding the similarities or patterns among small, decomposed problems that can help us to solve more complex problems more efficiently.</td>
<td></td>
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<tr>
<td>Abstraction</td>
<td>A way to make problems or systems easier to think about. It simply involves hiding detail, removing unnecessary complexity. The skill is in choosing the right detail to hide so that the problem becomes easier without losing anything that is important. A key part of it is in choosing a good representation of a system.</td>
<td></td>
</tr>
<tr>
<td>Algorithm</td>
<td>A sequence of instructions, or set of rules, for performing a task.</td>
<td></td>
</tr>
</tbody>
</table>

For game-based learning activity, only one element of game playing activity measurement was used which follow player’s perspective in a Mechanics-Dynamics-Aesthetics (MDA) framework, i.e. aesthetics. For the 21st Century skills, a list of Student 4IR Workforce Skill (World Economy Forum’s Future of Job Survey, 2016) was used as the main reference and the ten skills are: (1) complex problem solving, (2) critical thinking, (3) creativity, (4) people management, (5) coordinating with others, (6) emotional intelligence, (7) judgement and decision making, (8) service orientation, (9) negotiation, and (10) cognitive flexibility. On top of that, the 21st Century skills related to learning by playing games also includes: (1) information and communication skills, (2) thinking and problem-solving skills, and (3) interpersonal & self-directional skills (Pinto & Escudeiro, 2014). A meta-analysis study was conducted to map these elements from three areas and a process of selection and filtering was accelerated to get a taxonomy. The taxonomy was then being used for a case study which was described in the next phase.

Phase 2: Design and Development of a Case Study

Four contexts for analyzing tertiary student’s computational thinking activities were selected which are the programming context, game play context, game design context, and assignment context. For this purpose, a case study was conducted. The case study as a form of qualitative descriptive research illustrates the process of playtesting by small groups of participants. The case study involves with a group of ten participants for a game-playing session. The participants are randomly selected from tertiary students. The case study was conducted in Skyplay Lab, Universiti Pendidikan Sultan Idris.

Phase 3: The Case Study

Researchers collected data using multi-modal methods interview protocol, observations, and reflection notes (similar with “diary studies”) to analyze common experiences gained by the participants. For participants selection strategy, a brief “case history” was used on the participants of the study to provide researchers with a clearer understanding of their participants, as well as some insight as to how their own personal histories might affect the outcome of the study.

Phase 4: Results and Outcomes

Data were analysed through coding where researchers interpreted the data by systematically searching data to identify and categorize specific observable actions or characteristics. These observable actions became the key variables in the study. Adaptation from an analytic framework from Creswell (2013) was used for the organization and presentation of data: (1) the role of participants; (2) the network analysis of formal and informal exchanges among participants; (3) history; (4) thematic; (5) resources; (6) ritual and symbolism; and (7) critical incidents that challenge or reinforce fundamental beliefs, practices, and values. The case study measured and suggests ways to improve users experience in game playing activity.
Phase 5: Development of a Taxonomy

A taxonomy was designed and developed thoroughly after going through several phases. The taxonomy was named as “A Taxonomy of Computational Thinking for Enhancing 21st Century Skills in Game-Based Learning: A Playing Games Approach”. The development of the taxonomy was done iteratively by logically grouping the metadata and linkages among defined attributes from the three areas, i.e. computational thinking, game-based learning activity, and 21st Century skills for tertiary students.

4. Findings

Fundamental Issues in Computational Thinking and the 21st Century Skills among Tertiary Students

Computational thinking is a kind of analytical thinking that shares with mathematical thinking and logical thinking in the general ways in which can be used in solving problems. As the field of computing continues to mature, computational thinking is being taught at schools and higher institutions in formal learning settings to provide powerful building blocks for current and future generations. The fundamental issue is what would be an effective way in teaching students as their learning abilities and skills progresses over the years. With the current and future generation of learners and educators, nurturing computational thinking will provide some challenges and opportunities for them to understand and reinforce the learning concepts (Dazid&Yatim, 2020). By doing so, students can viscerally show their understanding and preparing themselves towards the 21st Century skills as needed in the era of IR4.0.

Attributes Embedded in Computational Thinking, Game-Based Learning, and the 21st Century Skills

Attributes embedded in computational thinking, game-based learning activities, and the 21st Century skills were simplified as follows:

1. Four main concepts of computational thinking were used in this study, i.e. (1) decomposition - breaking down a complex problem or system into smaller, more manageable parts; (2) pattern recognition – looking for similarities among and within problems, (3) abstraction – focusing on the important information only, ignoring irrelevant detail, and (4) algorithms - developing a step-by-step solution to the problem, or the rules to follow to solve the problem.

2. Only one element of game playing activity measurement was used which follow player’s perspective in a Mechanics-Dynamics-Aesthetics (MDA) framework, i.e. aesthetics. The element of aesthetics was divided into eight types of aesthetics, i.e. (1) Sensation (Game as sense-pleasure): Player enjoys memorable audio-visual effects, (2) Fantasy (Game as make-believe): Imaginary world, (3) Narrative (Game as drama): A story that drives the player to keep coming back, (4) Challenge (Game as obstacle course): Urge to master something. Boosts a game's replayability, (5) Fellowship (Game as social framework): A community where the player is an active part of it. Almost exclusive for multiplayer games, (6) Discovery (Game as uncharted territory): Urge to explore game world, (7) Expression (Game as self-discovery): Own creativity such as creating character resembling player's own avatar, and (8) Submission (Game as pastime): Connection to the game, as a whole, despite of constraints.

3. Ten skills was referred, i.e. (1) complex problem solving, (2) critical thinking, (3) creativity, (4) people management, (5) coordinating with others, (6) emotional intelligence, (7) judgement and decision making, (8) service orientation, (9) negotiation, and (10) cognitive flexibility.

4. A meta-analysis study was conducted to map these elements from three areas.

5. A process of selection and filtering was done using adaptation from an analytic framework for data organization and presentation

6. A taxonomy was created, which is summarized in the following section.

Taxonomy Classification of Computational Thinking, Game-Based Learning, and the 21st Century Skills

As mentioned, a taxonomy i.e. arrangement of classification, was designed and developed thoroughly after going through several phases. The taxonomy was named as “A Taxonomy of Computational Thinking for Enhancing 21st Century Skills in Game-Based Learning: A Playing Games Approach” (as depicted in Figure 2). The taxonomy is a hierarchical system used for classifying attributes from the three areas. The design and development of the taxonomy was ranks from general to specific attributes, but yet to be tested for future work.
5. Conclusion

As discussed earlier in the previous sections, this study described the fundamental issue of applying computational thinking to tertiary students in university setting towards nurturing 21st Century skills. The issues were then analysed using attributes embedded in three different areas which are the computational thinking, game-based learning activities, and the 21st Century skills. From the case study conducted a taxonomy of computational thinking for enhancing 21st Century skills in game-based learning (playing games) approach was developed to classifying computational thinking with student’s experiences in game-based learning activity.

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