# TEACHING SECONDARY MATHEMATICS: PRE-SERVICE TEACHERS' DIGITAL GAME DESIGN, PEDAGOGY AND 21ST CENTURY SKILLS

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## ABSTRACT

*This paper reports a study of preservice teachers' learning of pedagogy by immersing them in digital game design and building to teach secondary math. Specifically,*

1. *What pedagogical skills do pre-service teachers incorporate into their games?*
2. *What 21st century skills do pre-service teachers demonstrate in the design and implementation of their games?*

*Framed in a naturalistic research perspective, the participants were 21 preservice math teachers. Data included participants' created digital games, pre- and post-surveys, and interviews. The results showed that almost all pedagogical categories were being significantly addressed by the participants' created games. During the game building process, participants utilized every 21st century skill to a certain degree, most significantly: creativity, problem solving, collaboration, flexibility and adaptability, and perseverance.*

## INTRODUCTION

Technology development in the last decades has impacted our economy, culture and society drastically. To be productive and active members of this new society, we need to acquire different skills, namely the 21st century skills (Jenkins et al., 2006). How do educators prepare children for this new age? Learning-by-game-building is proposed to be an effective approach (Gee, 2009; Pacific Policy Research Center, 2010) to help students gain the 21st century skills, considering that 97% of teens aged 12-17 play digital games (Lenhart et al., 2008).

This highlights the need to empower preservice teachers (hereafter teachers) to develop the appropriate technological and pedagogical expertise required to adopt the learning-by-game-design approach. One way to address such need is to immerse preservice teachers in the experience of designing and building their own games. This experience can help pre-service teachers acquire knowledge and tools needed in their pursuit of teaching excellent (King, 2011). Further, it can provide them opportunities to experience and test the pedagogical and technical strategies to promote learning of 21st century skills.

This paper examines pre-service teachers' experiences of learning-by-game-building, guided by two research questions: 1) what pedagogical skills do pre-service teachers incorporate into their games? 2) What 21st century skills do pre-service teachers demonstrate in the design and implementation of their games?

## RELATED LITERATURE AND THEORETICAL PERSPECTIVE

Studies involving the use of technology in mathematics teacher education have focused on two areas: use of technology to explore the mathematics concepts (e.g. Bowers & Doerr, 2001; Ozmantar et al., 2010) and integrating the learning of content and pedagogy through the use of technology (e.g. Gorev et al., 2004; Ozgun-Koca et al., 2010). The study being reported in this paper contributes to this body of literature in terms of its focus on a different technological tool as well as skills involved in the game building process and the outcomes.

This paper is grounded in the theory of "enactivism" (Li et al., 2010) as applied to educational technology. The theory of enactivism has two major premises. The first premise is that the mind, body, and world are inseparable (Fenwick, 2000). Enactivism believes that the personal history of the subject and the setting affect the outcomes of events. That is, the outcome of a specific learning activity is determined by the environment of the activity (time, place, etc.) and by the participant (gender, cultural background, action, etc.) (Li et al., 2010).

The second premise is that learning occurs through feedback within the system (Fenwick, 2000). As such, cognition is a complex process of individuals interacting and affecting each other and their environments (Davis et al., 2008). Enactivism places emphasis on knowledge co-authoring. As researchers (Li et al., 2010) state "[a]ll living systems have to be involved in cognition, and cognition is active rather than passive." (p. 8).

Enactivism holds different beliefs from either behaviourism or constructivism. Behaviorism and constructivism share similar assumptions although they appeared to be completely different (Davis et al., 2000). A noticeable such shared assumption is that cognition sits inside the individual's body isolated from the world and other people. Reality (the real world) is separated from the mind, even though the two theories have different views about where it is. Behaviorists assert that reality is external to the knower, is structured, and that the structure can be modeled. The purpose of learning is to mirror this abstract reality and its structure through thinking (Davis & Sumara, 1997b). Constructivism, regardless of the version, assumes that reality is formed from the mind of the knower through his/her construction (Dewey, 1933; Piaget, 1954; Vygotsky, 1978). Therefore, both behaviorism and constructivism accepts dualism and interprets cognition in mechanistic ways.

Enactivism, in contrast, rejects dualism that divides self from world, mind from body, or subject from object. Therefore, both behaviorism and constructivism focus on knowledge, whereas enactivism emphasizes knowing. Enactivism rejects the idea that knowledge consists of separate objects different from the world. Rather, "all cognition exists in the interstices of a complex ecology of organism relationality" (Davis & Sumara, 1997a, p.110).

In enactivism, thinking and cognition are grounded in action (Holton, 2010). The core characteristics of digital game-building are doing and co-authoring, which provide an ideal platform for creating an enactivist world in the context of a participatory culture. In this learning world, the pre-service teachers are asked to design and build a digital game targeting a specific mathematics topic. The assumption is that the games they create will embody the cognitive processes used and the processes intended for students to use when playing their games.

## Methods

The study was framed in a qualitative, naturalistic research perspective (Creswell, 1998) that focused on capturing and interpreting the participants' thinking about the use of a technological tool in teaching mathematics

**Participants:** The participants were 21 students (10 males, 11 females) in the second semester of their two-year post-degree education program at a Canadian university, age ranged from 20 to 45 years old. This was their first course in mathematics education, so they had no instruction or theory on technology in mathematics education prior to this experience.

The course focused on promoting understanding of mathematics education in the context of learner-focused, inquiry-based, and field-oriented platform. Aside from various in class and outside tasks and assignments, a major component was to design and build a digital game. Participants worked individually or in small groups.

**Game Process:** Following is a brief outline of how this process engaged the participants

1. Beginning of semester:
    a. They completed a pre-survey examining their attitudes toward game based learning
    b. They played some existing educational games
    c. In small groups, each group was required to create a lesson plan to teach secondary math concepts integration educational games
2. Middle of semester:
    a. Working in small groups, each group created a board game based on an existing movie.
    b. Groups play-tested each other's board games and provided feedback
    c. They were briefly introduced to Scratch (a game development software) with no reference to teaching mathematics.
3. End of semester
    a. They were required to create games focusing on an algebraic concept of choice. They were required to play test their own prototype before developing the final game.
    b. They were required to complete a post-survey exploring their experience and perceptions related to game design.
    c. They showcased and played each other's games.

During this process, participants were not required to research the uses of games in teaching mathematics.

**Data and Instruments:** Three sets of data were collected: open-ended pre and post surveys, games created, as well as follow up interviews with selected participants. The pre-survey was given in the first week of class and the post-survey was given after participants had finished their games building. The second set of data was the participants' created games. The third set of data consisted the follow-up interviews of selected participants six weeks after the course completed. Also included was the notes made by the instructor based on individual, small-groups and whole-class discussions.

**Rubric:** In this study, a pedagogical rubric, including knowledge, game-play, and playability, was developed to evaluate the participants' created games. Each game was ranked as either "not meeting expectations", "meeting expectations", or "exceeding expectations".

The iterative development process started with a discussion of all researchers based on the curriculum standards, e.g. NCTM Standards (2000), and the critical pedagogical understanding required for pre-service mathematics teachers. Then, two researchers independently evaluated three representative games using the initial rubric. Then, five researchers worked together to compare the results, paying particular attention to disagreements. Such discussions then led to the modification of the instruments. After many rounds of testing and fine-tuning of each category of the rubric, a final version of the pedagogical rubric was developed and was used to evaluate all the games

**Analysis:** The first research question was answered by evaluating the games created based on the pedagogical rubric. Each category was assigned a rank. The games were then analyzed by looking at the descriptive statistics of the results. Since the data were non-ordinal, the median was used for analysis and no measures of variation were applied.

To answer the second research question, four researchers started to closely scrutinize the qualitative data, working independently, to identify themes related to the 21$^{st}$ century skills. Based on these themes, a coding form was developed and used to code the interviews, games, the surveys and the instructor's notes. Frequency analysis was made to support the qualitative findings regarding the distribution of the themes. Verification procedures included triangulation with the various data sources, cross checks by research team, and elimination of initial themes based on disconfirming evidence. This paper focus only on the findings pertaining to the two research questions previously noted.

## SUMMARY OF RESULTS

### Pedagogical Skills

What pedagogical aspects were demonstrated in preservice created games? Analysis of data showed that all but one pedagogical category was being significantly addressed by most games (see table 1 and 2). Specifically, more than half of the games achieved at least the rank of “meeting expectations” in the categories of *representation, active learning, exploration and reasoning, engagement/ motivation, participation*, and *user friendly.*

The category of *engagement/motivation* was worthy of a special notion because every game achieved “meeting expectations” or “exceeding expectations”. For *problem solving* and *strategy*, half of the games ranked “meeting expectations” or higher. C*onnections* was the only category that more than half of the games “not meeting expectations.”

In 12 of the 14 games, players were required to represent mathematical ideas in a variety of forms and apply different concepts across different mathematical areas. For example, in the game *Equalia*, players saw the equations as sets of objects on two sides of fence, interpreted these representations mathematically, then manipulated them to get the desired results.

*Active learning*, *problem solving* and *exploration and reasoning* were organically integrated in many of the game integrated. As exemplified in the game *Shellshocked 2*, these important pedagogical considerations were embedded into the fun and engaging game experience. In this game, the players needed to gain a certain number of fire and water crystals. They must actively develop a strategy on how they were going to arrive at their goal. They needed to explore different options and to reason their way through their problems. The mathematics concepts and principles were implicit, forcing players to use different skills.

Considering that all of the games at least met expectations in the category of *engagement and motivation*, thirteen of the fourteen games were designed to encourage the majority of students to play and enjoy the games, as well as eleven of the games were *user friendly*, we could conclude with confidence that pre-service teachers made reasonably enjoyable games.

*Connections* was another category that worthy of further discussion because it is the only category that more than half games failed. However, there were four games that focused entirely on applications of mathematical ideas to the real world, therefore making *connections* their main focus. For example, The *Date Game* was about either a child getting ready for a date by getting his/her hair done, buying a new outfit, and getting a present for his/her date. The game connected solving linear equations to students’ lives.

### Twenty-First Century Skills

During the game design and building process, participants utilized every 21$^{st}$ century skill to a certain degree. The following five dominant themes were identified: creativity and innovation, problem solving, collaboration, flexibility and adaptability, and perseverance.

*Creativity and innovation skills*: this theme was prominently demonstrated from three perspectives. The first perspective was the comparison of pre and post survey. In the presurvey, a majority of the participants identified the challenge being whether they would be creative enough to design games. Only one participant mentioned this challenge in the post survey, indicating that the design and building process allowed participants to exercise and discover their creative and innovative abilities. The second perspective was the follow up interviews, as exemplified by participant RK’s statement, “From nothing

**Table 1**
**Counts for each rank of pedagogical rubric (individual categories)**

| Category | Not meeting expectations | Meeting expectations | Exceeding expectations | Mean | Median | Mode |
|---|---|---|---|---|---|---|
| Problem solving | 7 | 3 | 4 | 0.79 | 0.5 | 0 |
| Representation | 2 | 10 | 2 | 1.00 | 1 | 1 |
| Active learning | 2 | 9 | 3 | 1.07 | 1 | 1 |
| Exploration and Reasoning | 6 | 6 | 2 | 0.71 | 1 | 0 |
| Connections | 9 | 3 | 2 | 0.50 | 0 | 0 |
| Strategy | 7 | 5 | 2 | 0.64 | 0.5 | 0 |
| Engagement/motivation | 0 | 13 | 1 | 1.07 | 1 | 1 |
| Participation | 1 | 10 | 3 | 1.14 | 1 | 1 |
| User friendly/ease of play | 3 | 9 | 2 | 0.93 | 1 | 1 |

- 0= “does not meet expectations,” 1= “meets expectations, and 2= “exceed expectations”.
  The highest score a game can get is 18 points.

I made a game." The third perspective came from the analysis of the games. All games incorporated creative or imaginative components to engage players.

*Problem solving*: This skill were constantly exercised, but most prominently occurred during the process of programming and de-bugging the game, as exemplified by the following comment: "Problem solving was a large component of the design. This was used in figuring out how the programming language worked and the debugging." (participant CV)

*Collaboration*: Although had the option to work individually or in small groups, all participants collaborated one way or another. Even for those who worked individually, their game design started in a small group setting and their prototypes of the games were tested and discussed during the class where classmates provided valuable feedback. For those who chose to work in groups, collaboration was an ongoing process from conceiving the game ideas to the final finishing of the game.

Collaboration was also demonstrated outside of small group work. Since everyone was learning how to use a game interface, they helped each other often even if they weren't in the same group. This was exemplified during one class when Participant MT had already learned to use Kodu and gave the class an impromptu lesson to introduce the software.

*Information literacy*: initially these skills were not considered necessary. Yet we were surprised by the extent that these skills were exercised. Many participants noted in class the use of tutorials and internet searches as methods for learning how to program in their chosen game interface. Using information literacy skills by finding, assessing, managing information's was common practice both in and out of classes.

*Perseverance:* although not outlined by the *Partnership for 21st Century Skills*, perseverance emerged as a crucial skill. Participants encountered many, from pedagogical to technical, challenges during their design and building process. Perseverance was a critical factor for ensuring the success of the game building. For example, when confronted with technical difficulties, many teams showed determination by trying a variety of different solutions until they found what worked. The follow up interviews also demonstrated this theme as exemplified by this comment: "I have learned to persevere. I had a lot of difficulty at the beginning, but kept at it and finally got a great product." (participant EM)

## DISCUSSION

In this study, we have intentionally provided rich opportunities for the preservice teachers to explore freely, engendering self-initiative and eliminating the crutches that give them excuses to give up. Digital game design, with no expert programmer or designer available, is a tool that embodies the skill of persistence. In this world, teachers have designed games in different programs that the instructor is not an expert in. Thus one of the biggest crutches in the classroom has been eliminated: the instructor sometimes does not know the answer. No longer can they rely on someone else to provide answers. In addition, self-initiative is encompassed in the process. When teachers overcome the problems, the result is a functional game that can be shared with others with excitement and pride. An important implication is that instructors should be comfortable not being an expert in every aspect and to provide learners freedom to discover. In this study, allowing the teachers to struggle through their difficulties has resulted in their discovery of their creativity and to build confidence.

Teachers in this study demonstrate all the 21st century skills through the game design and building experience. This is consistent with previous conclusion by Sardone and Devlin-Scherer (2010), demonstrating that the use of digital games in the classroom allow teachers to use twenty-first century skills, in particular in the area of learning and innovation.

Learning in such an enactivist world has impacted teachers positively in various ways, from changed perception to the demonstrated 21st century skills. From the enactivist perspective, it would be difficult to teach someone else a skill that was not currently embodied or experienced by the teacher. As such, providing teachers with experiences of exercising 21st century skills may help them better facilitate these skills in their future classrooms.

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**Table 2**
**Summary of pedagogical rubric (total scores)**

| Statistic | Result |
|---|---|
| Count | 14 |
| Mean | 7.9 |
| Median | 8 |
| Mode | 8 |
| Minimum | 3 |
| Maximum | 11 |

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