J Sci Educ Technol (2016) 25:860–876
DOI 10.1007/s10956-016-9628-2

Using Robotics and Game Design to Enhance Children's Self-Efficacy, STEM Attitudes, and Computational Thinking Skills

Jacqueline Leonard[1] · Alan Buss[1] · Ruben Gamboa[1] · Monica Mitchell[2] · Olatokunbo S. Fashola[3] · Tarcia Hubert[4] · Sultan Almughyirah[1]

Abstract This paper describes the findings of a pilot study that used robotics and game design to develop middle school students' computational thinking strategies. One hundred and twenty-four students engaged in LEGO® EV3 robotics and created games using Scalable Game Design software. The results of the study revealed students' pre–post self-efficacy scores on the construct of computer use declined significantly, while the constructs of videogaming and computer gaming remained unchanged. When these constructs were analyzed by type of learning environment, self-efficacy on videogaming increased significantly in the combined robotics/gaming environment compared with the gaming-only context. Student attitudes toward STEM, however, did not change significantly as a result of the study. Finally, children's computational thinking (CT) strategies varied by method of instruction as students who participated in holistic game development (i.e., Project First) had higher CT ratings. This study contributes to the STEM education literature on the use of robotics and game design to influence self-efficacy in technology and CT, while informing the research team about the adaptations needed to ensure project fidelity during the remaining years of the study.

Keywords Robotics · Game design · Computational thinking · Self-efficacy · STEM attitudes · Diversity in STEM

Introduction

If youth and young adults ages 16–36 are the Net Generation (Li 2010), then current PreK-12 students are the App Generation. The App Generation is savvy with tablets, smartphones, Wii U, and Xbox games, and they are eager to participate in a culture of digital game playing. Teachers in K-12 school systems would be wise to take advantage of students' excitement about robotics and gaming to broaden students' participation in science, technology, engineering, and mathematics (STEM) and to engage students in integrated curriculum (Barr et al. 2011; Brand et al. 2008; Bremner 2013; Li 2010; Matson et al. 2004; Webb et al. 2012). Districts and schools that are out in front of pedagogical change are redesigning curriculum to include robotics and game design during the school day (Repenning et al. 2010; Webb et al. 2012). This fundamental shift in creating a technology-rich teaching and learning environment has strong implications for education in the twenty-first century (Dede 2008; Li 2010). Robotics and game design have not only been extolled for their role in learning but have also been identified as pathways to broaden participation in STEM and STEM-related careers (Caron 2010; Ivey and Quam 2009; Sheridan et al. 2013).

The need for mathematicians and computer scientists is expected to grow 22 and 24 %, respectively, from 2012 to 2022 (Bureau of Labor Statistics, US Department of Labor 2014). However, the number of engineering students is not increasing and in some instances is declining, while the demand for engineers is expected to continue to grow

✉ Jacqueline Leonard
jleona12@uwyo.edu

[1] Science and Mathematics Teaching Center, University of Wyoming, 1000 E. University Ave., Wyoming Hall 454, Laramie, WY 82071, USA

[2] MERAssociates, Vienna, VA, USA

[3] Johns Hopkins University, Baltimore, MD, USA

[4] Lone Star College Montgomery, Conroe, TX, USA

(Hirsch et al. 2007). One reason that students are not choosing to study engineering is lack of information about the field of engineering, what it entails, and what engineers actually do (Hirsch et al. 2007). Exposing underrepresented students (e.g., females, minorities, and rural students) to pre-engineering skills through robotics and game design has the potential to increase their interest and to provide them with the skills needed to create a diverse workforce (National Research Council (NRC) 2011). Preparing students to succeed in STEM is crucial to ensuring that students have access to these and other STEM occupations in the future. "The rapidly increasing number of summer camps, afterschool programs, female and minority focused special programs, and computer clubs at the middle school level strongly suggests that there is a demand from students" for STEM programs (Repenning et al. 2010, p. 265), particularly among rural and indigenous students who often have limited access to STEM education and fewer opportunities to learn STEM through the use of cutting-edge technology.

In an effort to provide greater access and opportunities to these populations, the National Science Foundation funded the 3-year uGame-iCompute (UGIC) project under the Innovative Technology Experiences for Students and Teachers (ITEST) grant program in October 2013. The goals of the UGIC project are to develop, implement, and study four components of an iterative intervention: (1) culturally responsive pedagogy as the context in which diverse students learn and work; (2) in-school and afterschool robotics and game design clubs to apply spatial reasoning and computational thinking skills to improve attitudes toward STEM and STEM careers; (3) robotics competitions to serve as a setting to demonstrate those skills; and (4) professional development to implement in-school and afterschool applications of computational thinking across the STEM curriculum.

The UGIC project began with a pilot study in the Rocky Mountain region of the USA in the spring of 2014. Using culturally relevant and culturally specific pedagogy (Ladson-Billings 1995; Leonard 2008) as the underpinning to engage students, the purpose of the study was twofold: (a) to improve upper elementary and middle school teachers' ability to implement robotics and game design before, during, and/or afterschool to improve student outcomes in STEM education and (b) to improve students' self-efficacy in technology, interest in STEM/STEM careers, and computational thinking. Culturally relevant pedagogy was used because cultural context has been shown to increase student learning in STEM (Brenner 1998; Nasir 2005; Presmeg 2007). This paper focuses on student experiences in robotics and game design.

Increasing the number of females and underrepresented minorities in STEM careers remains a challenge after more than 30 years of effort (NRC 2011); yet, few studies address barriers and mitigating factors related to that participation. This paper addresses shortcomings in the literature by studying a project that provides girls and indigenous students with opportunities to learn STEM content by engaging them in robotics and game design. Studying the impact of both robotics and game design allowed us to consider students who are exposed to STEM from different perspectives, listen and learn from their interactions, and examine student outcomes and preferences for robotics, gaming, or combined robotics/gaming learning environments.

During the Year 1 study, three types of learning configurations to test instrumentation and assumptions about single and combined effects were observed and evaluated: (a) robotics only, (b) gaming only, and (c) robotics/gaming combined. Lessons learned during this pilot study provided important feedback for making needed adaptations to enhance teacher and student outcomes in the 3-year study. In Year 2, the effects of robotics only were studied in fall 2014 and gaming only in spring 2015. In Year 3 (fall 2015 & spring 2016), the combined effects of both gaming and robotics were investigated. The results of these intervention configurations are still pending.

Theoretical Framework

The framework that undergirds this study is Learning-for-Use (LfU) (Edelson 2001), and the constructs are culture and place. LfU is a technology design framework that is based on four principles: (a) knowledge construction is incremental in nature, (b) learning is goal directed, (c) knowledge is situated, and (d) procedural knowledge needs to support knowledge construction (Edelson, 2001). These principles inform robotics applications and game design and lend themselves to the interventions implemented in this study.

The first and fourth principles of the LfU model are the incremental development of new knowledge and procedures. Linking previous knowledge to new knowledge is the key here. The goal behind the progression of two intervention components—robotics and game design—is to engage students in an incremental process. Students incrementally add new concepts to memory, while subdividing existing concepts or making new connections between concepts. In LfU, procedural strategies for supporting and reinforcing incremental learning include observation, discussion, reflection, and application. New knowledge informs and empowers students to become proactive in their own learning.

In its second and third principles, LfU recognizes that acquisition of knowledge is goal directed and situated. The realization of gaps in one's knowledge, perhaps as the result of an elicited curiosity or external demand, can be used as a motivational goal for acquiring new knowledge. For example, in this study, the Project First approach allowed students to engage in goal-directed tasks and situated learning as they develop games by starting with an overarching goal or concept and then integrating the necessary tools to make the game functional (Webb et al. 2012). The study intervention was designed to encourage goal-directed tasks as students created games and simulations to learn and apply computational thinking skills, which are needed for computer science and Information Communications and Technology (ICT) careers.

In addition to LfU, the constructs of culture and place are important in this study. Rather than adhering to deficit theory, teachers and researchers should view students' culture as an asset upon which to build new knowledge (Bracey 2013; Leonard et al. 2005). In STEM education, it is critical to understand the importance of different ways of knowing and alternative forms of mathematical and scientific activity. Culture is embedded in the natural world and influences every aspect of our lives. According to Nieto (2002), culture is "the ever-changing values, traditions, social and political relationships, and worldview created and shared by a group of people bound together by a common history, geographic location, language, social class, and/or religion and how these are transformed by those who share them" (p. 53). "Games are inherently artifacts of culture through which cultural roles, values, and knowledge bases are transmitted" (Nasir 2005, p. 6). While not culturally monolithic, such artifacts reflect and reproduce culture simultaneously.

In gaming, goal structures are also associated with maximizing points (Nasir 2005), and in robotics, goals are associated with movement and carrying out specific tasks. Students may also engage in communal strategies in these settings as they learn to harness technology to complete specific goals. For example, in Arapaho tribal communities, goal structure can be found in artistic symbols (Kroeber 1900). The symbols of the Arapaho people can be classified into representations of abstract ideas, man-made objects, plants, nature, and animals, including buffalo and birds, such as the thunder bird, eagle, and crow (Kroeber 1900).

In addition to culture, place contributes to a "multidisciplinary construct…to unearth, transplant, and cross-fertilize perspectives…that can advance theory, research and practice in education" (Gruenewald 2003, p. 619). The context in which schools exist (i.e., place) and the supports (i.e., cultural and social capital) students have, in terms of access, play a role in educational outcomes (Gruenewald 2003). In this study, we acknowledge the roles of culture and place to scaffold student learning and increase motivation to participate in STEM/ICT.

Robotics, Digital Gaming, and Computational Thinking

While STEM encompasses a wide range of disciplines, this study looked at the potential of engaging youth in three areas: (a) robotics, (b) digital gaming, and (c) computational thinking.

Robotics

A growing number of STEM funded programs have turned to robotics to motivate students' interest in STEM fields (Brand et al. 2008; Caron 2010; Ivey and Quam 2009; Matson et al. 2004). Robotics not only allows students to learn about STEM concepts but also about STEM's interdisciplinary nature, encouraging students to work collaboratively (Yuen et al. 2014). In a study that examined elementary and middle school students' participation during a summer camp, robotics was found to be highly engaging as a majority of students exhibited a high number of on-task behaviors (Yuen et al. 2014). Additionally, programming robots helps students to engage in science inquiry as described by Linn and Hsi (2000): (a) science is made accessible by engaging with physical models; (b) thinking is made visible through construction and design principles; (c) students learn from each other through collaboration; and (d) autonomous learning skills are developed through self-directed learning. Whether it is through the engaging process of constructing robots or the excitement of the competitions, several robotics programs have resulted in an increase in students' comfort level with applications of STEM, development of twenty-first-century skills, and increased interest in pursuing STEM-related programs beyond high school (Brand et al. 2008; Caron 2010; Grubbs 2013; Ivey and Quam 2009; Matson et al. 2004).

Robotics may be promoted as a stand-alone subject area to provide students with the opportunity to learn engineering practices and technology education (Grubbs 2013). LEGO® robotics, specifically, is widely used in K-8 settings as an authentic and kinesthetic way to improve children's problem-solving skills, reinforcing science applications and concepts, while building upon informal learning activities often done at home (Karp and Maloney 2013). Using LEGO® EV3 robotics builds spatial visualization skills as students manipulate LEGO pieces to build the robot. Other mathematics skills include proportional reasoning as students calculate wheel rotation and approximate the distance the robot will travel once it is programmed (Grubbs 2013). "Not only does the design and hands-on component of technology stay intact, but students also enjoy solving a realistic engineering scenario, role playing…and constructing physical components through an open-ended design challenge" (Grubbs 2013, p. 12). In this pilot study, we were interested in how engagement in LEGO EV3 robotics activities developed students' self-efficacy in technology and their attitudes toward STEM.

Digital Gaming

Using games effectively during instruction encourages students to actively participate in their own learning (Bremner 2013). A variety of gaming strategies have been employed such as game design and programming (Webb et al. 2012), mobile games (Koutromanos and Avraamidou 2014), online games (Paraskeva et al. 2010), and game authoring tools (Robertson and Howells 2008). Studies related to gaming have demonstrated development of a more positive attitude and motivation toward mathematics (Ke 2008; Kebritchi et al. 2010). Ke (2008) conducted a study that explored the effect of using a series of web-based games called ASTRA EAGLE on cognitive mathematics accomplishment, metacognitive awareness, and favorable attitudes toward mathematics among elementary students in Pennsylvania. Results revealed that children showed considerable improvement in regard to developing positive attitudes toward learning mathematics through gaming.

Digital game playing has also been used successfully to teach mathematics problem-solving (Chang et al. 2012) and can be used as a social practice to support the development of "strategic thinking, planning, communication, application of numbers, negotiating skills, group decision-making, and data-handling" (Li 2010, p. 429). Incorporating computer games in the mathematics classroom has been shown to lead to favorable attitudes toward learning mathematics and to increases in mathematics achievement and student success. In this pilot study, we were interested in how game design and gaming developed children's self-efficacy in technology, STEM attitudes/STEM careers, and computational thinking.

Computational Thinking

While there is no standard definition of CT, this paper uses the International Society for Technology in Education (ISTE) definition: CT is a problem-solving process that includes formulating problems; logical organization of analysis of data; representation of data through abstractions; identifying and automating solutions through algorithmic thinking; analyzing and implementing possible solutions; and generalizing and transferring the problem-solving process (Barr et al. 2011; Ioannidou et al. 2011; Wing 2006).

Multiple initiatives have explored the use of games to improve student learning and CT (Li 2010), including the Scalable Game Design (SGD) project (Repenning et al. 2010; Webb et al. 2012). The SGD curriculum, which involves the use of instructional units to support game design and science simulations, has been shown to increase student transfer and address equity. For example, 64 % of girls and 69 % of minority students expressed high interest in game design (Repenning et al. 2010; Webb et al. 2012). Moreover, SGD uses an innovative way to measure computational thinking by analyzing students' games and simulations once they are uploaded to a video arcade. Students' thinking is compared to a basic game model to determine how it is similar or different from the model. Thus, generalization, learning transfer, and adaptive reasoning are measured. In this pilot study, students' games were influenced by the type of implementation teachers used, such as tutorials or holistic games (also known as Project First (Webb et al. 2012)).

The Research Study

This pilot study was conducted to inform the research community how the use of LEGO® EV3 robotics and Scalable Game Design software influenced rural and indigenous students' self-efficacy in technology, interest in STEM/STEM careers, and computational thinking skills during regular, before- and/or after-school settings. Additionally, the researchers examined how students infused elements of culture and place into the artifacts they developed.

The following research questions guided the researchers in this study of the three intervention configurations:

1. How did student participants' self-efficacy in technology change after engaging in the pilot study, and how did their self-efficacy differ by type of instruction: (1) gaming only and (2) robotics/gaming?
2. How did student participants' attitude toward STEM/STEM careers change after engaging in the pilot study?
3. What computational thinking strategies did student participants demonstrate during computer-based game design?

An additional question beyond the interventions posed was as follows:

4. How do students infuse place and culture in their gaming and robotics artifacts?

Context

Student participants used LEGO® EV3 robotics kits and SGD software—AgentSheets (two-dimensional) and

AgentCubes (three-dimensional)—to engage in computational thinking. LEGO® robotics kits contain a robot (also known as a brick), sensors, regular LEGO® pieces, and wheels that can be put together. MINDSTORMS® software allows students to download programming commands to make the robot move and play musical scores. AgentSheets/AgentCubes are object-based programming environments that are tailored for middle-grade students to design computer games. They can be used to explore various areas in computing, as evidenced by the variety of games and simulations that can be easily developed (i.e., Maze Craze, Pac Man, Frogger, and Journey).

In the robotics context, the first task students learned was to put basic LEGO® EV3 pieces together to make a robot, such as a simple two-wheeled rover (see Fig. 1). Then they learned how to use simple code using the MINDSTORM® software to move the robot (see Fig. 2). This required choosing a movement programming block and setting the speed and number of rotations (see "Appendix 1: robotics worksheet" for sample worksheet). Once students understood how many rotations it took for the robot to move specific distances, they altered the program to turn the robot left and right. Later, the students learned to use sensors, such as color and touch, that enable robots to move along a specific color-coded path and to move, turn, or stop when an obstacle is detected. Thus, students were able to create road maps for the robot to travel and worked on challenging tasks for the robot to perform (see Fig. 3). Culminating activities included learning to write advanced code that allowed the robot to play music, drop a ball in a cup, or traverse an obstacle course.

In the gaming context, SGD provided students with a robust curriculum to learn computational thinking patterns (Webb et al., 2012). The key components of an AgentSheets/AgentCubes program are *agents*, which are static or dynamic objects (see Fig. 4), and worksheets or game fields divided into a rectangular array of cells upon which agents are placed. Agents include player-controlled dynamic agents or avatars, artificial intelligent (AI) friends and foes, and scenery such as rocks or roads. Users program the agents' behaviors, such as movement, response to other objects, or communication with other agents.

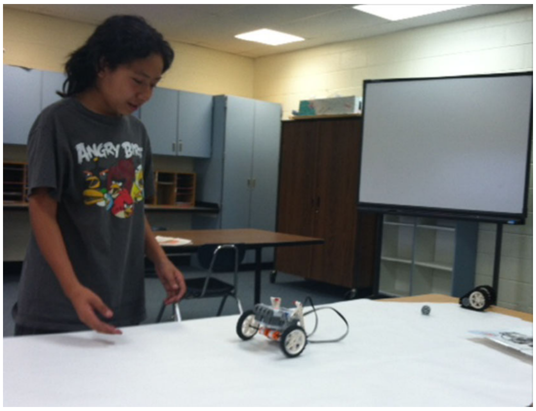


Fig. 1 Student demonstrating two-wheeled rover (Hiawatha School)

In this study, students learned how to program two different types of games: Maze Craze and Frogger. The goal of a maze game is to create a worksheet with a starting point and an end target along with a set of obstacles for the agent to encounter between the starting point and the goal. Other agents, such as antagonists, are also programmed to move in order to prevent the primary agent (i.e., protagonists) from reaching the goal. The program consists of a set of rules, each of which describes what the protagonist should do when a certain key is pressed (e.g., the right arrow key) and other conditions hold. For instance, the conditions may prevent the agent from moving through a wall. After creating a worksheet, students were presented with a variety of programming challenges, such as displaying the game score, and diffusion and hill climbing (which can be used to imbue the antagonists with rudimentary AI).

Methodology

To evaluate the efficacy of the interventions, a 3-year, counter-balanced, quasi-experimental research design was developed to examine changes in middle school students' self-efficacy in technology, attitudes toward STEM/STEM careers, and computational thinking strategies. Quantitative data alone do not totally explain changes or the lack thereof among student participants. Thus, mixed methods were used to collect data in this study. Teachers focused on robotics, gaming, or a combination of robotics/gaming to test the treatment variables in formal classroom settings and informal before and afterschool clubs. However, as a pilot study, the duration of each configuration was not controlled to explore different delivery models. Moreover, there were too few students to analyze data in the robotics only environment. Thus, we could not isolate the robotics treatment variable during this pilot study.

Sample

In the tradition of Creswell (1998), thick descriptions about the school setting and the classroom environment were employed to understand the learning context. Initially, teachers from Title 1 schools were recruited to participate in this study, which focused on underserved and

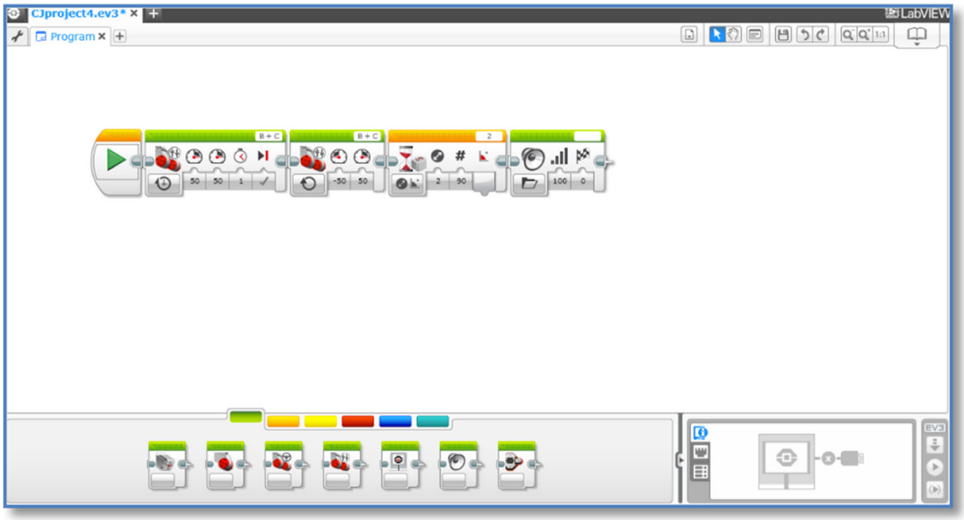


Fig. 2 Lillie's robotics code (Hiawatha School)

underrepresented students in Wyoming. Teachers from non-Title 1 schools were also invited to participate once a critical mass of Title 1 schools was reached. Teachers agreed to facilitate instruction before, during, and/or after school for 60 contact hours. In most cases, clubs met 2–4 days per week for 1–2 hours each day and instruction lasted for 6–10 weeks. In some cases, two or more teachers worked together to facilitate learning in clubs where there were more students.

Fifth- through eighth-grade students were recruited from eight schools in Wyoming. Students from diverse backgrounds were recruited on a first-come first-serve basis at pilot schools and were informed that their participation was voluntary. Two of the eight schools were reservation schools. Reservation schools were included because research on American Indian students is sparse, and these schools provided an opportunity for the researchers to learn more about how to engage this underrepresented population in culturally specific STEM education. Twenty American Indian students agreed to participate in this study. A few of these student participants attended rural schools, but the majority attended one of two reservation schools: Big Ridge or Hiawatha (pseudonyms). The remaining students in the study attended one of six rural schools: Anderson, Custer, Dillworth, Evans, Franklin, or Gable (see Table 1).

One hundred and twenty-four students assented and had parent consent to participate in the pilot study. Observation and attendance records show 101 students completed the study, but only 76 students completed both pre- and post-surveys. However, fewer students were included in analysis for each research question because of missing data and outliers (see Table 2). A large enough sample was available to disaggregate data to answer question one (self-efficacy in technology) as an entire

Fig. 3 American Indian students' robotics road map (Big Ridge School)

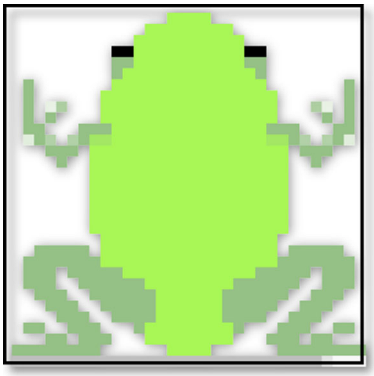


Fig. 4 Sample agent from the Frogger game

Table 1 Schools and students by type of school and type of treatment

Schools	Type of school	Type of treatment	# of students in analytic sample
Hiawatha	Reservation	Robotics only (R)	4
Big ridge[a]	Reservation	Gaming only (G)	3
Gable[a]	Rural	Gaming only (G)	28
Anderson[a]	Rural	Robotics/gaming (R/G)	7
Custer	Rural	Robotics/gaming (R/G)	1
Dillworth	Rural	Robotics/gaming (R/G)	11
Evans	Rural	Robotics/gaming (R/G)	9
Franklin[a]	Rural	Robotics/gaming (R/G)	13
Total students			**76**

[a] Schools included in G only and R/G analysis

Table 2 Number of students by research question

Student participants	#Program start	#Program end	#Analytic sample	#In RQ1a	#In RQ1b	#In RQ2	#In RQ3	#In RQ4
Total students	124	101	76	68	49	69	5	5

Table 3 Number of students by race/ethnicity and gender

Student demographics	#Analytic sample
Race/ethnicity	
Asian-American	1
Hispanic/Latino	8
Native American	6
White	55
Two or more races	6
Gender	
Female	28
Male	48
Total students	76

group and by type of instruction (i.e., robotics/gaming and gaming only). To answer research question two (STEM attitude/career), data were not disaggregated by type of instruction because we were interested in how students' attitudes toward STEM changed as an entire group. While more students had games that could have been analyzed to answer research questions three (CT strategies) and four (use of culture and place in gaming), only five focal students' games were selected for analysis due to space limitations in this paper.

Of the 76 students who completed pre- and post-surveys, 21 were minorities (including six Native American students) (see Table 3). Forty-eight students were males, and 28 were females. All of the students were from rural communities.

Data Sources and Instrumentation

Quantitative data sources included a self-efficacy survey and a STEM attitude and career survey, which students completed on a pre–post basis. The Self-Efficacy in Technology and Science instrument (SETS) developed by Ketelhut (2010) was adapted for use in the pilot study. Self-efficacy as defined by Bandura (1977) is the belief that one can successfully perform specific tasks, such as solving mathematics problems. We used the SETS to measure change in students' self-efficacy on three subscales: videogaming (8 items), computer gaming (5 items), and using the computer to solve problems (5 items). Videogaming refers to games that utilize a video monitor and a joystick, such as a television screen and controls used in current Wii U and Xbox games. Computer games are games played on a computer using keystrokes or a mouse. Cronbach's alpha was used to rate reliability on the SETS; alphas were 0.93 for videogaming and 0.84 for computer gaming, which are in the very good to excellent range (DeVellis 1991). Using the computer to solve problems (later referred to as computer use) referenced students' use of spreadsheets and other computer tools, such as built in calculators and algorithms, to solve non-routine problems. Cronbach's alpha was 0.79 for this subscale, which is in the acceptable range. Respondents rated the items using a 5-point Likert scale that ranged from 1 (strongly disagree) to 5 (strongly agree). Some of the items were negatively worded and, therefore, were reversed for scoring.

The student attitudes toward STEM survey developed by the Friday Institute (2012) consisted of three subscales: mathematics (8 items), science (9 items), and engineering/

technology (9 items). Cronbach's alpha coefficients were in the acceptable range ($\alpha > 0.83$) on the scales developed by the Friday Institute (2012). The STEM attitude subscales used a 5-point Likert scale that ranged from 1 (strongly disagree) to 5 (strongly agree). Some of the items were negatively worded and, therefore, were reversed for scoring. The future careers subscale was adapted and included in the survey as well. The future STEM careers subscale used a 4-point Likert scale to rate items (1: not interested at all; 2: not so interested; 3: interested; and 4: very interested). However, there is no Cronbach's alpha to determine the reliability of this subscale.

Qualitative data sources included field notes, screenshots, computer files, and photographs of student work and artifacts. Field notes were recorded during site visits to before or afterschool clubs as well as regular classrooms. The work samples of five focal students (four males and one female) were selected to show how computational thinking was demonstrated during game design. A rubric was created for this study to measure computational thinking using the ISTE definition as criteria (see "Appendix 2: computational thinking rubric").

In addition to computational thinking skills, students' use of indigenous culture, pop culture, and knowledge of off-shelf games were rated to evaluate game designs for creativity. The assumption was that student voice and choice in game design are critical to improving CT skills and increasing participation among females and underrepresented minority students in STEM/ICT.

Multiple raters practiced rating student work by examining screenshots, reviewing the code, and playing the students' games. After reviewing several games, interrater reliability was established at 86%. Students received ratings of 1 for emerging, 2 for moderate, and 3 for substantive evidence of CT based on their ability to formulate the problem (i.e., set up the game with appropriate agents), use abstraction (i.e., create a unique game with novel agents), engage in logical thinking (i.e., allow the agent to move randomly on the worksheet to score points), etc.

Data Analyses

The *T* statistic was used to compare pre–post scores on the SETS and STEM attitude/career surveys. While students were nested in schools, we do not report the adjusted standard mean error because of the small number of students included in the pre–post analyses. An analysis of covariance (ANCOVA) was also conducted to compare post-survey scores on each of the SETS constructs (i.e., videogaming, computer gaming, and computer use) by treatment type (gaming only and robotics/gaming). The CT rubric was used to rate five focal students' game designs. These students' artifacts were representative of the gaming and robotics/gaming-only environments.

Results

To answer the first two research questions, the results of the SETS survey and the STEM attitude/career survey are presented. To address the third and fourth research questions, qualitative data are provided to show how students' computational thinking (CT) strategies were evident in students' artifacts. Since games are cultural products, they were also evaluated for use of culture (e.g., indigenous culture, pop culture, music, voiceover, and current off-shelf games or images) in addition to CT.

Self-Efficacy in Technology and Science

Pre–post SETS survey scores are presented as aggregated data in Table 4. Results of a paired *t* test on each construct reveal no significant differences on videogaming and computer gaming. While there was a slight decline in scores, students' maintained positive self-efficacy on videogaming and computer gaming after engaging in the intervention, regardless of the type of instruction. On the contrary, scores on computer use declined significantly from pre- to post-survey ($t = 2.074$, $p = .042$). In future years, we will engage students in focus group interviews to explore positive and negative changes in beliefs as it relates to using computers to solve problems. Focus group questions would also illuminate students' efficacy beliefs about videogaming and computer gaming. According to Ketelhut (2010), videogaming scores are positively correlated with the amount of time spent videogaming.

In order to learn more about the influence that the type of setting may have had on self-efficacy in technology, we conducted an ANCOVA to determine whether there were significant differences by type of instruction. Only students who completed the paper version of the pre–post tests were included in this analysis ($n = 49$). The data were disaggregated into two groups: gaming only ($n = 29$) and robotics/gaming ($n = 20$). The dependent variable was the post-survey and the pre-survey was used as the covariate. Results of the ANCOVA show significant main effects on the videogaming construct by group: $F(1, 28) = 2.471$, $p = .015$ (effect size: $r^2 =$ 0.63). Student participants' self-efficacy scores on videogaming (construct 1) for the robotics/gaming group increased significantly from pre to post. When data on computer gaming (construct 2) and computer use (construct 3) were compared by type of instruction, the results of the ANCOVA were not significant. However, descriptive data reveal that scores dropped across all constructs in the gaming-only group, but

Table 4 Comparison of pre–post self-efficacy technology constructs ($n = 68$)

Self-efficacy constructs	Pre-score	SD	Std. mean error	Post-score	SD	Std. mean error
Videogaming	3.93	0.82	0.10	3.91	0.95	0.12
Computer gaming	3.82	0.76	0.09	3.74	0.90	0.11
computer use	4.01	0.74	0.09	3.79*	0.94	0.11

* $p < 0.05$

Table 5 Mean SETS post-survey scores by type of instruction

Group (n=49)	Number of students	Pre-survey mean	SD	Post-survey	SD
Videogaming					
Group 1 (G)	29	3.79	0.92	3.75	0.93
Group 2 (R/G)	20	3.68	0.62	4.14*	0.82
Computer gaming					
Group 1 (G)	29	3.57	0.77	3.43	0.88
Group 2 (R/G)	20	4.02	0.73	4.02	0.73
Computer use					
Group 1 (G)	29	4.06	0.71	3.61	0.88
Group 2 (R/G)	20	4.17	0.64	4.32	0.68

* $p < 0.05$

increased or remained the same for the robotics/gaming group (see Table 5). We will determine whether this trend continues in study Years 2 and 3.

STEM Attitudes and Future STEM Careers

The attitudes toward STEM scale developed by the Friday Institute (2012) was used to examine changes in students' attitudes toward STEM and future STEM careers. The subscales related to the STEM disciplines reveal that student attitudes were more positive in mathematics and engineering/technology before than after the study (see Table 6). Attitudes toward science was the only STEM domain that increased during this pilot study. However, there were no significant differences between pre–post scores on STEM attitude or interest in STEM careers for the overall group.

Computational Thinking Skills

Samples of sixth-grade students' game designs in settings where teachers used the tutorials resembled the traditional model for Frogger games. A screenshot of the Frogger game created by Larry (pseudonym) is shown in Fig. 5. He used a frog and trucks as agents while the worksheet included grass and water as obstacles for the frog to navigate. The code needed to produce a Frogger game similar to Larry's game is shown in Fig. 6.

Older students in a seventh-grade class also used the tutorial to create three-dimensional games using AgentCubes. However, their use of culture and abstraction allowed them to deviate from the traditional game model. The researchers observed the students' excitement as they played each other's games. The screenshots of two students' games (see Figs. 7, 8) show the abstract nature of the worksheets and agents, some coding, and the level of complexity involved in creating the games in three dimensions. Darren made 10 agents, and Angel created 17 agents for his game. As shown in the screenshots, Angel's game is more abstract than Darren's game. However, Darren made notes to explain each step in his game. These two games exemplify the use of procedural knowledge and incremental and goal-directed learning in game design (Edelson 2001).

The two final screenshots (see Figs. 9, 10) show games developed by Sher and Max, who were two sixth graders. They developed games in a setting where students produced the ideas to make the game first (Project First) and then learned the associated code without the use of a tutorial. Sher's screenshot is typical of the work students produced in this setting, which resembled the maze rather than the Frogger game. In this screenshot, the background of the worksheet is a place setting, which exhibits abstraction as well as Western culture. The agents consisted of a fairy (protagonist) and picnic baskets that had to be collected to maximize the score. While no code is visible, the researchers observed students playing the games produced in this setting, which kept score, exhibited sound, and provided a visual display, such as "you won" when the game ended. The protagonists in both games reflected pop culture as students used Tinkerbell$^{\mathrm{TM}}$ and Mario$^{\mathrm{TM}}$ images.

Table 6 Comparison of pre–post student attitudes toward STEM/STEM careers (*n*=69)

STEM domain	Pre-score	SD	Std. mean error	Post-score	SD	Std. mean error	Gain scores
Mathematics	3.76	0.83	0.10	3.66	0.91	0.11	(0.10)
Science	3.20	0.70	0.09	3.25	0.74	0.09	0.05
Engineering/technology	3.74	0.79	0.10	3.70	0.90	0.11	(0.04)
Future STEM career	2.46	0.58	0.07	2.39	0.63	0.08	0.07

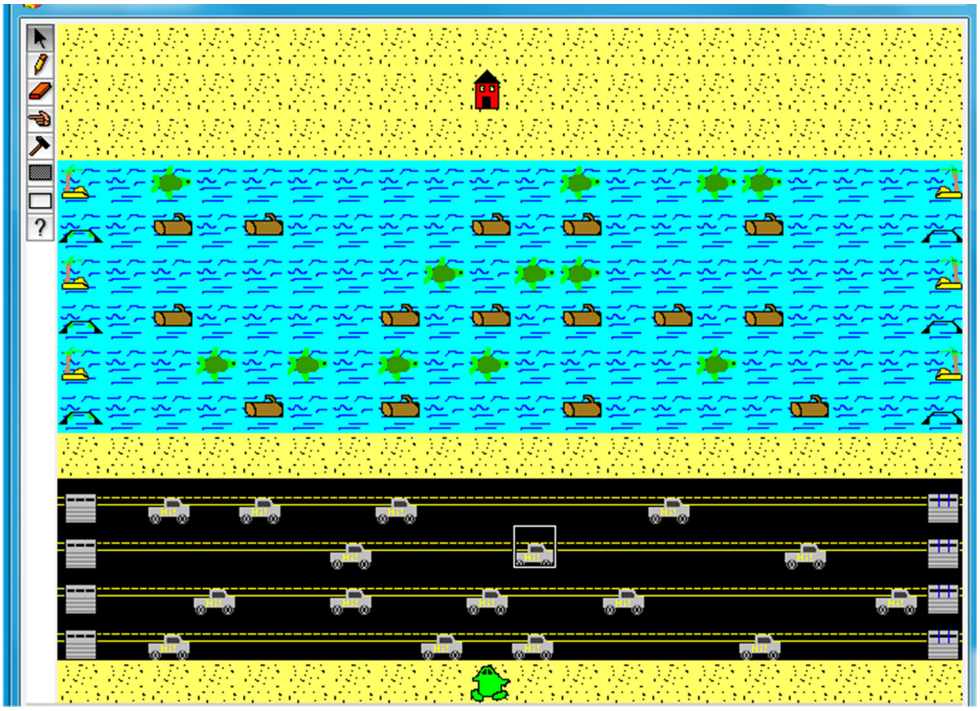


Fig. 5 Larry's Frogger game screenshot

Thus, these games illustrated the use of goal-directed and situated learning in game design (Edelson, 2001).

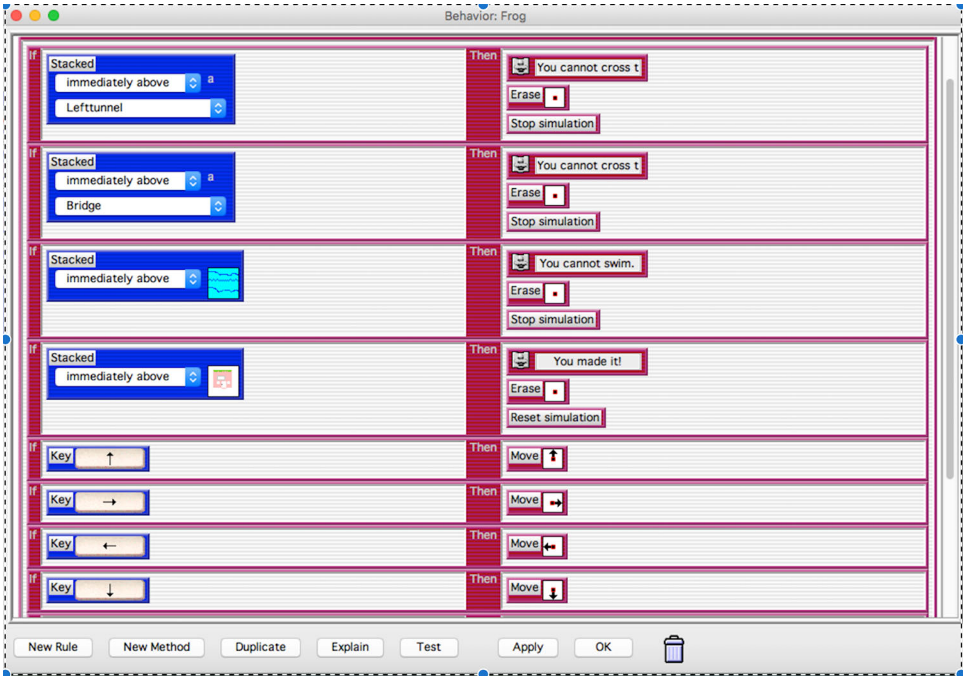
Using the CT rubric, students' games were rated as emerging (1), moderate (2), or substantial (3) (see Table 7). The screenshots as well as the programming code and actual games provided evidence of computational thinking. While the number of focal students is small, the games these students produced were similar to other Frogger and maze games, regardless of the setting.

In addition to CT strategies, digital games were analyzed for evidence of culture and place. Students in both tutorial and Project First contexts exhibited a variety of colors and objects in their games that were markers for culture or place. For instance, Angel named his protagonist R2D2, drawing on pop culture (prior to release of *Star Wars Episode VII: The Force Awakens*). Darren, an American Indian student, created a protagonist called *Nighthawk*, which drew upon the American Indian culture of creating birds in artistic representations (Kroeber 1900). Place was represented in Frogger games by the vehicles some students chose to create. A pickup truck is a common marker in rural towns where the study took place. Larry and Angel used pickup trucks rather than cars as obstacles for their protagonists to cross the road. Max also used place as his worksheet consisted of foothills, blue sky, and low clouds, which are typical in the Rocky Mountain west. These work samples are examples of how culture and place were exhibited in game design.

Discussion

The findings of this pilot study informed the researchers about student outcomes related to participation in robotics and game design. The results of this study reveal several important findings. First, student participants' self-efficacy on the construct of computer use declined significantly in this study. Perhaps the learning curve associated with

Fig. 6 Frogger game programming code



If Stacked immediately above a Lefttunnel Then You cannot cross t; Erase; Stop simulation

If Stacked immediately above a Bridge Then You cannot cross t; Erase; Stop simulation

If Stacked immediately above Then You cannot swim.; Erase; Stop simulation

If Stacked immediately above Then You made it!; Erase; Reset simulation

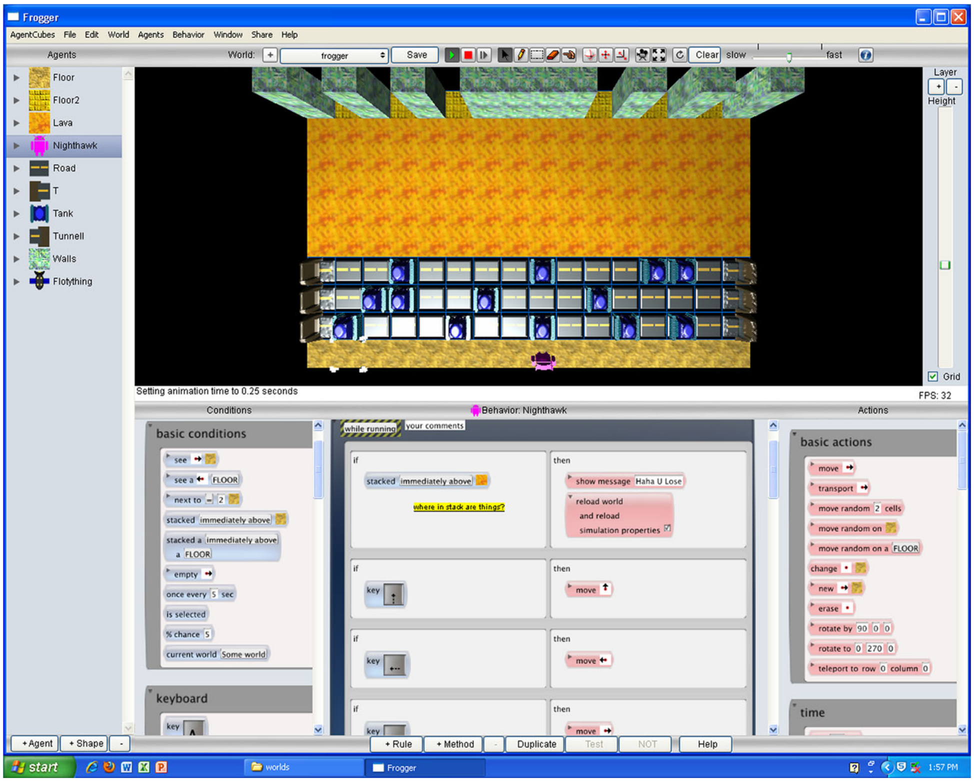
If Key ↑ Then Move ↑

If Key → Then Move →

If Key ← Then Move ←

If Key ↓ Then Move ↓

Fig. 7 Darren's game screenshot



Setting animation time to 0.25 seconds

if stacked immediately above — where in stack are things? — then show message Haha U Lose; reload world and reload simulation properties

if key then move ↑

if key then move ←

if key then move →

MINDSTORMS® programming during robotics and debugging issues while using Scalable Game Design affected this result. Questions on the survey included such items as: "It is hard for me to look for answers to questions on the Internet" and "Even if I try very hard, I cannot use the computer as easily as paper and pencil." We will explore this result further by conducting student focus groups in Years 2 and 3 of the study. When we examined the constructs of videogaming, computer gaming, and computer use by type of treatment (gaming only or

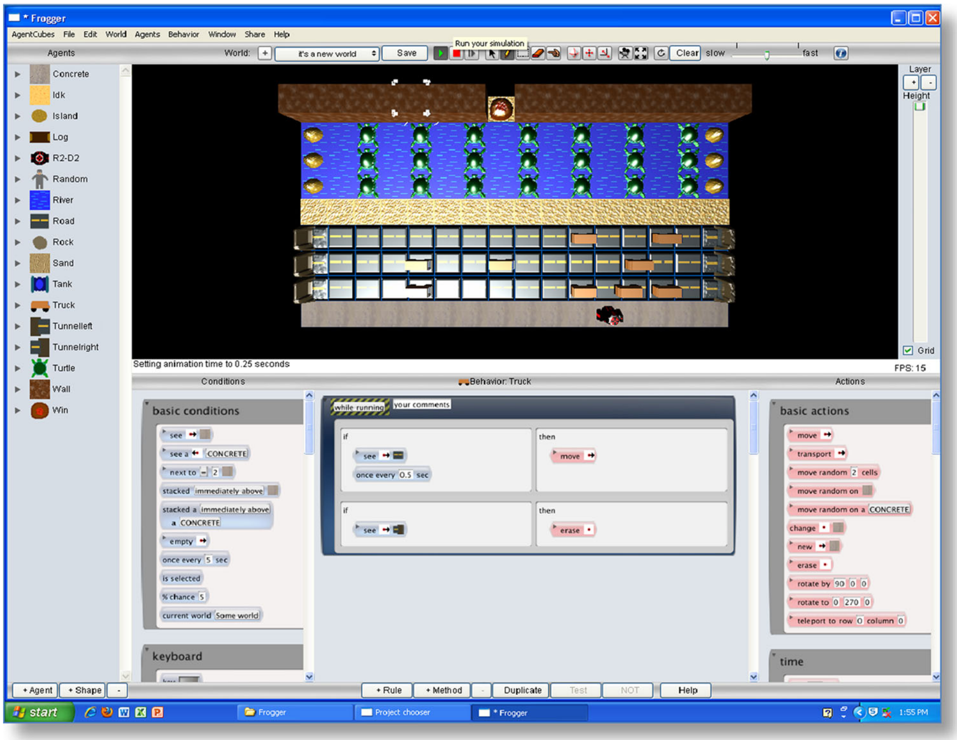


Fig. 8 Angel's game screenshot

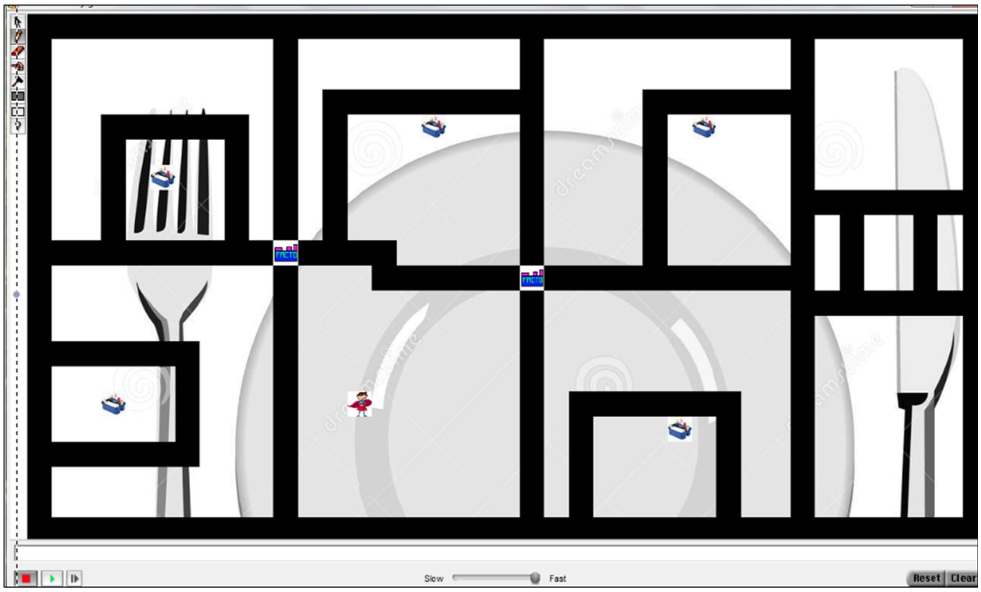


Fig. 9 Sher's maze game screenshot

robotics/gaming), students in the robotics/gaming clubs had significantly higher scores on videogaming. We believe the excitement of getting a robot to move and perform a task combined with the creativity associated with developing a game from scratch influenced this result. This finding is unique as blending robotics with game design is innovative and not found in the literature. The findings are supported by Dierking et al. (2003), Grubbs (2013), and Yuen et al., (2014) who described robotics as highly engaging and Ke (2008) and Kebritchi et al. (2010) who described gaming as motivational. Nevertheless, the learning environments for robotics and game design, as single treatment variables, need to be richer. In future years, professional development will focus on creating different types of robotics models (e.g., basic car, gyro boy, and crane) rather than a single robotics design, and teachers

Table 7 Ratings of focal students' game design for computational thinking

Student	Type of instruction	Problem formulation	Abstraction	Logical thinking	Algorithms	Analyzing and implementing	Generalizing and transfer	Use of culture	Average rating
Larry	Tutorial	2	1	2	1	2	1	1	1.43
Darren	Tutorial	2	1	2	2	3	2	2	2.00
Angel	Tutorial	3	2	2	2	3	2	2	2.29
Sher	Project First	2	3	3	3	2	2	2	2.45
Max	Project First	3	3	3	3	2	2	2	2.57

Fig. 10 Max's maze game screenshot

will learn how to use and facilitate game design using different kinds of software.

The second finding is that attitudes toward STEM/STEM careers remained constant, indicating there was no statistically significant change as a result of the study. It is unclear whether the short duration of the program or data washout contributed to these results. We will include females and indigenous students in focus groups in Year 2 to determine how to improve project deliverables and to ensure that instruments and instruction are appropriate for their learning styles. In Year 3, we may have large enough samples to analyze the surveys by gender and race/ethnicity to determine the impact of the project on females and underrepresented minority students.

The third finding relates to the development of computational thinking. Analyses of the focal students' screenshots, code, and actual games are encouraging. Some students were able to design creative and interesting games with instructional scaffolding while others followed the tutorial without much modification. While tutorials were helpful to younger students and reduced cognitive load, CT and creativity were less evident when teachers used this instructional method. Some of the tutorials contained errors that frustrated some students, while others enjoyed catching the mistakes. While the use of tutorials was helpful for teachers and students, in Years 2 and 3 we will recommend that teachers show students a completed game first and allow them to play the game before they create one. From our observations, this Project First pedagogical approach helped to maintain students' motivation in spite of debugging issues because they were eager to see the end product.

On the contrary, working only on AgentSheets for 10 weeks caused some students to lose interest regardless of the pedagogical approach. This was particularly true for females in the self-contained classrooms. Their participation in game design during the regular school day was mandatory because AgentSheets was a required classroom activity whether they enjoyed it or not. This finding conflicts with the findings of Webb et al. (2012), who reported that female participation was high during the regular school day. To maintain student motivation, we will encourage teachers to use a combination of tutorial and scaffolding approaches to teach game design. Moreover, we will expand the game design portfolio to include AgentSheets, AgentCubes, and Scratch (developed by MIT) to help maintain student interest. We will also submit students' games to the video arcade, which analyzes students' computational thinking patterns by comparing their games to a prototype (Repenning et al. 2010). Furthermore, we will use focus groups to examine how diverse students react to robotics and game design components in Year 2 and the combined treatment in Year 3.

Fourth, we found that students were able to infuse some elements of culture and place into game design (Bracey 2013; Gruenewald 2003; Leonard et al. 2005). Indigenous students were influenced by Indian culture (e.g., birds and animals) as well as popular culture (i.e., R2D2). Rural students used backgrounds indicative of the communities where they lived. Thus, children drew upon cultural capital and place to engage in game design. To enhance our understanding of cultural underpinnings and place, we will collect a broader sample of student work and conduct student focus groups to obtain specific explanations from students' about how their design principles incorporated culture and place. If we can use these constructs to maintain student interest, we may be able to influence more positive attitudes toward STEM, self-selection of advanced STEM coursework, and interest in future STEM careers.

Finally, student attrition was an issue in this pilot study, particularly among American Indian students. Thirty percent of American Indian students dropped out of the study compared with 18.5 % of all students. We will work with reservation teachers, administrators, and families to determine how to better facilitate the program with this population and attend to their cultural needs. Another factor related to attrition, as reported by teachers, was participation in sports. In future years, middle school teachers will be encouraged to run the UGIC program during the summer (Yuen et al. 2014) or the regular school day (Repenning et al. 2010). Some of the school districts in Wyoming have technology classes (e.g., Raspberry Pi) in middle schools that could easily incorporate robotics and game design. Moreover, we will recruit third and fourth graders to participate in the study since younger students often participate in fewer extracurricular activities. Teachers will also be supported with resources to offer snacks to students during afterschool clubs.

In summary, the results of this study show students' self-efficacy significantly declined on the construct of computer use. However, students who participated in blended robotics/gaming clubs had significantly higher self-efficacy scores on the construct of videogaming. Computational thinking skills also varied by type of instruction as students who participated in the Project First method had higher levels of computational thinking (CT). This finding is supported by Repenning et al.'s (2010) research on CT. We believe the high cognitive load of creating a game influenced these results.

Limitations

The results of this study are limited to the participants and settings where the study took place and should not be generalized to students in other contexts. Major limitations in this study were student attrition and a low survey response rate. The attrition rate was 18.5 % since 101 students out of 124 completed the study. However, only 76 students completed pre–post surveys. In some cases, parents did not provide written consent, and in other cases, students opted out of taking the surveys. This impacted our ability to calculate the adjusted mean error to account for students being nested in schools because the number of students completing pre–post surveys at several schools was extremely small. As we build trust and relationships with families and schools, particularly on the Indian reservation where attrition was 30 %, we expect survey completion rates to increase as stronger community ties develop. Another limitation included our inability to measure self-efficacy in technology and STEM attitude/careers in the robotics only context given the small number of students who participated in this treatment. The research design calls for robotics-only and gaming-only treatments in Year 2 and a combination of robotics/gaming treatment in Year 3. In future years, we anticipate 400–500 students will participate as we expand to more schools. A great number of students in the sample will inform the interpretation of scores by type of instruction. Finally, the methods employed in this study did not offer opportunities to determine the participants' computational thinking strategies a priori. Nevertheless, given the qualitative nature of this aspect of the study, we captured the essence of students' artifacts. In future years, we will examine a broader range of student products across multiple school settings to show how diverse students' computational thinking strategies developed.

Conclusions

Digital gaming has become a popular way for youth and young adults in the Net Generation as well as younger children in the App Generation to spend their time. Popular games can be played in the home on Wii U and Nintendo PlayStation. However, schools have been slow to harness technology to improve student outcomes. Ketelhut (2010) claims that videogaming, computer gaming, and using the computer to engage in problem solving enhance students' self-efficacy in technology and science.

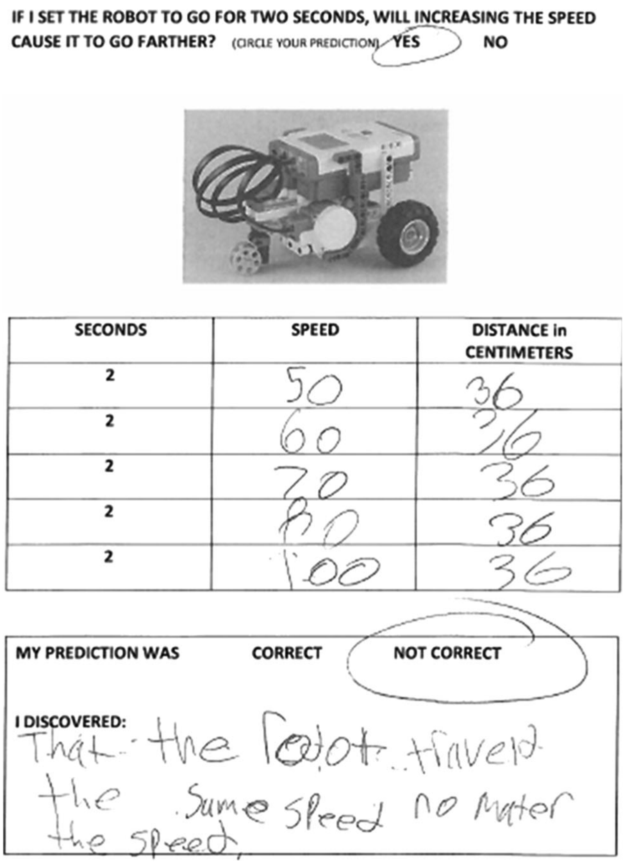
Culture is a critical element in gaming (Barr et al., 2013; Nasir 2005) and game design. While the products students made in this study exhibited elements of student culture and place, using digital games to transmit cultural knowledge has yet to be studied in depth. We anticipate that focus group interviews with students who identify as gamers may help us to understand the influence of culture and place in robotics and digital gaming. This study contributes to the literature on blending technology with culture and place. We encourage teachers to use culturally relevant pedagogy and place-based education (i.e., students' culture and place) as springboards to maintain student interest in STEM education given the results of this exploratory study.

In terms of promoting a diverse STEM workforce, the State Department of Workforce Services in Wyoming estimated the need for 1791 more workers in computer science; 1818 in installation and repair; and 5589 in architecture and engineering in this decade (Wyoming Department of Education 2004). While our goal is to expose diverse students to STEM so that they may become college STEM majors, many STEM jobs do not require a college degree but technical training. It is important to show students multiple pathways to STEM careers as well as alternative means to making a livable wage. Given their communal nature, indigenous students may be more willing to choose STEM careers if they believe the knowledge is culturally specific and would enhance their community.

This study provided females and underrepresented minority students with opportunities to develop and demonstrate STEM content knowledge by programming robots to complete particular tasks and designing digital games. Students engaged in scientific processes and co-constructed knowledge by producing knowledge as opposed to merely receiving it (Dierking et al. 2003; Ladson-Billings 1995). Thus, students had great potential to increase scientific, mathematical, and technological competencies to improve computational thinking skills. Our work is ongoing; we anticipate the results of our second and third study years will build upon the successful results reported here as we expand the research from eight schools in five districts to 20 schools in ten districts throughout the state of Wyoming and to four schools in an urban district in Pennsylvania.

Acknowledgments This material is based upon work supported by the National Science Foundation (DRL #1311810). Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. The authors thank the teachers and students throughout Wyoming for their participation in the study.

Appendix 1: Robotics worksheet



IF I SET THE ROBOT TO GO FOR TWO SECONDS, WILL INCREASING THE SPEED CAUSE IT TO GO FARTHER? (CIRCLE YOUR PREDICTION) [✓ YES] NO

SECONDS	SPEED	DISTANCE in CENTIMETERS
2	50	36
2	60	36
2	70	36
2	80	36
2	100	36

MY PREDICTION WAS CORRECT [✓ NOT CORRECT]

I DISCOVERED: That the Robot traveld the Same Speed no Mater the Speed,

Appendix 2: Computational thinking rubric

CT components	Emerging (1)	Moderate (2)	Substantive (3)
Formulating problems	If–then statements unclear in terms of problem goals (e.g., "Can pigs fly?")	If–then statements create conditions allow agent to move through program using a single condition (e.g., if you see a ghost move left)	If–then statements more complex and agent moves to more than one set of criteria (e.g., if you see a ghost and a scarecrow move to the left and/or up)

CT components	Emerging (1)	Moderate (2)	Substantive (3)
Abstraction	Agent and background resemble tutorial in Frogger game	Agent or background is non-traditional and created by the student	Agent and background are non-traditional and created by the student
Logical thinking	If–then statements do not follow logical path (e.g., agent is stuck and cannot move through the program)	If–then statements follow logical path with some complexity (e.g., agent moves through the program but no real challenges)	If–then statements follow logical path with more complexity (e.g., agent moves through program but can run into danger)
Using algorithms	No evidence of algorithmic use (i.e., game **cannot** keep score)	Some evidence of algorithm use (i.e., the game **can** keep score)	Evidence of algorithm use and final score (i.e., the games keeps score and says "you won")
Analyzing and implementing solutions	No evidence of the ability to debug the program	Some evidence of debugging	Strong evidence of debugging
Generalizing and problem transfer	Game resembles Frogger example	Game has some evidence of Frogger but some differences	Game is not similar to Frogger at all and shows creative use of knowledge transfer
Use of pop gaming culture	No evidence of including elements from other off-shelf games	Some similarities to current off-shelf games	Substantial modeling or similarities to current off-shelf games with improvements and/or significant modifications

References

Bandura A (1977) Self-efficay: toward a unifying theory of behavioral change. Psychol Rev 84:191–215

Barr D, Harrison J, Conery L (2011) Computational thinking: a digital age. Learn Lead Technol 38(6):20–23

Bracey J (2013) The culture of learning environments: black student engagement and cognition in math. In: Leonard J, Martin DB (eds) The brilliance of black children in mathematics: beyond the numbers and toward new discourse. Information Age Publishing, Charlotte, pp 171–194

Brand B, Collver M, Kasarda M (2008) Motivating students with robotics. Sci Teach Wash 75(4):44–49

Bremner A (2013) Singing and gaming to math literacy. Teach Child Math 19(9):582–584

Brenner ME (1998) Adding cognition to the formula for culturally relevant instruction in mathematics. Anthropol Educ Q 29:214–244

Bureau of Labor Statistics, U.S. Department of Labor (2014) Occupational outlook handbook. Retrieved on March 14, 2014 from http://www.bls.gov/ooh/computer-and-informationtechnology/computer-and-information-research-scientists.htm

Caron D (2010) Competitive robotics brings out the best in students. Tech Dir 69(6):21–23

Chang K, Wu L, Weng S, Sung Y (2012) Embedding game-based problem-solving phase into problem-posing system for mathematics learning. Comput Educ 58(2):775–786

Creswell JW (1998) Qualitative inquiry and research design choosing among five traditions. Sage Publications, Thousand Oaks

Dede C (2008) Theoretical perspectives influencing the use of information technology in teaching and learning. In: Voogt J, Knezek G (eds) International handbook of information technology in primary and secondary education. Springer, New York, pp 43–62

DeVellis RF (1991) Scale development. Sage Publications, Newbury Park

Dierking LD, Falk JH, Rennie LJ, Anderson D, Ellenbogen K (2003) Policy statement of the ''Informal Science Education'' ad hoc committee. J Res Sci Teach 40(2):108–111

Edelson DC (2001) Learning-for-use: a framework for the design of technology-supported inquiry activities. J Res Sci Teach 38(3):335–385

Friday Institute for Educational Innovation (2012) Upper elementary school student attitudes toward STEM survey. Author, Raleigh

Grubbs M (2013) Robotics intrigue middle school students and build STEM skills. Technol Eng Teach 72(6):12–16

Gruenewald DA (2003) Foundations of place: a multidisciplinary framework for place-conscious education. Am Educ Res J 40(3):619–654

Hirsch LS, Carpinelli JD, Kimmel H, Rockland R, Bloom J (2007, October) The differential effects of pre-engineering curricula on middle school students' attitudes to and knowledge of engineering careers. In: 37th ASEE/IEEE frontiers in education conference, Milwaukee, WI

Ioannidou A, Bennett V, Repenning A, Koh KH, Basawapatna A (2011) *C*omputational thinking patterns. In: Paper presented at the 2011 annual meeting of the american educational research association (AERA), Division C, New Orleans, LA.

Ivey D, Quam G (2009) 4-H and tech ed partnership gets students geeked about STEM. Tech Dir 69(3):19–21

Karp T, Maloney P (2013) Exciting young students in grades K-8 about STEM through an afterschool robotics challenge. Am J Eng Educ 4(1):39–54

Ke F (2008) A case study of computer gaming for math: engaged learning from gameplay? Comput Educ 51(4):1609–1620

Kebritchi M, Hirumi A, Bai H (2010) The effects of modern mathematics computer games on mathematics achievement and class motivation. Comput Educ 55(2):427–443

Ketelhut DJ (2010) Assessing gaming, computer and scientific inquiry self-efficacy in a virtual environment. In: Annetta LA, Bronack S (eds) Serious educational game assessment: practical methods and models for educational games, simulations and virtual worlds. Sense Publishers, Amsterdam, pp 1–8

Koutromanos G, Avraamidou L (2014) The use of mobile games in formal and informal learning environments: a review of the literature. Educ Media Int 51(1):49–65

Kroeber AL (1900) Symbolism of the Arapaho Indian. Bull Am Mus Nat Hist 13:69–84

Ladson-Billings G (1995) Toward a theory of culturally relevant pedagogy. Am Educ Res J 32(3):465

Leonard J (2008) Culturally specific pedagogy in the mathematics classroom: strategies for teachers and students. Routledge, New York

Leonard J, Davis JE, Sidler JL (2005) Cultural relevance and computer-assisted instruction. J Res Technol Educ 37(3):259–280

Li Q (2010) Digital game building: learning in a participatory culture. Educ Res 52(4):427–443

Linn MC, Hsi S (2000) Computers, teachers, peers: science learning partners. LEA, Mahwah

Matson E, DeLoach S, Pauly R (2004) Building interest in math and science for rural and underserved elementary school children using robotics. J STEM Educ 5(3&4):35–46

Nasir NS (2005) Individual cognitive structuring and the sociocultural context: strategy shifts in the game of dominoes. J Learn Sci 14(1):5–34

National Research Council (2011) Successful K-12 STEM education: identifying effective approaches in science technology, engineering and mathematics. National Academy Press, Washington

Nieto S (2002) Language, culture, and teaching: critical perspectives for a new century Mahwah. Lawrence Erlbaum, NJ

Paraskeva F, Mysirlaki S, Papagianni A (2010) Multiplayer online games as educational tools: facing new challenges in learning. Comput Educ 54(2):498–505

Presmeg NG (2007) The role of culture in teaching and learning mathematics. In: Lester FK (ed) Second handbook of research in mathematics teaching and learning. National Council of Teachers of Mathematics, Reston, pp 435–460

Repenning A, Webb D, Ioannidou A (2010) Scalable game design and the development of a checklist for getting computational thinking into public schools. In: Proceedings of the 41st ACM technical symposium on computer science education. Milwaukee, WI, pp 265–269

Robertson J, Howells C (2008) Computer game design: opportunities for successful learning. Comput Educ 50(2):559–578

Sheridan KM, Clark K, Williams A (2013) Designing games, designing roles: a study of youth agency in an urban informal education program. Urban Educ 48(5):734–758. doi:10.1177/0042085913491220

Webb D, Repenning A, Koh K (2012) Toward an emergent theory of broadening participation in computer science education. In: Proceedings of the ACM special interest group on computer science education conference. Raleigh, North Carolina, pp 173-178

Wing J (2006) Computational thinking. Commun ACM 49(3):33–35

Wyoming Department of Education (2004) Computer and mathematical occupations. http://doe.state.wy.us/lmi/200404/PAGE0006.HTM

Yuen TT, Boecking M, Stone J, Tiger EP, Gomez A, Guillen A et al (2014) Group tasks, activities, dynamics, and interactions in collaborative robotics projects with elementary and middle school children. J STEM Educ Innov Res 15(1):39–45