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Computational Thinking and Teacher Education: Can Digital Game Building Help?

By Qing Li[*]& Arkhadi Pustaka[±]

Background: *Computational thinking (CT) is an important 21st century skill that needs to be mastered by every k-12 student. Teachers are, therefore, increasingly called upon to teach CT and integrate CT into curriculum. Teachers who are equipped with the needed skill sets and knowledge based to teach CT remain scarce. Teacher education needs to be changed to address this shortage of teachers. We need more empirical studies that explore class-based intervention related to CT education for teachers.* ***Purpose:*** *This study examines the potential of digital game based learning to enhance teachers' understanding of computational thinking (CT) skills grounded in enactivism - a relatively new theoretical perspective. Specifically, this study examines the extent of CT skills and pedagogical aspects demonstrated in teacher self-created games. It also investigates the potential connection between CT and pedagogy as reflected in teacher created games.* ***Sample:*** *participants are 80 teachers enrolled in a graduate course focusing on digital game based learning.* ***Design and methods:*** *A quantitative design was adopted. Data collected include the teacher created games containing their design documents and the digital version of those games. A total of 57 games created by these 80 teachers were analyzed to answer the research questions.* ***Results:*** *First, the process of game design and building offers teachers' opportunities to exercise CT and enhanced their understanding of CT concepts. Also, a few pedagogical perspectives have been fairly or extensively represented in teacher created games, indicating their deep understanding of and ability to apply these aspects.* ***Conclusions:*** *Digital game building has great potential to help teachers develop CT skills and thus should be considered as an effective venue to promote CT education. While game building is a complex problem-solving process that involves critical thinking, strategizing and other important skills in real world contexts, teachers still need support to transfer these important thinking skills into their self-created games.*

Keywords: *Computational thinking, Digital game, Enactivism.*

Introduction

We live in an ever-changing society where the advancement of technology has significantly changed our ways of working, living, socializing, playing and learning. This calls for the change not only the way we educate our students, but also the types of skills and knowledge to be learned. It has been widely documented that 21st century skills are a necessity for our students to acquire so that they can become competent citizens (Jenkins 2007).

[*]Professor, Towson University, USA.
[±]Towson University, USA.

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Computational thinking (CT) has been argued as an important 21st century thinking skill. Wing, who first coined the term, defined CT as "the thought processes involved in formulating a problem and expressing its solution(s) in such a way that a computer-human or machine-can effectively carry out" (Wing 2014). In recent years, various groups, including the White House, start to recognize its significance and claim that CT has become a new "basic skill" just like mathematics, reading and writing skills, that every k-12 student needs to master (Smith 2016, Yadav et al. 2014). Consequently, teachers are increasingly called upon to teach computational thinking skills and integrate CT into curriculum. While there is a nationwide push on teaching CT for all students , there is a lack of teachers who are equipped with the needed skill sets and knowledge base to teach CT (Lockwood and Mooney 2017). This calls for changes in teacher preparation programs and professional development to help teachers of all subjects and age levels to gain the required knowledge. In fact, researchers have claimed that teacher education is critical for the improvement of CT education and argued the need of empirical studies that explore class-based interventions related to CT education (Grover and Pea 2013, Lockwood and Mooney 2017). Experts also suggest that CT need to be integrated into different areas of teacher education (Lockwood and Mooney 2017). However, many questions remain unanswered due to the infancy of CT education. For example, can CT be organically incorporated into all subjects in existing teacher education programs? If yes, how? If no, what subjects are more suitable for embedding CT learning, and how?

Digital game based learning, especially digital game building, offers rich opportunities for learners to interact with programming - a key area closely related to CT, and thus may provide a fit breeding ground for CT learning. This study, therefore, examines the potential of digital game (hereafter game) based learning to enhance teachers' understanding of CT skills grounded in enactivism - a relatively new theoretical perspective.

Theoretical Framework

Enactivism, a relatively new philosophical perspective, provides the theoretical framework for this study. Current prevailing theoretical perspectives in cognitive science and education like constructivism and behaviorism, though looking very different on the surface, share similar dualistic assumptions that separate mind from body, self from the world, and perception from action (Davis and Sumara 2002). Such shared assumptions, according to Davis and Sumara (2002) take the Cartesian-dualist perspective that separates mind from body, self from the world. For example, behaviorist view that reality is external to us, not only is structured but also can be modeled. Learning is to mirror objective reality onto learners. Constructivism considers that reality lies inside our mind that is separated from our body and the environment (Jonassen 2001). Whether considering reality resides outside the knower (e.g. behaviorism) or inside the knower (e.g. constructivism), these perspectives treat reality as a separate entity from the mind, believing that cognition lies inside the knower's body that is separated from the world and other people. Recognizing various limitations and criticisms brought by such dualistic views, scholars have called for alternative theoretical standpoints and proposed enactivism to be a fit philosophical view that can address these limitations (Davis and Sumara 2002, Hutto et al. 2014, Li et al. 2010).

Rejecting such dualism and the representational views of the mind, enactivism considers cognition is not only embodied but also inseparable from the environment. In other words, our mind, body, and world are conjoined and cannot be separated (Li et al. 2010).

The origins of enactivism can be traced back to the work of Maturana and Varela (1991). Phenomenological perspective based on Merleau-Ponty's work and Buddist viewpoints also contribute to enactivism (Reid and Mgombelo 2015). Enactivism focuses on the importance of action in cognition and embodiment. It regards cognition as an active process where "perception consists in perceptually guided action" (Varela et al. 1991). Rather than considering perception as passive, enactivists believe that cognition is active, dynamic and situated. According to Varela et al. (1991), structural determinism is a fundamental concept of enactivism. In this view, all living systems are structurally determined and cognition is based on our bodies. When an organism continually changes its structure so that "it goes on acting adequately in its medium, even though the medium is changing" (Maturana 1987), learning has occurred.

Doing is at the heart of enactivism, as reflected in the famous enactivist slogan: "all doing is knowing, and all knowing is doing" (Varela and Maturana 1992). The core focus of gaming on doing provides an optimal condition to apply enactivism. Teacher game building, therefore, offers an ideal context for us to study teachers' cognitive process of learning different topics such as pedagogy and CT. From the enactivist viewpoint, teachers' understanding of CT is reflected in their acts of the game design and development tasks where CT skills are integrated. Therefore, whether teachers are conscience about their understanding of the specific CT knowledge or not, their building of the specific games in which different CT skills were employed demonstrates their knowing of CT.

Another essential enactivist concept is co-emergence of our mind and the environment (Li et al. 2010, Reid and Mgombelo 2015). In this view, a carefully designed world that merges our physical, biological and electronic systems can greatly enhance learning. Gaming has a unique ability to let players easily immersed in the virtual world and real world simultaneously. Game building thus has a great potential to promote co-emergence of our biological and electronic systems. When teachers designing and developing their educational games, they need to consider the learners' game playing (i.e., involving our physical and biological systems) in the game environment (i.e., electronic systems), thus uniting these different systems.

Literature Review

Definitions of CT and Games

To date, there is no universally accepted definition of computational thinking. In addition to Wing's definition stated at the beginning of this paper, the Royal Society (2012) considered CT as "the process of recognizing aspects of computation in the world that surrounds us, and applying tools and techniques from computer science to understand and reason about both natural and artificial systems and processes" (p. 29). Many scholars attempted to define CT by considering its core characteristics (Voogt et al. 2015). The International Society for Technology in Education (ISTE) and the Computer Science Teachers Association (CSTA) provided an operational definition of CT as "a problem-solving process that includes (but is not limited to) the following characteristics:

- Formulating problems in a way that enables us to use a computer and other tools to help solve them.
- Logically organizing and analyzing data.
- Representing data through abstractions such as models and simulations.
- Automating solutions through algorithmic thinking (a series of ordered steps).
- Identifying, analyzing, and implementing possible solutions with the goal of achieving the most efficient and effective combination of steps and resources.
- Generalizing and transferring this problem solving process to a wide variety of problems.

These skills are supported and enhanced by a number of dispositions (http://www.iste.org/docs/ct-documents/computational-thinking-operational-definition-flyer.pdf). While different definitions exist, a review paper states that it is widely accepted that CT involves the following attributes:

- Abstractions and pattern generalizations (including models and simulations).
- Systematic processing of information.
- Symbol systems and representations.
- Algorithmic notions of flow of control.
- Structured problem decomposition (modularizing).
- Iterative, recursive, and parallel thinking.
- Conditional logic.
- Efficiency and performance constraints.
- Debugging and systematic error detection.

(Grover and Pea 2013)

There are various definitions of CT in the literature and many focus on cognitive outcomes. However, CT goes beyond these cognitive outcomes and affective aspects are equality important. Examples of these attitudes and dispositions include, as defined by CSTA, "confidence in dealing with complexity, persistence in working with difficult problems, tolerance for ambiguity, the ability to deal with open-ended problems, the ability to communicate and work with others to achieve a common goal or solution" (http://www.iste.org/docs/ct-documents/computational-thinking-operational-definition-flyer.pdf). This study, although recognizing the importance of these affective variables, focuses on cognitive outcomes. Further review and discussions of the affective aspects are beyond the scope of this paper.

Computer programming, computer science, and CT are different concepts and fields of study even though they are closely related. Although computational thinking is by no means a new concept and the importance of CT skills has long been realized, it is not until recently that CT is considered as basic skills that need to be obtained by everyone rather than just experts in computer related fields (Oluk and Korkmaz 2016, Rehmat et al. 2020). The growing interest in CT and computer science in k-12 education resulted in an increasing number of research studies and the development of tools that foster CT. The tools took a variety of forms, starting from Papert's pioneer work of *LOGO,* to *Scratch, Alice,* and *Kodu* (Grover and Pea 2013).

While preparing teachers to teach with k-12 computing curricula would be the logical first step to insure successful integration of CT in k-12 education, equip teachers with needed skill sets remains a great challenge (Grover and Pea 2013, Rehmat et al. 2020). Though limited, there are studies that explored how digital games can be used to teach CT skills (Kynigos and Grizioti 2020), however, these efforts focused on CS education instead of teacher education. For example, one study (Kazimoglu et al. 2012) used a Flash game to teach coding and basic CT concepts to college CS introductory course. In the game, players need to control a robot using "solution algorithms" through programming commands. The game was designed where the game structure was mapped to certain CT concepts. An informal test of 25 students who had taken at least one programming course was conducted. The feedback from these students showed that the game involved the following CT skills: algorithm building, conditional logic, tracking a simulation, debugging, unfortunately empirical evidences were missing. As well, the game enhanced these students' interest in coding and problem-solving skills. A review paper (Kafai and Burke 2015) of 55 research studies indicates that abundant existing work has shown the benefit of game building in helping k-12 students learn program concepts and computational practices. Further review of this area is beyond the scope of this paper.

CT & Teacher Education

While CT has gained new impetus in the field of education and studies of CT exist, research focusing on teacher education remained scantily (Cetin 2016). Cetin (2016) examined the impact of using Scratch, a visual programming software, on preservice teachers' learning of basic CT skills and their attitudes toward coding. Adopting a mixed-methods approach, data collected included achievement tests, a survey and interviews. Participants were 74 preservice teachers enrolled in a technological application class. The results indicated that using Scratch, preservice teachers' understanding of basic computing concepts was significantly improved.

Yadav et al. (2014) believed that teacher preparation programs provide an ideal milieu to help teachers not only learn CT skills but also how to integrate CT into content. Yadav et al. (2014) investigated the impact of a one-week workshop aiming to improve preservice teachers' CT understanding and attitudes. Using a quazi-experimental design, participants were preservice teachers enrolled in a required introductory psychology course. The experimental group learned through a module focusing on CT topics while the control group did not work on the module. Their results showed that the module did enhance teachers' understanding of CT. On the one hand, the preservice teachers in the control group misunderstood CT as technology integration into classrooms. On the other hand, a majority of the preservice teachers in the experimental group considered CT as using algorithms to solve problems. Additionally, when compared with the control group, participants from the experimental group had a better sense of how to integrate CT into their teaching practices.

Angeli et al. (2016) convincingly argued that rather than only consider CT/CS education in secondary schools, it is vital to integrate CT starting from Kindergarten learners. They proposed a curriculum framework for k-6 CT education, specifying indicators of competence for five CT skills: abstraction, generalization, decomposition, algorithmic thinking and debugging. They stressed the importance of the holistic approach for designing CT curriculums. Further, they conducted a study of 15 in service elementary teachers' experience of CT learning. The participants were graduate students enrolled in an instructional technology course focusing on CT integration in k-6 classrooms. All participants had no prior CT knowledge. Meeting 3 hour weekly for 13 weeks, teachers learned CT by designing models of real world phenomenon and then translate them to computer programs using Scratch in order to solve real life problems. Their preliminary analysis showed that developing a model, even without coding, was extremely challenging for the teachers because teachers could not effectively use the abstraction skill. Through on going practices, along with the instructor's assistance, these teachers eventually had enhanced understanding of abstraction. Explicit instruction on how to create models such as identifying important constructs and their characteristics of the model deemed to be critical. With respect to teaching programming, CT topics including data process, sequencing, loops, parallel processing, events, conditions, operators, variables and data flow of control were all introduced. When ample programming examples were used to illustrate those topics, teachers could easily understand these concepts, although variables and conditional logic were considered the more difficult ones.

Cabrera (2019) examined 24 existing papers and identified that teachers tended to hold preconceptions impacting their understanding of CT. Specifically, they often equate CT to one of the following concepts: 1) technology integration, 2) coding, 3) problem solving, and 4) "thinking like a computer". Further, preconceptions included CT should not be part of k-12 education for various reasons, ranging from CT is too difficult to learn, to certain student groups could not manage to acquire such skill, to conflicts with the curriculum, to constraints such as time limitation and instruction structure of schools.

In summary, while CT has gained increasing attention from various groups, studies that focused on teacher education are still relatively limited. At the same breath, while numerous studies exist indicating that school students could learn coding and programming through designing and building their own games, few studies have emphasized on teachers (Kafai and Burke 2015). Amongst this limited exploration, even less work has examined teacher game building in connection with CT. This study bridges this gap by exploring the potential of practicing teachers' experience of designing and building their own instructional game through the new theoretical lens of enactivism.

Research Questions

The study aims to examine, through the lens of enactivism, teachers' experience of designing and developing educational games for their own students, with a focus on CT in connection with pedagogy. Specifically, this study is guided by the following research questions:

1. What levels of computational thinking do teachers demonstrate in their self-created games?
2. To what extent do different pedagogical components emerge when practicing teachers develop games?
3. Does the level of computational thinking connect to the pedagogical level as reflected in teacher created games?

Methods

The current study was part of a large project focusing on digital game based learning. Adopting a qualitative research approach, this study focused on CT skills and pedagogical components practicing teachers employed when designing and building their own games.

Participants and Context

The participants were 80 graduate students (31 males and 49 females) enrolled in a digital game based learning course. A majority of these students were practicing teachers in k-16 schools and a few were trainers working in organizations or private sectors. For simplicity, the participants were referred to as teachers in this paper.

The course was designed based on enactivism, with carefully crafted rich stimuli integrated. The learning environment was complex where varied incitements were intertwined to guide teachers' attention to specific content and educational goals, while specific outcomes were negotiated and revised throughout the process (Li et al. 2010). As well, doing was placed at the center of learning, reflecting the enactivist view of embodiment. Knowledge coauthoring, a critical aspect of enactivism, was partially realized through the adaptation of teacher game creation promoting teachers' development of new relationships with knowledge. Teacher collaboration was promoted throughout the course.

The course was an introduction to digital game based learning for teachers to explore theories, possibilities and considerations related to the design of instructional games, and the use of games for education in classroom and out-of-class settings. CT, however, was not the focus of the course.

The 15-week course offered 7 times: twice were administered on campus and five times online. The on-campus version of the course was about 70% of face-to-face meeting times and 30% online, while the online course meant that 90% or more of the class meetings online. Among the teachers, about 90% of the teachers had no or limited programming background. Nobody had prior game design experience. Regardless of the format, the course followed this general procedure: it started with an introduction to digital game based learning (GBL) where fundamental theories and principles of GBL were discussed (about 3 weeks). Teachers were then asked to explore various games and considered how games could be integrated into their teaching practice (about 4 weeks). Towards the second half of the course, the teachers designed their own educational games, producing their game design documents. The culminating project was the digital version of their proposed games (or initial levels of the games) using different software. While allowed to resubmit their work if there were deficiencies, no body resubmitted their assignments. During the first meeting, Scratch was introduced to teachers by showing the homepage of the Scratch website (https://scratch.mit.edu/) and asking teachers to freely explore the projects shared on the website. This introduction of *Scratch* lasted less than 15 minutes if the first meeting were face-to-face. In the subsequent classes, small Scratch tasks were built in to the weekly assignments to scaffold teachers' skills of using Scratch. For example, a week 2 Scratch task was: "whirl a photo: choose a photo and make it whirl by moving the mouse around the screen".

Instruments

CT skills were measured using Dr. Scratch, a free web based instrument that could automatically evaluate projects created by the software: Scratch. Dr. Scratch rated the CT levels of a Scratch project based on the following 7 aspects: *abstraction, synchronization, analogy/parallelism, data representation, user interactivity, logical thinking,* and *control flow* (Moreno-León and Robles 2015). It was claimed that Dr. Scratch was a valuable tool to evaluate CT skills. For instance, a study of 5th graders compared Dr. Scratch scores with their Computational Thinking Levels Scale. Their statistical analysis showed that Dr. Scratch was reliable and could appropriately assess CT skills (Oluk and Korkmaz 2016).

Pedagogical aspects were evaluated using the Pedagogy Rubric of Teacher-Created Games adapted from the original pedagogical and cognitive rubric (Li

2014). The prior work based on the original rubric showed that this was a reliable tool that included the key aspects to effectively assess teacher designed instructional games. The original rubric was developed based on enactivism where doing and knowing were placed at the center of learning. Stressing the learners' active role in cognition, categories in the knowing area were created, which included but not limited to: *problems soling, critical thinking/reasoning, scaffolding*. At the same time, the importance of emotion underscored in enactivist view led to the creation of *engaging* and *motivating* categories. Co-emergence and structured coupling, two critical enactivist concepts, argued that a new transcendent harmony would arise when people engaged a shared action (Varela et al. 1991); hence, the inclusion of the categories: *social learning* and *connecting*. Embodied cognition, a foundation of enactivism, led to the development of the doing categories, such as *ease of using* and *strategizing*.

The Pedagogy Rubric of Teacher-Created Games (see Appendix for details) included the following 12 categories: *problem solving, critical thinking/reasoning, strategizing, connecting, engaging, motivating, visual learning, ease of using, multiple representation, scaffolding, social learning,* and *assessing*. The definitions of these categories are:

- Problem solving: using prior knowledge or generic methods to find a solution of a problem. Recalling simple facts (e.g. simple algebra equation) without any context does not count as problem solving.
- Critical thinking/reasoning: using different types of reasoning (e.g. deductive) that is appropriate for a given situation, or analyzing a situation objectively in order to come up with a conclusion (Partnership for 21st Century Skills 2007).
- Strategizing: the mental process including planning, control and working memory to attain a particular goal (Diamond 2013). In gaming, it relates to how gamers use different approaches to reach the objectives.
- Connecting: presenting leaning materials that ties different topics, subject areas, or real-world problems.
- Engaging: the degree of effort or time spent on a particular task, which is often related to motivation (Trowler 2010). The amount of time is determined based on the game artifacts created by the learners.
- Motivating: referring to perceived challenge and/or perceived enjoyment of the game.
- Visual learning: designing of visual components in order to achieve learning objectives and/or to create memorable experiences.
- Ease of using: the level of clarity of the game objectives and the degree of difficulty associated with the navigation of the game.
- Multiple representation: align with the Universal Design for Learning (UDL) (Rose and Meyer 2007), representing materials in multiple ways, including text, audio, illustrations, animation, and video.
- Scaffolding: providing structures to support students' learning. Examples of scaffolding include tutorials, guides to help learners while the game progress.

- Social learning: game elements promoting collaboration and or social learning. For example, the player is asked to help non-player characters (NPC) or involved in social interaction, or allowing/encouraging collaborative game play.
- Assessing: providing structures to inform the learners about their current state of skills/knowledge. For example, scoring systems or hit points are typical assessing structures in games.

Data and Analysis

This study was part of a larger research project in which various data sets were collected. The focus of this paper was on teachers' educational game design in connection with CT. Specifically, two sets of data: teachers' game design documents and the games they developed based on these design documents were used in this study. Teachers' design documents included their design rationales, educational objectives of their games, design constraints and ways in which the games could be used for learning. The games were initial levels of the games described in their design documents, supplied with the prototypes and tutorials.

Because teachers had the option to work collaboratively, the 80 participating teachers developed a total of 59 games amongst which 57 were accessible (2 games became inaccessible due to technical problems). Amongst these 57 functional games, only 48 were created using Scratch and therefore could be analyzed by Dr. Scratch. The 9 non-Scratch games were created by Java (5 games), Starlogo TNG (1 game), and Kodu or other software. As a result, CT skills and pedagogical perspectives were calculated for these 48 games.

Enactivists believe that reality exists inside the observer (Maturana and Varela 1987), hence research is an active process in which we form a complex world. Accordingly, it is critical to work from multiple perspectives which might include the embracement of different researchers as well as examination and reexamination of multiple forms of data (Reid 1995, Reid and Mgombelo 2015). In this study, multiple perspectives were adopted at different levels and using different approaches. For example, varied forms of data sets were collected and constantly re-visited for the purpose of deep analysis. Additionally, different researchers were involved in order to compare and contract divergent perspectives and enrich the interpretation of the results.

To answer the first and second research questions, descriptive statistics were adopted with the frequency counts and percentages reported. CT levels were assigned the following numbers: basic level= 1, developing level=2, proficient level =3. To answer the third research question, inferential statistics were conducted. Specifically, Fisher's exact tests were used to test the relationships between the CT levels and the Pedagogical levels demonstrated in teachers' games. Initially, chi-square tests were planned to examine these relationships. However, due to the fact that at least one cell had a sample size smaller than 5 in all the data tables, chi-square tests were replaced by Fisher' exact tests.

A total of 3 researchers were acted as the evaluator of the games. Realizing the subjective nature of some subscales of the Pedagogy Rubric of Teacher-

Created Games, consistent training to the evaluators was provided. Inter-rater reliability was also tested. First a total of 5 representative games were selected that reflected the wide spectrum of the teacher-created games. The 3 evaluators scored the 5 games and results were compared. The inter-rater reliability was lower than 0.80, a meeting was conducted to discuss the process, with a special focus on the discrepancies and possible reasons that caused the differences. An agreement was reached towards the end of the meeting. Then, the evaluators scored another 3 representative games and the inter-rater reliability was calculated again, reaching a score of 0.80.

Results

The first research question: "What levels of computational thinking do teachers demonstrate?" was answered by descriptive statistical analyses of the data. Dr. Scratch was used to calculate the levels of CT integrated in the games. Note that teachers were allowed to work in small groups, many chose to collaboratively develop their games. As a result, 57 games were created and within which only 48 were created using *Scratch*. Since *Dr. Scratch* can only apply to games created by *Scratch*, these 48 games were calculated for their CT skill levels. The frequency counts are detailed in Table 1.

Table 1 showed that all the games demonstrated a developing level of *user interactivity*. This is the only CT concept that was demonstrated by all the games, although no game scored proficiency. Similarly, almost all games (over 95%) scored developing for the concept of *abstraction*, while one game achieved proficiency level. *Parallelism* was the concept with the highest mean score where almost 89%, the highest percentage, of games achieved the proficiency level. This score was followed by the CT skill *synchronization* where over 60% (30 games) marked as proficient plus almost 30% (14 games) of the games were at the developing level. The concepts: *logic* and *flow control* both had over 40% (21 games) reached proficiency level, and about another 40% of the games achieved developing level. The means scores illustrated that on average, all the games scored at least the developing level for each of the CT concept evaluated.

Table 1. *Frequencies of CT Demonstrated in Games (N=48)*

	None	Basic (%)	Developing (%)	Proficient (%)	Mean score
Flow control	0 (0)	9 (18.8)	18 (37.5)	21 (43.8)	2.25
Data rep.	0 (0)	4 (8.3)	34 (70.8)	10 (20.8)	2.13
Abstraction	0 (0)	1 (2.1)	46 (95.8)	1 (2.1)	2.06
User Interact.	0 (0)	0 (0)	48 (100)	0 (0)	2.00
Synchronization	2 (4.2)	2. (4.2)	14 (29.2)	30 (62.5)	2.50
Parallelism	2 (4.2)	6 (12.5)	2 (4.2)	38 (79.2)	2.58
Logic	4 (8.3)	4 (8.3)	19 (39.6)	21 (43.8)	2.19

The frequency counts for the overall all CT levels and the mean score for all the games were also calculated, as shown in Table 2. According to Moreno-León and Robles (2015), an overall CT score with up to 7 points are considered at a basic level, scores between 8-14 points indicate a developing level, and 15 points or more are referred to as proficient. Table 2 shows that only 1 project scored 7, which belonged to the Basic level of CT. Over 40% of the projects demonstrated a developing level of CT skills. The majority of the project, that is, over 55% of the projects showed that teachers were able to demonstrate their CT skill at the proficiency level. The mean score of 15.71 indicated that on average, the games created by the teachers demonstrated an overall proficiency level of CT skills. Almost 98% of the games demonstrated the developing or proficient levels of CT skills.

Table 2. *Overall CT Levels as Demonstrated in Games*

	Basic level* (%)	Developing level (%)	Proficient level (%)	Mean score
Projects	1 (2.1)	20(41.7)	27 (56.2)	15.71

*basic level=1, developing level=2, proficient level=3

The research question 2 focused on the extent of pedagogical components teachers considered when building their own games. The descriptive statistics of pedagogy scores were detailed in Table 3 and showed that some interesting patterns emerged. First, *visual learning* had the highest percentage of games that is over 80%, scored fair or extensive presentation. Additional four pedagogical components also had more than half of the games achieved a rank where they fairly or substantially represented every category. These categories were *engaging* (72.7%), *ease of using* (63.2%), *assessing* (63.2%), and *motivating* (56%). In comparison, only 5 of the 57 games, i.e., less than 10% integrated *strategizing*, while similar number of games (i.e., close to 90%) only minimally integrated *problem solving*. For the categories *scaffolding*, *connecting* and *critical thinking*, only about one in four games represented them fairly or substantially.

Table 3. *Frequencies of Pedagogical Components Integrated in Games (N=57)*

	Level 0* (%)	Level 1 (%)	Level 2 (%)	Mean
Pro. Solv.	50 (87.7)	5 (8.8)	2 (3.5)	0.16
Cri. Th./ reasoning	42(73.7)	12 (21.1)	3 (5.3)	0.32
Connecting	42 (73.7)	12 (21.1)	3 (5.3)	0.32
Strategizing	52 (91.2)	4 (7.0)	1 (1.8)	0.11
Engaging	19 (33.3)	28 (49.1)	10 (17.5)	0.84
Motivating	25 (43.9)	28 (49.1)	4 (7.0)	0.63
Visual learning	10 (17.5)	41 (71.9)	6 (10.5)	0.93
Ease of using	21 (36.8)	31 (54.4)	5 (8.8)	0.72
Multiple representation	33 (57.9)	19 (33.3)	5 (8.8)	0.51
Social learning	33 (57.9)	23 (40.4)	1 (1.8)	0.44
Scaffolding	43 (75.4)	13 (22.8)	1 (1.8)	0.26
Assessing	21 (36.8)	31 (54.4)	5 (8.8)	0.72

*Level 0= minimally represented; level 1= fairly represented; level 2= substantially represented

The third research question aimed to investigate whether the level of computation thinking was connected to the pedagogical levels. Fisher exact tests were used to examine possible relationships between CT variables and Pedagogy with an alpha of 0.05. Due to the relatively small sample size, both the CT levels and pedagogy categories were reorganized. The CT levels were regrouped into 2 categories: the *None* and *Basic* levels were grouped together defined as the *Entry* level, and the *Developing* and *Proficient* levels were grouped into the *Competent* level. Similarly, the pedagogical levels were regrouped into 2 categories: level 0 was considered as the *Trivial* level, while the levels 1 and 2 were combined to form the second category named as the *Ample* level. Significant relationships were identified in five sets of variables. See Tables 4-9 for the Fisher exact tests results.

Table 4. *Fisher's Exact Test -Flow Control*

		Entry	**Competent**	**p-value**
Problem Solving	Trivial	9	36	1.00
	Ample	0	3	
Critical Thinking / Reasoning	Trivial	7	29	1.00
	Ample	2	10	
Connecting	Trivial	8	29	0.66
	Ample	1	10	
Strategizing	Trivial	8	38	0.34
	Ample	1	1	
Engaging	Trivial	4	14	0.71
	Ample	5	25	
Motivating	Trivial	5	19	1.00
	Ample	4	20	
Visual Learning	Trivial	1	9	0.66
	Ample	8	30	
Ease of Using	Trivial	2	17	0.29
	Ample	7	22	
Multiple Representation	Trivial	5	25	0.71
	Ample	4	14	
Social learning	Trivial	7	23	0.45
	Ample	2	16	
Scaffolding	Trivial	8	32	1.00
	Ample	1	7	
Assessing	Trivial	3	15	1.00
	Ample	6	24	

Table 5. *Fisher's Exact Test - Data Representation*

		Entry	Competent	p-value
Problem Solving	Trivial	4	41	1.00
	Ample	0	3	
Critical Thinking / Reasoning	Trivial	3	33	1.00
	Ample	1	11	
Connecting	Trivial	4	33	0.56
	Ample	0	11	
Strategizing	Trivial	4	42	1.00
	Ample	0	2	
Engaging	Trivial	4	14	0.02*
	Ample	0	30	
Motivating	Trivial	4	20	0.11
	Ample	0	24	
Visual Learning	Trivial	3	7	0.03*
	Ample	1	37	
Ease of Using	Trivial	3	16	0.29
	Ample	1	28	
Multiple Representation	Trivial	3	27	1.00
	Ample	1	17	
Social learning	Trivial	3	27	1.00
	Ample	1	17	
Scaffolding	Trivial	4	36	1.00
	Ample	0	8	
Assessing	Trivial	4	14	0.02*
	Ample	0	30	

Table 6. *Fisher's Exact Test - Abstraction*

		Entry	Competent	p-value
Problem Solving	Trivial	44	1	1.00
	Ample	3	0	
Critical Thinking / Reasoning	Trivial	35	1	1.00
	Ample	12	0	
Connecting	Trivial	36	1	1.00
	Ample	11	0	
Strategizing	Trivial	45	1	1.00
	Ample	2	0	
Engaging	Trivial	17	1	0.38
	Ample	30	0	
Motivating	Trivial	23	1	1.00
	Ample	24	0	
Visual Learning	Trivial	10	0	1.00
	Ample	37	1	
Ease of Using	Trivial	18	1	0.40
	Ample	29	0	
Multiple Representation	Trivial	29	1	1.00
	Ample	18	0	
Social learning	Trivial	29	1	1.00
	Ample	18	0	
Scaffolding	Trivial	39	1	1.00
	Ample	8	0	
Assessing	Trivial	18	0	1.00
	Ample	29	1	

Table 7. *Fisher's Exact Test - Synchronization*

		Entry	Competent	p-value
Problem Solving	Trivial	4	41	1.00
	Ample	0	3	
Critical Thinking / Reasoning	Trivial	4	32	0.56
	Ample	0	12	
Connecting	Trivial	4	33	0.56
	Ample	0	11	
Strategizing	Trivial	4	42	1.00
	Ample	0	2	
Engaging	Trivial	3	15	0.14
	Ample	1	29	
Motivating	Trivial	4	20	0.06
	Ample	0	24	
Visual Learning	Trivial	1	9	1.00
	Ample	3	35	
Ease of Using	Trivial	2	17	1.00
	Ample	2	27	
Multiple Representation	Trivial	3	27	1.00
	Ample	1	17	
Social learning	Trivial	3	27	1.00
	Ample	1	17	
Scaffolding	Trivial	4	36	1.00
	Ample	0	8	
Assessing	Trivial	2	16	0.62
	Ample	2	28	

Table 8. *Fisher's Exact Test - Parallelism*

		Entry	Competent	p-value
Problem Solving	Trivial	8	37	1.00
	Ample	0	3	
Critical Thinking / Reasoning	Trivial	8	28	0.17
	Ample	0	12	
Connecting	Trivial	8	29	0.17
	Ample	0	11	
Strategizing	Trivial	8	38	1.00
	Ample	0	2	
Engaging	Trivial	5	13	0.13
	Ample	3	27	
Motivating	Trivial	7	17	< 0.05*
	Ample	1	23	
Visual Learning	Trivial	2	8	0.67
	Ample	6	32	
Ease of Using	Trivial	5	14	0.24
	Ample	3	26	
Multiple Representation	Trivial	7	23	0.23
	Ample	1	17	
Social learning	Trivial	7	23	0.23
	Ample	1	17	
Scaffolding	Trivial	7	33	1.00
	Ample	1	7	
Assessing	Trivial	4	14	0.45
	Ample	4	26	

Table 9. *Fisher's Exact Test - Logic*

		Entry	Competent	p-value
Problem Solving	Trivial	8	37	1.00
	Ample	0	3	
Critical Thinking / Reasoning	Trivial	8	28	0.17
	Ample	0	12	
Connecting	Trivial	7	30	0.66
	Ample	1	10	
Strategizing	Trivial	8	38	1.00
	Ample	0	2	
Engaging	Trivial	5	13	0.13
	Ample	3	27	
Motivating	Trivial	7	17	< 0.05*
	Ample	1	23	
Visual Learning	Trivial	3	7	0.34
	Ample	5	33	
Ease of Using	Trivial	4	15	0.70
	Ample	4	25	
Multiple Representation	Trivial	6	24	0.70
	Ample	2	16	
Social learning	Trivial	7	23	0.23
	Ample	1	17	
Scaffolding	Trivial	8	32	0.32
	Ample	0	8	
Assessing	Trivial	5	13	0.13
	Ample	3	27	

The Fisher exact tests showed a total of 5 significant relationships, which are described below. *Data representation*, a subcategory of CT, demonstrated significant associations with 3 pedagogical elements: *engaging*, *visual learning* and *assessing*.

First, a Fisher exact test indicated a significant association between *engaging* level and *Data Representation* used in the games, p=0.02. A significant greater number of games with high engagement representations demonstrated high levels of data representation than low engagement games.

Second, *Data Representation* integrated in games was positively associated with *visual learning* level, as indicated by a Fisher exact test, p=0.03. That is, significantly more high-visual learning games than low-visual learning games showed competent level of Data Representation.

Third, *Data Representation* integrated in games had a positive relationship with *Assessing* level as indicated by a Fisher exact test, p=0.02. That is, a significantly greater number of games with Competent level of data representation had Ample level of assessing than the games with only the entry-level of data representation.

Fourth, a Fisher exact test demonstrated that Parallelism skills in games was positively connected with Motivating levels, p<0.05. More games with Competent level of Parallelism had the Ample level of Motivating when compared with games of only entry-level Parallelism skills.

Last, *Logic* integrated in games was positively associated with *Motivating* level, $p<0.05$. That is, a greater number of Competent *Logic* games had the Ample level of *Motivating*.

Discussion

Aiming to understand enactivism through the application of the theory to practice, this study has successfully implemented the theory in a teacher education classroom. The enactivist learning world incorporates complex real-world problems to stimulate learners' curiosity while providing them great freedom of exploration.

Major Findings

This study of teacher game design in relation to CT reveals a few key findings worthy of further discussion. It is important to note that all the teachers had created games individually or collaboratively. Because many teachers worked in small groups, only 57 games (48 games created using Scratch) have been developed by the 80 teachers.

While shedding new lights on several fields of study, the most significant result is that the enactivist learning world has created rich opportunities for teachers to grow professionally, allowing them to develop competencies in both digital game based learning and CT. On average, the teacher created games demonstrate an overall proficiency level of CT skills. This is particularly interesting because CT has never been the focus of the content learning. In the course, although some small coding tasks have been integrated in the course to scaffold teachers' game development, it is important to note that the learning have been aimed to enhance teachers understanding of pedagogical knowledge related to game based learning rather than CT. Further, almost all of the Scratch games evaluated were created by teachers with limited or no prior coding experience. Yet, the teachers, through the *doing* of game design, have learned a great deal of CT skills, as proved by the fact that on average, the games demonstrate the overall CT skills at the proficiency level, and almost all the games created achieved either the developing or proficiency level of CT. An important implication is that learning through game design can provide a valuable platform to integrate CT education while learners study different content subjects. Since finding time for standalone computer science/CT courses remains to be a significant challenge, the idea of integrating CT in learning of different subject matter deem to be optimal. As researchers have argued (Yadav et al. 2017), teacher education programs need to prepare teachers with required skills, knowledge, and pedagogy to incorporate CT into their teaching practice. The current study suggests that learning through game building can provide an ideal setting to help teachers gain essential skills to embed CT into their classrooms. This, of course, depends on the readiness of the environment, including the technical requirements for making digital games are enabled. It also confirms previous work (Yadav et al. 2017) that although coding is a critical aspect of CT, standalone courses focusing on teaching programming per se in teacher preparation programs is not required. Rather, as illustrated in this study, CT can be organically embedded in the teachers' content learning.

Enactivism views that knowing is a process of adaptation and evolution (Maheux and Proulx 2015). In this view, learning is the learner's interaction with the environment where s/he and the environment coevolve in an adaptive fashion: teachers' behavior, their gaming experience, their coding, their explorations, although may not be the best, are adequate acts that allow them to function in the environment, in this case to build functional educational games. To know, from an enactivist perspective, is to be functional in the environment. Teachers' knowing of CT is the coevolving acts of the teachers and their milieu that enable them to respond sufficiently in the course, e.g. to produce operable games. In this study, an enactivist learning environment has been built where teachers unintentionally gain CT skills through the doing of game design and building. Teachers continued interaction with their environment, including the software, the games, the design conversations, the fellow teachers, their own students, all contributes to their learning of both CT and pedagogy, and enables them to maintain their fit into the context.

Secondly, in a vast majority of the teacher-created games, five (i.e., visual learning, engagement, ease of use, assessment, motivation) of the 12 pedagogical components are fairly or extensively represented. The fact that over 80% of the games scored fair or extensive in the visual learning components indicates that most of the games have a highly visual design. This is exciting because sight is the dominant sense for most of us to understand the world. Good visual design in educational games, therefore, can significantly aid students' learning (Plass et al. 2014). Previous research (Ruecker et al. 2007, Taylor and Baskett 2009) shows that good visual design can improve confidence and make players to be more engaged in the gaming experience. In this study, these games with high levels of visual design mean that the teachers not only understand the significance of visual learning but also able to successfully integrate the visual design elements in their games.

On the one hand, the motivational value of good games has long been recognized (Gee 2009). Although not surprising, we applaud that the teachers have put considerable amount of efforts on making the games engaging and motivating for their audiences and are able to transfer such pedagogical aspect into their game design. On the other hand, three aspects (i.e., scaffolding, connecting, critical thinking) are fairly or extensively represented in only one fourth of the games, while strategizing and problem solving are barely expressed in almost 90% of the games. This points to a significant issue that deserves further exploration. Game design and building is a complex process demanding teachers to constantly solve problems, connect different content knowledge, and think critically. In the course, scaffolds have been provided throughout their development of the games. Yet, as shown in study, transferring these skills into their own educational games remains to be challenging. This is consistent with previous results that transferring knowledge into action is difficult (Ward et al. 2009).

In this study, although most of the teachers had zero or limited prior programming experience, let alone game design knowledge, all the teachers eventually have mastered enough skills within the gaming software to generate adequate games that at the very least give a fair representative score on the Pedagogy Rubric. Koehler and Mishra (2005) suggest that while teachers' knowledge of technology is important, it is what teachers can do with technology that is specifically critical to them in the conveyance of content knowledge. Technology in this respect is games. This puts forward the possibility that the game design approach may be able to create a contextual platform for learning of content as well as CT. Game building may provide a great platform for cross-curricular embedding and merging several contents, whether math, social studies, science or other topics, into one location: the game itself.

Third, the results of this study also show interesting relationships between some CT concepts and pedagogical aspects demonstrated in these teacher-created games. For one, affective pedagogical perspectives like *motivating* are related to both *parallelism* and *logic*, while *engaging* is positively associated with *data representation*. Since the engagement value is a common part of gaming, and the teachers often realize the significance of this value in learning, it makes sense to encourage the integration of affective perspectives when teachers develop educational games as it may also enhance their understanding of various CT skills. As well, *visual learning* is positively correlated with *data representation*. The educational benefit of visual learning associated with games is already proven, suggesting that we should stimulate teachers' interest in visual design elements while designing their games. This may in turn, enhance teachers' understanding of certain CT skills.

A fourth key finding relates to the topic of unintentional learning. Unlike other theoretical perspectives such as behaviorism and constructivism that ignore unintentional learning, enactivism pays particular attention to such learning (Davis et al. 2008). In this study, many of the teacher-created games fairly or extensively represented in the rubric categories, suggesting that game building is complex yet manageable for teachers. One might question that since the focus of the course is on pedagogy of digital game based learning, why do some games not score high enough in certain pedagogical aspects? It is important to point out that the focus of the course is to help teachers develop pedagogical knowledge to integrate games into classrooms rather than integrating pedagogy into game design/development, two separate, but overlapping, concepts. Since the strategies of using existing games for instructional purposes or learning through game building are different from integrating sound pedagogy into instructional game development, it is not surprising that discrepancies are identified. That is, while teachers have good understanding of how to appropriately employ instructional games in classrooms (as demonstrated in their course grades and other artifacts which are beyond the scope of this paper), some may not know how to incorporate good pedagogy into game design.

The fact that almost all the games demonstrate at least a developing level in CT skills and an average score of the overall CT skills at the proficiency level highlights the value of game building in helping teachers exercise their CT skills, probably even without noticing. In here, teachers' co-evolvement with their environment, including the game developing software, to create functional games for their learners has resulted in their advanced understanding of CT skills - an outcome that is not originally considered and has never been the focus. This confirms the significance of such inadvertent learning as emphasized in enactivism.

Another important contribution of this study is the adoption of quantitative design to explore enactivism. A review of the existing literature related enactivism shows that a vast majority, if not all, of enactivist studies have employed qualitative approaches. Enactivism stresses the importance of multiple perspectives, which therefore, suggests a dire need of enactivist works utilizing varied research design to broaden our understanding of this theoretical framework and its application. This study adds to the field of enactivism through a quantitative design to examine teachers' game building experience.

Conclusions

Like any educational research, this study has its limitations. First, although 80 teachers participated, many worked in small groups of two or three. As a result, only 57 games are developed and only 48 games are available for the analysis related to CT due to the limitation of the analysis tool: *Dr. Scratch*. Future studies with a larger sample size of the games are therefore recommended. Another limitation is the teacher created games are analyzed without involving the intended audience-their students. Future work is suggested to integrate long-term testing, allowing teachers to work directly with their audience to iteratively produce a mutually successful game and at the same time practicing CT skills.

Another limitation is the narrow focus of CT studied in this paper. Although the definitions described in the literature section contains rich concepts that go beyond programming alone, this study only focuses on the cognitive aspects. Future work is recommended to include other essential components, such as affective factors.

From an enactivist perspective, it would be challenging, if not impossible, to teach someone else skills that are not currently embodied or experienced by the teachers. As such, providing teachers with opportunities of practicing CT skills may help them better facilitate these skills in their own classrooms. Further, the focus of the current study is not on the development of effective games but rather on the teachers' development of sound pedagogy situated in the context of game design and building. This suggests that teachers spend more time on pedagogical learning of how to integrate games into classrooms instead of polishing the quality of the games, although we see from the results discussed above that the teachers have produced 'good enough' games. The unintentional outcome of teachers' enhanced CT skills underscores the significance of the successful development of the enactivist learning world.

As discussed above, game design process encompasses complex problems that require the designer to constantly solve problems, think critically, connect learning to different subjects and the real world, and strategize. Yet, the results of the study show that teachers require support to transfer their experiences in these fields to their games. While involving teachers in their own game design and building is a positive move forward, additional guidance in this area would further benefit teachers. The potential of digital game building is unlimited and we can expect that it can empower teachers and their students in this information era.

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Appendix

Pedagogical Rubric

#	Category	Minimal Representation	Fair Representation	Extensive Representation
1	Problem solving	No events or one small event that promote problem solving.	One substantial event, or two to three distinct events that promote problem solving.	More than one substantial event, or more than three distinct small events that promote problem solving.
2	Critical thinking	No events or one small event that promote critical thinking.	One substantial event, or two to three distinct events that promote critical thinking.	More than one substantial event, or more than three distinct small events that promote critical thinking.
3	Connecting	No events or one small event that showed the connection of the learning materials to the other context/real world problem.	One substantial event, or two to three distinct events that showed connection of the learning materials to the other context/real world problem.	More than one substantial event, or more than three distinct small events that showed connection of the learning materials to the other context/real world problem.
4	Strategizing	No events or one small event that promote executive functions/strategy.	One substantial event, or two to three distinct events that promote executive functions/strategy.	More than one substantial event, or more than three distinct small events that promote executive functions/strategy.
5	Engaging	The game can be done in less than five minutes, and gamers most likely do not want to replay the game.	The game can be done in five to ten minutes but gamers are not likely willing to replay the game. Or gamers are likely willing to replay the game and the game can be done in less than 5 minutes.	The game can be done in more than 10 minutes and the gamers may not want to replay the game. Or the game can be done in more than five minutes and gamers are likely willing to replay the game.
6	Motivating	The game play/activity is not challenging or fun to play	The game play/activity is challenging and or fun to play	The game play/activity is extremely challenging and or really fun to play
7	Visual learning	The game has unappealing or	The game a clean and coherent visual design	The game has exquisite visual design that is

		incoherent visual representation. And/or contains unnecessary visual elements that distract game play and or learning.	without unnecessary visual elements that distract game play or learning process. It is somewhat aesthetically pleasing.	unique and creates memorable learning experience. All visual elements are carefully designed without anything distracting players.
8	Ease of using	Confusing or unclear objectives and or instructions. Five or more elements that caused major frustration in play and may cause player to stop playing	Clear objectives and instructions of the game. One to four elements that cause minor frustration in play	Very clear objectives and instructions of the game. No elements that cause frustration.
9	Multiple representation	The game relies on single representation of the learning materials.	The game presents the learning materials on two kinds of representation.	The game presents the learning materials on more than two kinds or representation.
10	Social learning	The game doesn't promote any form of collaborations/social interaction with other players or with other objects in the game.	One substantial event, or two to three distinct events that promote collaboration/social interaction whether it is with non-player characters or with other players.	More than one substantial event, or more than three distinct small events encourage collaborations/social interaction whether it is with non-player characters or with other players in the game play.
11	Scaffolding	No scaffolding occurs within the game. There is no support for progression of knowledge or concepts in the game	The game creates scaffolding through tutorials or guides, but the scaffolding is incomplete or in appropriate in some way.	The game includes very clear scaffolding structures. It sets up stages and levels so that the concepts progress in an increasingly challenging way.
12	Assessing	The game has no structure that helps gamers assess their level or situation within the game. Gamers may feel lost when trying to understand their abilities and/or achievement in the game.	The game provides tools (e.g. hit points, level ups, etc.) to assess the gamers' progression in some but all aspects.	The game is set up in a way that makes the gamer knows how his/her character is doing, what levels have been achieved or need to be, and is able to make conjectures on the gameplay because of it.

Total Score: xx/ 24