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An implementation of design-based learning through creating educational computer games: A case study on mathematics learning during design and computing

Fengfeng Ke*

Educational Psychology and Learning Systems, College of Education, Florida State University, Tallahassee, FL 32306-4453, USA

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ABSTRACT

This mixed-method case study examined the potential of computer-assisted, math game making activities in facilitating design-based math learning for school children. Sixty-four middle school children participated in Scratch-based, math game making activities. Data were collected via activity and conversation observation, artifact analysis, interviewing, and survey. The study findings indicated that participants developed significantly more positive dispositions toward mathematics after computer game making. The study also found that experience-driven game design processes helped to activate children's reflection on everyday mathematical experiences. Mathematical thinking and content experience were intertwined within the process of computer game authoring. On the other hand, children designers were involved in game-world and story crafting more than mathematical representation. And it was still challenging for them to perform computer game coding with abstract reasoning.

1. Introduction

Constructionists argue that learners actively construct knowledge out of their experiences, especially when they are engaged in building objects (Kafai, 1995; Papert, 1980). That is, learning occurs when the learners' active exploration (i.e., artifact design and creation) makes them develop a knowledge representation of their experience or discover an inconsistency between their current knowledge representation and their experience. Attributed to social constructivism, learning usually occurs within a social context in which interactions between learners and peers will activate collaborative exploration, articulation, reflection, and hence assimilation or accommodation for improved knowledge representation (Piaget, 1957; Vygotsky, 1978). Thus collaborative design can be considered as a *mindful* approach to learning or a meaningful environment of knowledge construction (Langer, 1997). The previous projects on learning by design also provided empirical evidence for design-based math and science learning (Kafai, 1995, 2006; Kolodner et al., 2003).

However, questions remain as to how design thinking and content-specific reasoning or knowledge development interact with each other during collaborative design, especially for novice designers. Therefore, this case study examined an implementation of design-based learning through educational computer games making by middle school children. In particular, it explored the presence and contexts of math learning of middle school children during the processes of collaborative design and computer-assisted game making.

2. Literature review

2.1. Learning by design or making

According to the theories of problem-based learning, case-based reasoning, and situated learning (Brown, Collins, & Duguid, 1989; Kolodner, 1993; Shank, 1999), design creates contextualized and authentic learning in that design tasks can make students resort to real-life skills and domain knowledge in doing project-like work, thus making knowledge and skills acquired in such situations more

* Tel.: +1 850 644 8794; fax: +1 850 644 8776.
E-mail address: fke@fsu.edu.

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transferable to future situations (de Vries, 2006). The prior research on learning by design and making suggest that design, as a formal and problem-solving process, should get learners to carry out inquiries or investigations, perform problem representation and solving by applying knowledge and skills, reflect on design and problem solving experiences, and engage in self-explanation and communication activities. It is argued that design will get learners in active and collaborative learning.

Earlier works on design-based learning examined the potential of using artifact designing and making as either a learning inquiry that contextualizes curricular activities (e.g., Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004; Kolodner et al., 2003), or a meaningful and engaging context that allows the designers to implement and ground content knowledge and critical thinking skills such as representation, reasoning, and creative thinking (e.g., Kafai, 1995, 2006; Li, 2012; de Vries, 2006). Kafai (1995), taking the perspective of constructionism, conducted a longitudinal study on a class of fourth-grade students who used *Logo* to program computer games to teach fractions. The study indicated that students got to construct mathematical representations during the design process, and game design can act as a tool for knowledge reformulation and personal expression. Kolodner et al. (2003) developed and examined a middle-school science program called *Learning by Design*™ (LBD) that integrated the theoretical propositions of case-based reasoning into the educational practice of problem-based learning. A structured sequence of small-group and whole-class investigation, iterative design, construction, and presentation activities was orchestrated and ritualized to reinforce design-based scientific discovery learning. The study suggested that LBD students consistently learned earth and physical science content as well or better than comparison students, and performed significantly better in scientific experiment design, analysis, collaboration, and metacognitive skills. Fortus, Dershimet, Krajcik, Marx, and Mamlok-Naaman (2004) examined the effect of design-based science pedagogy on the development of scientific knowledge and real-world problem solving skills of high-school students. Like Kolodner et al. (2003), they made the design inquiries and design-based problem-solving as the heart of the science curricular activities. Their study findings indicated that knowledge-test-based learning occurred for both high and low achievers after their participation in the design-based learning program. Recently, Li (2010, 2012) examined design-based learning using 'enactivism' – a theoretical framework that argues for a close connection between the affordance of a learning environment and a learner's capacity of action and perception, and a participatory culture in knowledge development. She proposed that gaming and game design should afford embodied and contextualized enactment of knowledge authoring. In an exploratory case study, Li (2012) reported that teachers' game design and building experience enabled them to re-conceptualize pedagogy and teaching practice.

On the other hand, the prior research underlined a variety of issues to be tackled when constructing and implementing a design-based learning program. In particular, it is challenging to connect design activities to the targeted domain content. That is, learners can be involved in visual or technical design and development rather than content exploration or the development of formal knowledge (Kafai, 1995, 2006; Kolodner et al., 2003). Besides, research by de Vries (2006) and Kolodner et al. (2003) highlighted the challenge of executing practices of design in a proficient way in the school classroom setting. Integrating studio-like, iterative design processes into fixed school sessions and the traditional classroom environment is in need of careful consideration and examination. As such, it is warranted to conduct a study examining how design and artifact-making processes invite and sustain content-specific reasoning and knowledge construction, representation, or reconceptualization in the school setting.

2.2. Learning by computer game making

Computer game making has been considered and examined as a "powerful learning environment" to stimulate active, autonomous learning via rich contexts and authentic tasks of composition and construction (Robertson & Howells, 2008; Smeets, 2005). The practice of having students as designers of computer games can actively engage learners and offer them opportunities to exercise the skills of digital storytelling, computational thinking, and creative thinking (Habgood, Ainsworth, & Benford, 2005; Kafai, 1995, 2006; Kelleher, Pausch, & Kiesler, 2007; Leng, Ali, & Baki, 2010; Robertson & Good, 2005; Vos, van der Meijden, & Denessen, 2011). Educational game making that requires content application can be applied as a "microworld" in which designers or learners get to explore, represent, and test their domain knowledge and skills and integrate them into the game designed (Mitchell, Kelleher, & Saundry, 2007; Roblyer & Edwards, 2000; Shaffer, 2005).

Based on the prior research and theoretical discussions on design-based learning in general and computer game making in particular, this study speculates that the following three meaningful interactions in computer-assisted math game making should be critical for the processes of creative composition and construction to be transformed into mathematical reasoning and understanding.

2.2.1. Interaction between students and math game design

As students design a math game, they will need to explore and represent their understanding of a math concept or interpretation of a math problem via scenarios and objects in the game world. The process should help students articulate, self-check, and constantly accommodate their prior mental framework (Shaffer, 2005). Thus design will act as a vehicle for the articulation and application of what they have learned about math. Prior research on design-based math learning also reports that students can "formulate mathematical conjectures during, and as a consequence of, their design activity" (Kafai, 1995; Shaffer, 2005, p. 7). These mathematical conjectures, representing students' ability to "form inferences about general principles from specific observations", are significant for mathematical understanding (Davis & Hersh, 1982; Shaffer, 2005, p. 7).

2.2.2. Interaction between students and design-based computing

Recent studies on computer game making by youth reported that design-based computing, or game programming, is motivating, reinforces esteem, and develops young people's higher-order thinking – computational thinking in particular (Habgood et al., 2005; Robertson & Howells, 2008). A variety of visual programming and game design applications, such as *Scratch* by MIT Media Lab, *Kodu* by Microsoft Research, *Game Maker* by YoYo Games, *Alice* by Carnegie Mellon University, have been used and investigated in previous learning-through-game-making studies, with evidence suggesting their positive effect in reinforcing computational thinking (Hayes & Games, 2008).

Computational thinking, being a universally applicable attitude and a fundamental reasoning skill, refers to "the thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent" (Wing, 2011). The core process of computational thinking is to create and make use of different levels of