

# Preparing Teachers to Engage Rural Students in Computational Thinking Through Robotics, Game Design, and Culturally Responsive Teaching

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## Abstract

This article examines teacher preparation and teacher change in engineering and computer science education. We examined culturally responsive teaching self-efficacy (CRTSE), culturally responsive teaching outcome expectancy (CRTOE) beliefs, and attitudes toward computational thinking (CT) as teachers participated in one of three treatment groups: robotics only, game design only, or blended robotics/game design. Descriptive data revealed that CRTSE gain scores were higher in the robotics only and blended contexts than in the game design only context. However, CRTOE beliefs were consistent across all treatment groups. In regard to CT attitudes, teachers' gain scores were higher in the game design only and blended contexts than in the robotics only context. In addition, there were differences by treatment group related to STEM (science, technology, engineering, and mathematics) practices, while cultural artifacts were evident in each learning environment. The results of this study reveal some variability by treatment type and inform future research on equitable practices in engineering and computer science education.

## Keywords

computational thinking, culturally responsive teaching, self-efficacy, robotics, game design, equitable teaching

Computer science is a rapidly growing field (Bureau of Labor Statistics, U.S. Department of Labor, 2014) that offers youth a broad, multidisciplinary pathway to occupations that provide both intrinsic and extrinsic rewards and benefits. Introducing K-12 students to computer science through computer programming is currently in the forefront of educational reform with some countries developing content specific courses, while others include coding in Information and Communications Technology (ICT) and general technology courses (Falloon, 2016; Moreno-León, Robles, & Román-González, 2016). As school-based access to technology increases, educational uses of technology are also expanding throughout the curriculum in formal and informal learning environments. This expansion presents a critical need to identify the tools, pedagogy, and practices deemed essential for promoting learning, especially given the data-rich context in which we currently live. In the United States, K-12 students in urban and rural areas have become increasingly more culturally and linguistically diverse with students of color and poor students representing more than 50% of the national population in public schools (Blad, 2015). Preparing underrepresented students in the United States with the

STEM (science, technology, engineering, and mathematics)/ ICT skills needed to fill 21st-century jobs is both a national priority (National Science Foundation [NSF], 2010) and a social justice imperative (Leonard & Martin, 2013).

The benefits of learning to code include the development of computational thinking (CT; Falloon, 2016; Leonard et al., 2016; Moreno-León et al., 2016; Repenning, Webb, & Ioannidou, 2010; Wing, 2008) skills. CT, which emerged from the work of Seymour Papert (1993) who first coined the term, is an evolving field. Wing (2006) defined CT as a human endeavor that “involves solving problems, designing

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systems, and understanding human behavior by drawing on the concepts fundamental to computer science” (p. 33). However, the literature is sparse in terms of understanding how CT supports “critical competencies like creative problem solving, collaboration, and programming skills” in robotics (Sullivan & Heffernan, 2016) and digital game design (Jenson & Droumeva, 2016, p. 111).

The purpose of the current study was to examine teacher preparation in computer science and teacher change as it related to (a) culturally responsive teaching (CRT) efficacy beliefs, (b) attitudes toward CT, and (c) facilitating equitable STEM practices during informal school settings. Equitable STEM practices “disrupt inequities that occur at the level of classroom interaction” (N. Shah et al., 2013, p. 263) and promote access to rich content, high-quality instruction, collaborative peer relationships, and STEM identities. This article describes how our Year 2 and 3 interventions influenced teaching in the context of learning during informal STEM settings. Specifically, we were interested in how beliefs about CRT and attitudes toward CT shifted as a result of participating in the study. We also examined how CRT influenced teachers’ STEM practices as they taught in one of three different learning environments—(a) robotics only, (b) game design only, or (c) blended robotics and game design. We anticipated the robotics and game design software would create challenges and successes related to student outcomes that would influence elementary and middle school teachers’ beliefs and practices in informal learning environments.

While several teachers in this study were familiar with robotics, few had previously worked with game design or used culture to motivate students to learn. Our pedagogical approach—to couple robotics and game design within the context of student cultural norms—is both necessary and unique. In this study, we define robotics as use of robotic construction kits, specifically LEGO® EV3 and NXT robots. Game design, in this study, is the art of using drawing tools to develop unique characters (i.e., agents) and game boards (i.e., worksheets) along with specific codes (i.e., if/then statements) to move the characters through a set of obstacles to win the game. Gaming is the act of playing computer games developed by other students as well as off-shelf games. Culture is defined as “a group’s individual and collective ways of thinking, believing, and knowing, which includes their shared experiences, consciousness, skills, values, forms of expression, social institutions, and behaviors” (Tillman, 2002, p. 4).

## Background of the Study

We drew upon self-efficacy theory and the constructs of culturally responsive pedagogy (CRP) and CT as the basis for examining teacher preparation (i.e., professional development) and teacher change.

## Self-Efficacy Theory

Bandura (1977) developed what is now known as self-efficacy theory, which connects the predictive value of an event’s success to the confidence that one has to perform it. Developing a strong sense of efficacy is required to put pedagogical skills to use (Bandura, 1997; Siwatu, 2007). However, simply acquiring knowledge, skills, and competence in subject matter does not ensure the implementation of equitable and best practices, particularly in STEM education (Leonard, 2008; Pajares, 1996). According to Bandura (1986), knowledge and action are mediated by belief in one’s ability to implement the acquired skills in a specific learning environment.

Applying Bandura’s self-efficacy theory to the construct of teacher efficacy is critical to understanding how teachers believe they can control their environment and what they believe students can learn (Siwatu, 2007). Bandura (1997) identified two factors that affect teacher self-efficacy: personal efficacy and outcome expectancy. When applied to teaching, personal self-efficacy is defined as perceived judgment about one’s ability to teach (Newton, Leonard, Evans, & Eastburn, 2012). Outcome expectancy is “a person’s estimate that a given behavior will lead to certain outcomes” (Bandura, 1977, p. 193). Siwatu (2007) developed a measure of teachers’ sense of efficacy based on Bandura’s (1997) efficacy scales. Siwatu’s scales were used to measure teacher change related to CRP in this study.

## CRP

CRP (Gay, 2010) is critical to understanding the current study. Gay (2010) defined CRP as using cultural awareness, previous experiences, points of reference, and cultural expressions to make learning more relevant and equitable for ethnically diverse children. CRP is validating, comprehensive, multidimensional, empowering, transformative, and emancipatory (Gay, 2010). CRP creates the opportunity for students to learn in a third space where ethnic ways of knowing and core identities are valued alongside dominant canons of knowledge (Brown-Jeffy & Cooper, 2011; Gay, 2010; Lipka et al., 2005). CRP promotes equitable teaching and learning in settings where “the classroom can become a site for social change” (Niето, 2002, p. 66). Equitable teaching in computer science education provides opportunities for students to build computer science identities as well as their capacity to do computer science in school and beyond (N. Shah et al., 2013).

In this project, students’ cultural artifacts were incorporated into game boards for LEGO® robotics and into Scalable Game Design (SGD) curriculum. MINDSTORMS® software was used to program LEGO® EV3 and NXT robots to move along specific paths on challenge-specific game boards, which may be cultural in nature. SGD allowed students to

create two-dimensional (i.e., AgentSheets) and three-dimensional (i.e., AgentCubes) computer games (Repenning et al., 2010), which may also reflect culture and design features (i.e., color, style, shape, sound, etc.). For example, Native American students used native symbols as agents in their games (i.e., a native symbol of a turtle). Thus, encouraging students to embed elements of culture into robotics and game design enhances students' motivation and interest, and promotes STEM identity development that may lead to greater social agency and STEM participation (Hughes, Nzekwe, & Molyneaux, 2013; Reynolds, 2016).

## CT

CT is associated with competence-based technological literacies that include tech prototyping, fostering applied creativity, and design thinking (Jenson & Droumeva, 2016). While there is no standard definition of CT, most agree on the operational definition set forth by the International Society for Technology in Education (ISTE) and the Computer Science Teachers Association (2011) that 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. Moreover, CT is intertwined with and “fundamental to perspectives that require the modeling of complex systems” (Berland & Wilensky, 2015, p. 631). However, the simplest form of expressing CT is by writing code to use abstraction, algorithmic thinking, and learning transfer in game design (Ioannidou, Bennett, Repenning, Koh, & Basawapatna, 2011; Repenning et al., 2015). CT is further described as it applies to the specific contexts of robotics and game design.

*CT in robotics.* Participation in robotics provides students with hands-on experiences that support teamwork and create opportunities for engagement in multidisciplinary tasks (Caron, 2010; Karp & Maloney, 2013). Robotics advances knowledge of engineering and what it entails (Blanchard, Judy, Muller, Crawford, & Petrosino, 2015; Karp & Maloney, 2013; Nugent, Barker, Grandgenett, & Adamchuk, 2010), engages students in scientific processes (Blanchard et al., 2015; Karp & Maloney, 2013), and has been shown to improve spatial visualization skills and attitudes toward STEM (Coxon, 2012; Julià & Antolí, 2016). LEGO® robotics, specifically, is widely used in K-8 settings as an authentic and kinesthetic way to improve children's problem-solving skills, reinforce science applications and concepts, and build upon informal learning activities often done at home (Karp & Maloney, 2013; Leonard et al., 2016).

Robotics construction kits support student development of CT skills through manipulation. Sullivan and Heffernan (2016) described computational manipulatives as those that

have internal computing capabilities, programming, or microcomputers embedded in the hardware. Grounded in the LOGO programming language (Papert, 1993), computational manipulatives allow children to engage in analytical and embodied cognition. During LEGO® robotics, students may mimic the physical motions of the robot as it travels along a path while also engaging in reasoning, reflection, discussion, and problem solving to complete a robotics task. We adapted Sullivan and Heffernan's learning progression model of sequencing, causal inference, conditional reasoning, and systems thinking to include proportional reasoning. Sequencing involved following directions to build the robot and program it; proportional reasoning was used to determine how many rotations were needed to make the robot move a certain distance; causal inference relied on if/then reasoning to adjust the program; conditional reasoning involved the use of logic in programming sensors to work with robots; and systems thinking involved understanding how different components interacted together to produce outcomes. In this study, we used robotics construction kits to provide elementary and middle school students with an opportunity to learn about complex systems, and to develop CT as they engaged in robotics programming (Berland & Wilensky, 2015).

*CT in game design.* Digital games can be used to broaden students' participation in STEM and to engage students in integrated curriculum (Barr, Harrison, & Conery, 2011; Webb, Repenning, & Koh, 2012). There is also evidence that designing digital games increases student confidence and builds students' capacity to learn computer science and other STEM subjects (Jenson & Droumeva, 2016). For example, Webb et al. (2012) described effective pedagogical strategies for teaching SGD. The central question was “whether instructional experiences should start with programming techniques (e.g., loops, if-then-else statements, etc.)” before advancing to actual game design or should the game be designed first and students learn as they go—an approach they called project-first, which “allows students to immediately engage in computer programming design experiences and to learn concepts as the need arises” (Repenning et al., 2015, p. 11.8).

Tutorials developed by Webb et al. (2012) offer users a platform to begin designing their own games. However, using the tutorial without deviation may adversely affect student motivation, engagement, and ownership of the game or simulation created (Leonard et al., 2016). On the contrary, researchers found that the project-first approach positively affected the motivation of females and underrepresented minority students. As a result, Webb et al. suggested that guided inquiry similar to Vygotsky's (1978) Zone of Proximal Development (ZPD) should be used to provide just enough assistance to support student mastery of CT patterns while also maintaining student interest and motivation. These findings had a direct bearing on the present study. We grappled

with how to prepare teachers effectively, given a limited amount of time to learn robotics and game design principles to implement them during informal school settings.

## The Research Study

The current study is part of a larger 3-year study that was designed to enhance middle-grade students' spatial visualization and CT through engagement in engineering and computer science tasks. In the larger study, we examined participatory methods of instruction that blended formal and informal learning in rural and Indigenous communities in Wyoming. We promoted robotics and game design clubs before, during (i.e., lunch and technology classes), and/or after school as a hook to engage students in STEM activities to enhance their spatial visualization and CT skills. Participation in the clubs was voluntary but provided a pathway to broaden students' access to STEM education while orienting them toward STEM/ICT careers. In the current study, we focused on teacher preparation and teacher change, as teacher participants reflected and altered their practices in the learning context to create unique learning opportunities for their students.

## Research Questions

This study is focused on teacher variables related to engaging rural students in robotics and game design, and it was guided by the following research questions:

**Research Question 1:** How did teachers' culturally responsive self-efficacy and outcome expectancy beliefs change after participating in the study?

**Research Question 2:** How did teachers' attitudes toward CT change after participating in the study?

**Research Question 3:** How did teachers' STEM practices compare and contrast in different types of learning environments (i.e., robotics only, game design only, or blended robotics/game design)?

**Research Question 4:** How did students' cultural artifacts compare and contrast in different types of learning environments?

**Research Question 5:** Which CT strategies and cultural elements were evident in three focal teachers' classrooms during robotics and/or game design lessons?

## Method

After obtaining institutional review board (IRB) approval, we conducted the pilot study. During the pilot study, teachers focused on robotics, game design, or a combination of robotics/game design to test the treatment variables in formal classrooms and informal before- and after-school clubs (Leonard et al., 2016). In Year 2, we isolated the variables and encouraged continuing and newly recruited teachers to

facilitate robotics or game design. A blended approach was used to examine the impact of teaching both robotics and game design in Year 3. Year 2 and 3 results, as they relate to teacher outcomes, are the focus of this article.

Yet, quantitative data alone do not fully explain teacher change in school environments where conditions are in a constant state of flux. In the tradition of Creswell (1998), we employed thick descriptions about school settings and classroom environments to understand the learning context. Specifically, microethnographic research methods were used to collect qualitative data. Microethnography is a process of "combining participant-observation with detailed analyses of audiovisual records of naturally occurring interaction" (Erickson & Mohatt, 1982, p. 133). The specific microethnographic method used in this study is the case study. Case studies are used primarily for deep examination of processes that emerge from phenomena, providing critical data that are often overlooked in quantitative analyses (Bogdan & Biklen, 2006). In the current study, we present case studies of three focal teachers, highlighting their journal reflections as well as their work with randomly selected students in their classrooms to link their practices to student artifacts. We examined teachers' STEM practices to understand how teachers facilitated CRT and CT during robotics and/or game design clubs. Thus, we unveil the complexity of enacting CRP in robotics and game design, adding to the extant literature on teachers' efficacy and CT beliefs in STEM education.

## Setting and Participants

This study was conducted with teachers at elementary, middle, and junior high schools in Wyoming. Incentives for teachers included paid stipends and professional development along with a tuition-free course that offered graduate credit. We initially recruited 12 teachers in Cohort 1 who agreed to participate in the pilot year of this 3-year study. In Year 2, we recruited 24 teachers to participate in either the robotics or game design intervention (six continued from Cohort 1). In Year 3, 34 teachers participated in the blended robotics/game design intervention. Nine teachers in Year 3 taught in an urban setting outside of the state of Wyoming and were removed from the sample, reducing the number of teachers to 25 (12 continued from Cohort 2, and one continued from Cohorts 1 and 2 to participate all 3 years). A total of 33 new teachers participated in the study in Years 2 and 3. In all, 45 teachers (35 female, 10 male) participated in the 3-year study. Table 1 shows the teacher sample for each year of the study, and Table 2 describes teacher demographics for each year and cohort, including subject taught and years of service.

In terms of student participants in Wyoming, 314 students at 15 schools participated in the Year 2 study, and 365 students at 16 schools participated in the Year 3 study. Approximately 68% of the students were male and 32% were female. Demographics in Wyoming reveal that student populations were 77.8% White, 15.3% Latin@, 3.6% Asian, 2.2%

**Table 1.** Sample of Wyoming Teacher Participants by Year/Cohort.

Learning environment	Year 1 (Cohort 1) pilot	Year 2 (Cohort 2) R only	Year 2 (Cohort 3) G only	Year 3 (Cohort 4) blended R/D
New teachers	12	10	8	12
Continuing		4	2	13
Total teachers	12	14	10	25

Note. R = robotics; G = game design.

**Table 2.** Demographics of Wyoming Teacher Participants by Year/Cohort.

Teacher demographics <sup>a</sup>	Year 1 (Cohort 1) pilot	Year 2 (Cohort 2) R <sup>a</sup> only	Year 2 (Cohort 3) G <sup>a</sup> only	Year 3 (Cohort 4) blended R/G
Race				
White	9	7	6	10
Native American	2	0	0	0
African American	1	0	0	0
Hispanic	0	3	2	2
Other	0	0	0	0
Gender				
Males	4	1	2	3
Females	8	9	6	9
Years of service ( <i>M</i> )	14	18	13	11
Subject taught				
Elementary	3	6	5	3
MS mathematics	2	1	0	1
MS science	2	0	0	1
Technology	4	1	2	4
Other professional	1	2	1	3

<sup>a</sup>Teacher data listed for new teachers only. R = robotics; G = game design.

American Indian, 2.1% African American, and 2.5% two or more races.

We selected three focal teachers for case studies. These three focal teachers present a convenience sample that was diverse in terms of gender and race. Furthermore, the focal teachers participated in multiple cohorts, providing ample samples of their STEM teaching over time. Each of these focal teachers had four Dimensions of Success (DoS) observations and numerous student artifacts to draw upon (A. M. Shah, Wylie, Gitomer, & Noam, 2014). These teachers had eight to 15 students in their after-school clubs. The average class size in Wyoming is about 15 students. Selection of these three focal teachers allowed for more robust descriptions of CRP and student engagement in robotics and games design to facilitate CT.

### Instrumentation

Participating teachers completed two surveys to determine how their beliefs about CRT and attitudes toward CT were influenced by the study. These surveys were administered on a pre–post basis. Teachers completed the presurvey during the first 1 or 2 weeks of the study and the postsurvey at the

end of the study. Ideally, teachers completed the presurvey prior to taking the online professional development course, which began 3 to 4 weeks after the semester started.

The survey on CRT developed by Siwatu (2007) is based on equitable teaching and culturally sensitive instruction (see Appendix A). The Culturally Responsive Teaching Self-Efficacy (CRTSE) scale measures the extent to which teachers have a sense of efficacy for engaging in specific instructional tasks related to CRT. The Culturally Responsive Teaching Outcome Expectancy (CRTOE) scale measures the extent to which teachers learn to associate positive student outcomes with CRT. The CRTSE consisted of 40 items, and the CRTOE consisted of 26 items with internal reliability of .96 and .95 (Cronbach's  $\alpha$ ), respectively.

The CT survey developed by Yadav, Zhou, Mayfield, Hambrusch, and Korb (2011) was used to assess teachers' attitudes and understanding related to CT (see Appendix B). The CT survey consisted of five components: (a) Understanding CT, (b) Self-Efficacy, (c) Intrinsic Motivation, (d) Integration of CT in Classroom Practice, and (e) Career Relevance of CT. A 4-point Likert-type scale was used to rate survey items that ranged from 1 = *strongly disagree*, 2 = *disagree*, 3 = *agree*, and 4 = *strongly agree*. During the study, teachers learned to use

MINDSTORMS® software as well as AgentSheets (two-dimensional) and AgentCubes (three-dimensional) (Repenning, 2013) to facilitate CT among their students.

The DoS rating tool (A. M. Shah et al., 2014) was used to observe teachers' STEM practices with students in this study. The DoS observation tool utilizes a 4-point rubric to rate teachers' STEM practices across 12 domains. Factor analysis of the instrument revealed that the domains can be aggregated into two groups: (a) learning environment and (b) student learning. Student learning may be further divided into three categories: (a) Activity Engagement, (b) STEM Knowledge and Practices, and (c) Youth Development (Gitomer, 2014). According to developers of the DoS instrument, scores in the 1 to 2 range are generally weak indicators of STEM program quality, whereas scores of 3 and 4 are generally strong indicators (Papazian, Noam, Shah, & Rufo-McCormick, 2013).

Finally, the research team developed a rubric that used a 3-point Likert-type scale to rate students' games as emerging (1), moderate (2), or substantive (3) based on evidence of CT and culture (see Appendix C). The rubric was developed based on the ISTE (2011) definition of CT and was field-tested by multiple raters. Interrater reliability was established at 86%.

### Procedures

Prior to participating in the study and working with students, teachers enrolled in an online graduate course that focused on CRP and either robotics, game design, or blended robotics/game design to coincide with the assigned treatment. The class was online because teachers were dispersed throughout the state of Wyoming. However, teachers attended face-to-face logistics meetings on the university campus before and after the study.

To learn about CRP, teachers read and discussed several articles that were related to the project (Bishop, 1988; Leonard, Napp, & Adeleke, 2009; Paznokas, 2003). Bishop's (1988) article helped teachers to understand how culture was related to counting, locating, measuring, designing, playing, and explaining. The researchers' prior work with teachers on culturally responsive tasks was shared to help teachers avoid using deficit-oriented or superficial examples of CRT. As art and design were directly connected to the project, teachers were shown how quilt patterns could be used to create the game worksheet (Paznokas, 2003). An Arapahoe teacher from Year 1 shared her Indigenous students' work along with the culturally specific strategies she used to encourage incorporating American Indian culture into game design. Researchers also explained how robots could move to music and patterns that illustrated skating or dancing. During the course, teachers developed digital games and programmed the robot to move in geometric formations and to play music. Teachers submitted their games and robotics code to the instructors for feedback. After the course, teachers recruited students to participate in after-school clubs.

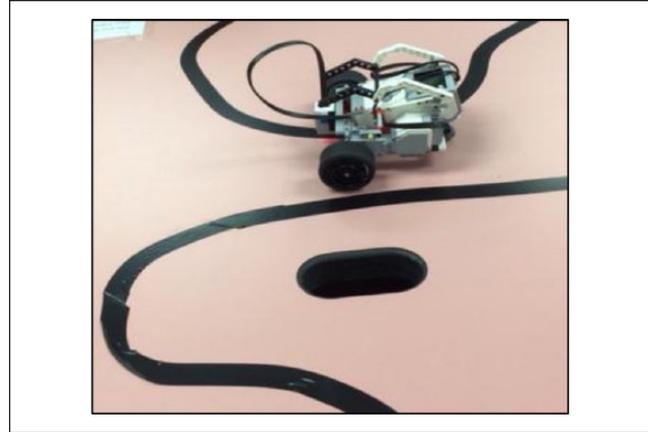
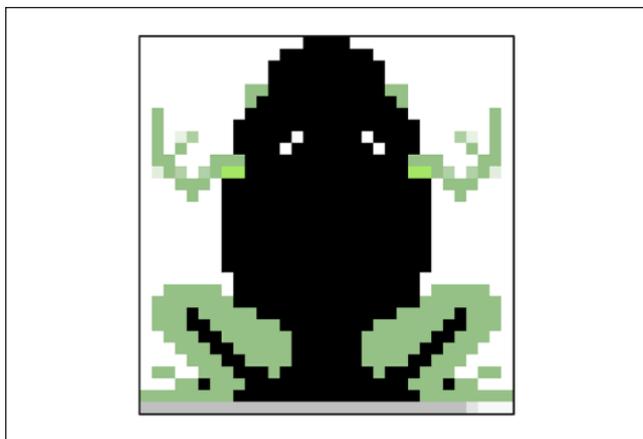


Figure 1. EV3 robot using color sensor.

In the robotics context, teachers followed basic protocols to make a 5-min bot, basic car, and/or rover to complete a task. They used specialized LEGO® pieces and a brick (brain of the robot) to make the bot. Then, they used MINDSTORMS® software downloaded onto computers to control the bot's movements. CT as well as proportional reasoning are needed to understand how to set the speed and number of rotations for the bot to move forward, backward, left, or right. Teachers also learned to use light, ultrasonic, and infrared sensors to get the bot to complete more sophisticated tasks. These sensors allowed the bot to move along a color-coded path, push or pull an object, or stop or start when an obstacle was detected (see Figure 1). When teachers reported problems with debugging, screenshots were provided to troubleshoot programming issues.

In the game design context, an online Learning Management System (LMS) with conference capabilities was used to demonstrate AgentSheets and AgentCubes (Repenning et al., 2010). The key components of an AgentSheets program are *agents*, which model all objects in a screen or scene, which is called a *worksheet*. The worksheet is divided into a rectangular array of cells, and each agent lives inside one of the cells. More than one agent may occupy the same cell at a time, with one agent on top of another. During the online course, teachers created agent depictions (see Figure 2) and the corresponding worksheet. Next, teachers programmed their agent to move in response to the arrow keys. Then, they used code to determine the set of conditions and behaviors (see Figure 3) that controlled what the agent did when a certain key is pressed (e.g., right arrow key moves agent to the right). Finally, we presented teachers with a variety of challenges, such as programming the game to keep score.

Following professional development, teachers introduced their students to engineering by building and programming robots. In robotics, students engaged in CT as both physical and cognitive skills were used in a learning progression that involved sequencing, causal inference, conditional reasoning, and systems thinking (Sullivan & Heffernan, 2016).



**Figure 2.** Sample agent depiction.

Likewise, students were introduced to computer science by creating and playing digital games. In game design, CT involved coding to create behaviors and actions such as generating agents on the left-hand side of the worksheet to absorb them on the right-hand side of the worksheet or using one agent to transport another agent.

To assess teachers' STEM practices, six researchers and two graduate students were trained to use the DoS. The training involved being able to correctly score each dimension using a 4-point rubric. Teachers usually taught for 1 to 2 hours at least 2 times per week for a total of 40 to 50 contact hours with students. In some instances, two teachers combined their students to co-teach the lessons. A calendar was created for members of the research team to observe teachers at their respective school sites. Teachers were observed at least 2 times by the research team. On many occasions, two researchers observed the teachers' instruction during robotics and/or game design lessons. If the raters differed on their assessment of the ratings, they reached consensus based on the evidence. Analysis of six randomly selected co-observations on the DoS revealed that interrater reliability was 83%. During the prearranged observations, field notes were recorded, and ratings were given on all 12 of the DoS domains. Ratings were shared with teachers after they participated in the study as member checks.

### *Data Sources and Data Analyses*

Mixed methods were used to collect and analyze quantitative and qualitative data in this study. The data sources for quantitative analyses were the teachers' pre-post survey scores on the following scales: CRTSE/CRTOE (Siwatu, 2007) and CT (Yadav et al., 2011). The DoS tool (A. M. Shah et al., 2014) was used quantitatively to rate teachers' enactment of STEM practices and their interactions with students, "where 1 indicates little evidence and 4 indicates strong evidence of quality in that dimension" (Papazian et al., 2013, p. 20). For qualitative

analysis, we examined teachers' journals as well as our field notes to develop case studies about teaching in the context of learning.

### *Limitations of the Study*

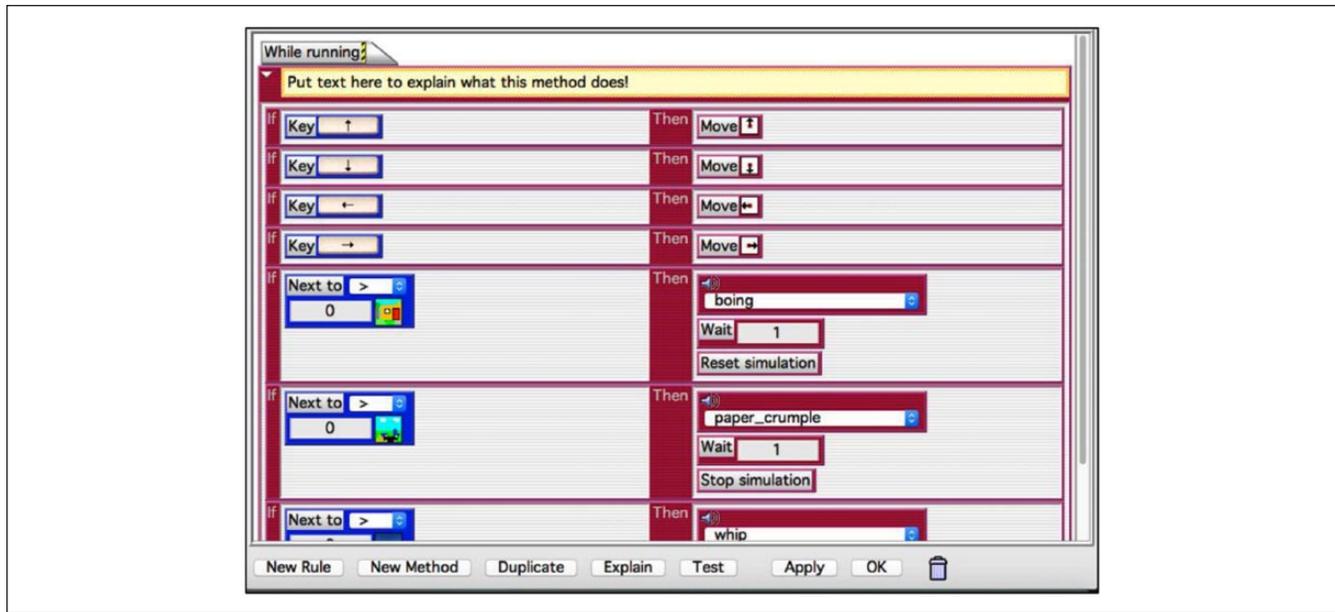
The results of this study are limited to the participants and settings where the study took place, and should not be generalized to teachers in other contexts. A major limitation in this study was teacher self-report, which is often less reliable than other forms of data. Second, the 8-week, online professional development course was too short a duration to attend to all of the learning goals for teachers. Moreover, teachers in this study needed explicit, culturally specific examples to learn how to enact CRT while teaching students how to code, regardless of the learning context. A third limitation was small class sizes during the after-school clubs. This limitation prevented quantitative analyses to tie student outcomes to teacher practices. Finally, the methods employed did not offer opportunities to determine students' CT strategies a priori. However, we were able to capture the essence of students' CT through a limited number of artifacts.

### **Results**

To answer the research questions, we present the results of the CRT and CT surveys first, and then provide descriptive data on the DoS. Next, we analyzed student artifacts for cultural elements in each learning environment. Finally, we present the focal teachers' case studies as evidence of CRT along with student work samples as examples of cultural referents.

### *Culturally Responsive Beliefs and Outcome Expectancy Surveys*

Pre-post survey results on the Culturally Responsive Beliefs and Outcome Expectancy scales are presented as descriptive data given the small sample sizes. Teachers in each analysis were unique to the study. In other words, we did not include teachers who participated in more than one cohort in multiple analyses. One teacher unique to Cohort 4 did not complete the CRT postsurvey, which reduced the number in the sample from 12 to 11 teachers. Data analyses (see Table 3) revealed that self-efficacy scores (i.e., CRTSE) increased from pre-post among teachers in all cohorts: pre-CRTSE-2  $M = 78.18$  to post-CRTSE-2  $M = 84.91$ ; pre-CRTSE-3  $M = 83.21$  to post-CRTSE-3  $M = 84.11$ ; pre-CRTSE-4  $M = 77.18$  to post-CRTSE-4  $M = 82.07$ . However, teachers in Cohort 2 had the highest gain scores on the CRTSE (mean difference = 6.73) compared with those in Cohort 3 (mean difference = 1.90) and Cohort 4 (mean difference = 4.89). Data analyses also show that mean scores on student outcome expectancy (i.e., CRTOE)



**Figure 3.** Sample program of agent behavior.

**Table 3.** Comparison of Pre–Post Culturally Responsive Self-Efficacy and Outcome Beliefs.

Cohort	Pretest	SD	Posttest	SD	Gain score
Cohort 2-R only ( $n = 10$ )					
CRTSE-2	78.18	18.78	84.91	13.55	6.73
CRTOE-2	86.56	18.11	88.16	18.33	1.58
Cohort 3-G only ( $n = 8$ )					
CRTSE-3	83.21	11.72	84.11	14.54	1.90
CRTOE-3	89.55	15.88	91.16	10.34	1.61
Cohort 4-R/G ( $n = 11$ )					
CRTSE-4	77.18	15.47	82.07	14.80	4.89
CRTOE-4	83.53	11.68	85.60	7.25	2.07

Note. CRTSE = culturally responsive teaching self-efficacy; CRTOE = culturally responsive teaching outcome expectancy; R = robotics; G = game design.

**Table 4.** Comparison of Pre–Post CT Attitudes.

Cohort	Pretest	SD	Posttest	SD	Gain score
Cohort 2-R only ( $n = 9$ ) CT-2	3.11	0.77	3.13	0.86	0.02
Cohort 3-G only ( $n = 8$ ) CT-3	3.25	0.63	3.37	0.51	0.13
Cohort 4-R/G ( $n = 11$ ) CT-4	3.36	0.23	3.46	0.31	0.10

Note. CT = computational thinking; R = robotics; G = game design.

increased from pre–post for all cohorts (pre-CRTOE-2  $M = 86.58$  to post-CRTOE-2  $M = 88.16$ ; pre-CRTOE-3  $M = 89.55$  to post-CRTOE-3  $M = 91.16$ ; pre-CRTOE-4  $M = 83.53$  to post-CRTOE-4  $M = 85.60$ ). While gain scores were small: Cohort 2 (mean difference = 1.58), Cohort 3 (mean difference = 1.61), and Cohort 4 (mean difference = 2.07), teachers' scores were fairly consistent on outcome expectancy. Nevertheless, results should be interpreted with caution given the small samples.

### CT Survey

We measured changes in teachers' attitudes toward CT using the survey developed by Yadav et al. (2011). Pre–post CT scores increased for all cohorts (see Table 4): pre-CT-2  $M = 3.11$  to post-CT-2  $M = 3.13$ ; pre-CT-3  $M = 3.25$  to post-CT-3  $M = 3.37$ ; and pre-CT-4  $M = 3.36$  to post-CT-4  $M = 3.46$ . Again, one teacher did not complete the postsurvey on CT in Cohort 4, and one teacher in Cohort 2 did not complete the

**Table 5.** DoS Ratings by Cohort.

Cohort	Activity Engagement			STEM Knowledge and Practices				Youth Development				
	Participation	Purposeful activities	STEM engagement	Domain mean	STEM learning	Inquiry	Reflection	Domain mean	Relationship/ interaction	Relevance	Youth voice	Domain mean
Cohort 2 ( <i>n</i> = 10)	3.7	3.4	3.7	3.6	3.3	3.5	3.0	3.3	4.0	3.3	3.4	3.6
Cohort 3 ( <i>n</i> = 8)	3.2	3.5	3.7	3.5	2.8	3.2	2.8	2.9	3.8	2.5	3.2	3.2
Cohort 4 ( <i>n</i> = 9)	3.5	3.8	3.9	3.7	3.6	2.9	3.5	3.3	3.8	2.0	3.4	3.1

Note. DoS = Dimensions of Success; STEM = science, technology, engineering, and mathematics.

presurvey and the postsurvey. However, teachers in Cohorts 3 and 4 had higher gain scores (Cohort 3: mean difference = 0.12; Cohort 4: mean difference = 0.10) than teachers in Cohort 2 (mean difference = 0.02). These data imply that teachers in the game design only and robotics/game design treatment groups had more robust CT. The literature suggests that CT patterns are highly associated with game design (Falloon, 2016; Repenning et al., 2015). Although game design was more difficult for teachers to learn and facilitate, perhaps once the code for SGD was mastered, it resulted in more positive attitudes toward CT. These results should be interpreted with caution given the small samples.

## DoS

Descriptive data show mean ratings for teachers by cohort on the categories of Activity Engagement, STEM Knowledge and Practices, and Youth Development (see Table 5). We report results of the final observation reports for teachers in each cohort to compare their STEM practices at the end of the study to reflect the benefit of feedback and member checks. Only teachers who had not participated in previous cohorts were rated.

DoS ratings on the category of Activity Engagement show similar mean scores for teachers in each learning environment (Cohort 2:  $M = 3.6$ ; Cohort 3:  $M = 3.5$ ; Cohort 4:  $M = 3.7$ ). Cohort 3 had the lowest mean score on the STEM Knowledge and Practices category (Cohort 2:  $M = 3.3$ ; Cohort 3:  $M = 2.9$ ; and Cohort 4:  $M = 3.3$ ). In particular, Cohort 3 had the lowest scores on the dimensions of STEM learning ( $M = 2.8$ ) and reflection ( $M = 2.8$ ) in this category. Cohort 2 ( $M = 3.6$ ) had the highest mean score on the Youth Development category, whereas Cohort 4 ( $M = 3.1$ ) had the lowest mean score. Specifically, teachers in Cohort 2 ( $M = 3.3$ ) had a higher score on the relevance dimension than teachers in Cohort 3 ( $M = 2.5$ ) and Cohort 4 ( $M = 2.0$ ). Teachers in all three learning environments were fairly consistent in attending to youth voice (Cohort 2:  $M = 3.4$ ; Cohort 3:  $M = 3.2$ ; and Cohort 4:  $M = 3.4$ ). In this domain, teachers were rated on their ability to prompt student thinking,

facilitate student discourse, and support creative expression as children shared what they learned during the lesson.

## Cultural Artifacts in Robotics and Game Design

To compare and contrast the cultural artifacts students created in the three types of learning environments, we used the cultural dimension of the CT rubric previously described to rate students' products. Five focal students were randomly selected from one class in both the robotics and game design only contexts. Ten students (i.e., robotics [ $n = 5$ ]; game design [ $n = 5$ ]) were randomly selected from one class in the blended robotics/game design context. These classes were convenience samples that were selected based on the number of students in the classes ( $n > 15$ ) and the availability of substantial data for analysis. Field notes obtained from DoS observations and MINDSTORMS® or SGD code were used to describe and rate student artifacts. Products were rated 1 for emerging, 2 for moderate, and 3 for substantive cultural elements. The results of this analysis are presented along with evidence in Table 6.

The data show that students used sound effects or music and routine tasks, such as racing or pushing an object, to make cultural connections during robotics clubs. One of the songs that a robot played in Class A was "Santa on the Rooftop" (see Figure 4). Culture was also evident in game design as students created a host of characters from Disney movies and off-shelf games. The type of game compared and contrasted in the game design only and blended contexts was the AgentSheets maze. For example, one student's worksheet was an abstract representation of various forms of water (see Figure 5).

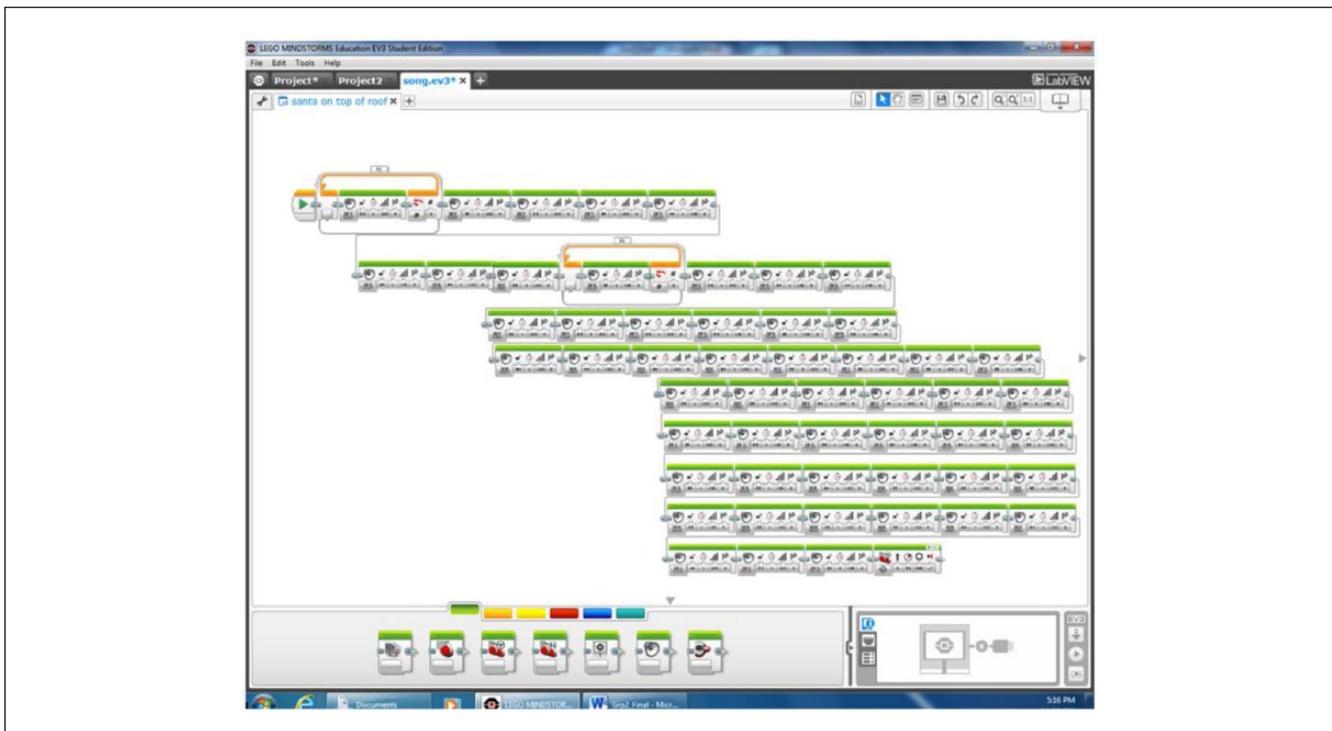
Another student programmed his robot to play the musical score to *Jurassic World*. When asked about this, he said the following:

I took piano lessons and could peck out the tune on the computer. I like robotics better than game design because I understand it better. When I was younger, I enjoyed playing with LEGOs. Now I can do that and apply what I learned in piano class as well.

**Table 6.** Comparison and Contrast of Students' Cultural Artifacts by Learning Environment.

Culture artifacts	Emerging (1)	Moderate (2)	Substantive (3)
Cohort 2 (R) Class A (n = 5)		60% car programmed to push ball into cup on obstacle course with <i>no</i> sound effects	40% car programmed to push ball into cup after traversing an obstacle course with sound effects of dog barking or alarm
Cohort 3 (G) Class B (n = 5)	20% trouble with SGD coding with incomplete game	80% (games with monsters and Halloween and Christmas themes with sound effects such as screams and hallelujah)	
Cohort 4 (R/G) Class C (n = 5)—R	20% trouble with MINDSTORMS® coding	60% programmed basic car to race with <i>no</i> sound effects	20% programmed basic car with musical score for <i>Jurassic World</i> theme
Class C (n = 5)—G		60% (games with characters such as Lego man, Cyborg, and Elves)	40% (games with abstract water maze, kings, and bobbies)

Note. SGD = Scalable Game Design; R = robotics; G = game design.

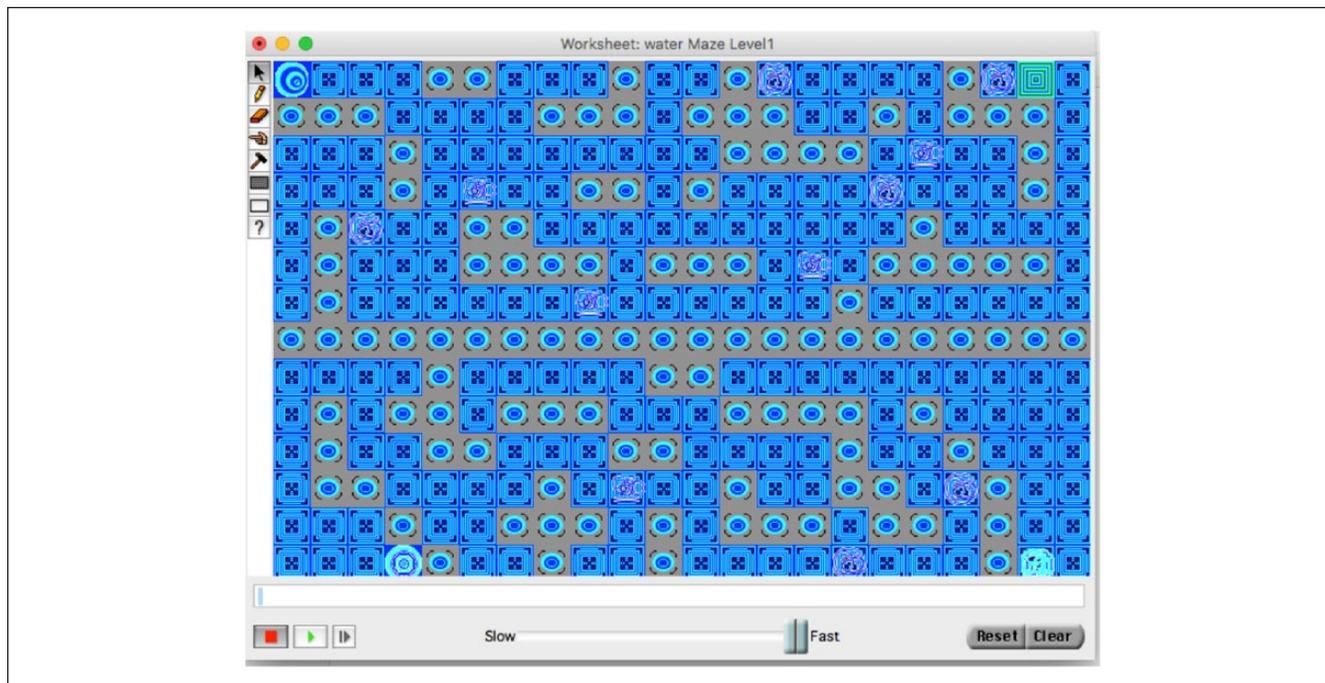


**Figure 4.** MINDSTORMS® code with Christmas tune.

In general, the evidence in Table 6 suggests that students were creative in each of the learning environments. Twenty percent of students struggled with coding and debugging, and had limited use of culture in the game design only and blended robotics/game design contexts. The majority of students were rated moderate as they exhibited common cultural tasks during robotics or traditional cultural referents during game design. Students exhibited substantive cultural elements in every context except game design only. However, these results should be viewed with caution due to the small sample size.

### Focal Teacher Case Studies

One male and two female teachers from diverse backgrounds and teaching experiences were selected as focal teachers. We used pseudonyms to identify each of these focal teachers. Mr. Gibbs taught American Indian students at a reservation school in central Wyoming in Cohorts 1 and 2. Mrs. Ayers taught students in a rural school in Western Wyoming in Cohorts 2 and 3, and Mrs. Cobb taught rural students in northern Wyoming in Cohorts 3 and 4. Each of these teachers participated in two cohorts and thus have multiple DoS ratings to



**Figure 5.** AgentSheets maze with water theme.

consider. We included the best three out of four observations to show changes in their pedagogy from initial to final observations (see Table 7). These data are followed by case studies of the narratives drawn from field notes, teacher journals, and student work samples in robotics and/or game design.

*Mr. Gibbs's case.* Mr. Gibbs is an African American male who participated in the study during spring and fall 2014. His position was a school counselor at a middle school on an American Indian reservation, and he had 10 years of experience. One hundred percent of the students at his school identified as American Indian, and 82% of the students received free and reduced price lunch. Mr. Gibbs taught sixth- through eighth-grade students ( $n = 8$ ) robotics/game design during the pilot year, and robotics only in Year 2 two days per week for 10 weeks each term.

The following excerpt was written in Mr. Gibbs's journal during the spring 2014 online course. These excerpts provide insight into his teaching of robotics and game design during the pilot study:

I created a program to present to the students that used a lot of the images from the Arapahoe culture. I incorporated Arapahoe symbols for lake, rocks, tipi, and turtle. The students continued working on their games and some started working on their Pac-Man games. Kids are still interested but not sure how to incorporate cultural imagery. At times, I feel like the kids would prefer not to use the imagery because they feel that it is not interesting or possibly not something they feel comfortable using in a video game. From what I understand, they might feel like they are disrespecting me as a teacher, because I am asking them to use some imagery, but they also might feel like using traditional

imagery in a video game is against their culture. As I have been told, some Native people, they would rather not even talk about it when asked rather than disrespect me or their culture further.

This excerpt reveals that conflict may occur when teachers who are outside of the students' culture attempt to facilitate CRP (Leonard et al., 2009). Mr. Gibbs was unaware that his Indigenous students were uncomfortable about embedding certain aspects of their culture into a computer game. Fortunately, his colleagues informed him of the cultural dissonance. Mr. Gibbs had no way of knowing if he offended his students by selecting cultural symbols for them to include in computer games. His Indigenous students faced the dilemma of wanting to please him and honoring their cultural heritage. Mr. Gibbs explained his rationale for attempting to use Indigenous culture during a follow-up communication:

I have found that many Native American students have more invested interest in pop culture than they do in their own, so they would prefer to use something cool from the Internet. In an effort to get them to learn something more about their culture, I asked them try to incorporate cultural symbols. Their hesitation to use these symbols was a speculation on my part. They did not know whether or not the use of the symbols in a video game was taboo.

In response to trying to elicit ideas from the students for the games, Mr. Gibbs gave the following response:

The Native American students that I have tend not to talk a lot when you ask them something. This was particularly evident among computer loving, middle school students, who

**Table 7.** Dimensions of Success Ratings for Focal Teachers During Robotics and Game Design.

Teacher/context	Activity Engagement				STEM Knowledge and Practices				Youth Development			
	Participation	Purposeful activities	STEM engagement	Domain mean	STEM learning	Inquiry	Reflection	Domain mean	Relationship/interaction	Relevance	Student voice	Domain mean
Mr. Gibbs												
Spring 2014/R	4	4	2	3.3	1	3	1	1.7	4	2	3	3.0
Fall 2014/R	4	2	4	3.3	2	3	2	2.3	4	1	4	3.0
Fall 2014/R	4	4	4	4.0	3	3	4	3.3	4	4	4	4.0
Ms. Ayers												
Fall 2014/R	4	3	3	3.3	2	3	2	2.3	4	2	4	3.3
Fall 2014/R	4	4	4	4.0	4	4	4	4.0	4	3	4	3.7
Spring 2015/G	4	4	4	4.0	3	3	3	3.0	4	3	4	3.7
Mrs. Cobb												
Spring 2015/G	2	3	3	2.7	2	2	2	2.0	4	1	2	2.3
Spring 2015/G	4	4	4	4.0	3	3	3	3.0	4	2	3	3.0
Fall 2015/R	4	4	4	4.0	4	4	4	4.0	4	4	4	4.0

Note. STEM = science, technology, engineering, and mathematics; R = robotics; G = game design.

volunteered to come after school so they can play on computers. Spending lots of time discussing and analyzing things is not so inviting for them. They want to play.

This explanation sheds light on Mr. Gibbs's ambivalence about asking students to create agents from American Indian culture. He did not want to risk turning his students off, but he also wanted the products to be authentic. Teachers must decide which details, cultural or otherwise, are important to emphasize and which details should be ignored to encourage students to produce authentic cultural artifacts (Leonard et al., 2016; Wing, 2008).

A second excerpt reveals how Mr. Gibbs introduced and taught robotics lessons to his Indigenous students. Students worked in pairs to put the robotics kits together (see Figure 6). Mr. Gibbs was often observed working with students one-on-one as they used MINDSTORMS® programming to get their robots to perform challenges.

Today, we talked about how robots move and how robots can work. Went through a lot of the LEGO robotics program. Had kids just experiment with the programming and letting them see what they could make the robot do. Each day I would have a challenge, and I would walk them through how to make the robot do whatever the challenge was for the day. I am looking forward to getting four [more] robotic kits from an elementary school colleague so the kids can do more hands-on activities. Some of the challenges were turning, stop, and go, touch sensor, [color] sensor, and line following.

This excerpt reveals that Mr. Gibbs allowed his students to tinker with simple challenges using LEGO® EV3 and NXT robotic kits. Mr. Gibbs reported that his students learned how to make the robots “turn, stop, and go.” He also shared that he experimented with touch and color sensors, which allowed the robots to follow a line. Thus, the students were able to engage in four levels of our modified learning progression: sequencing, causal inference, proportional reasoning, and conditional reasoning. There was no evidence of systems thinking. Nevertheless, students engaged in moderate CT during robotics lessons as they completed several challenges.

Analysis of Mr. Gibbs's DoS reports shows growth over time (see Table 7). In the category of Activity Engagement, he consistently showed strong evidence of equitable STEM practices in this category ( $M_1 = 3.3$  to  $M_3 = 4.0$ ). In the category of STEM Knowledge and Practices, Mr. Gibbs ratings improved from a low of  $M_1 = 1.7$  (weak evidence) to  $M_3 = 3.3$  (good evidence). He also showed growth in the category of Youth Development ( $M_1 = 3.0$  to  $M_3 = 4.0$ ), improving on the relevance dimension by his final observation. This case shows Mr. Gibbs's ability to work effectively with Indigenous students while discovering how to respect their culture and ways of knowing and learning.



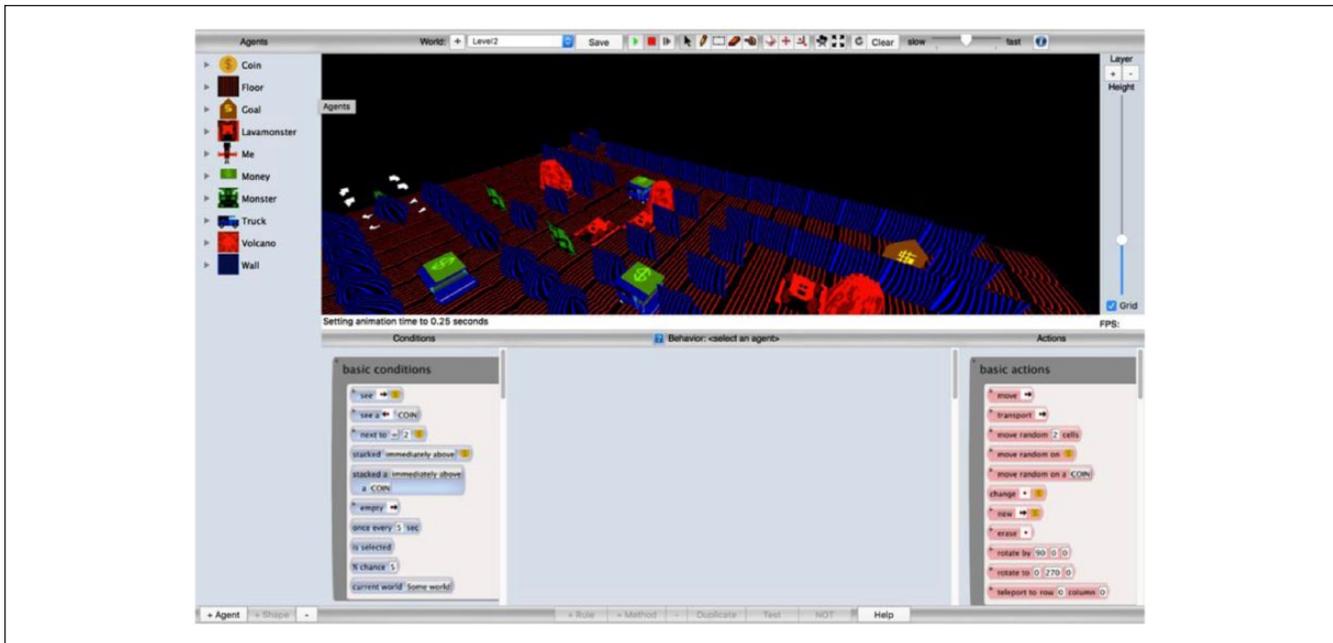
**Figure 6.** Indigenous students building robots.

*Ms. Ayers's case.* Ms. Ayers is a White female who participated in the study during fall 2014 and spring 2015. She was a technology facilitator at an elementary school where she worked with fourth- and fifth-grade students ( $n = 15$ ). Demographics revealed that the student population was 88% White, 11% Hispanic, and 1% American Indian/Alaskan Native. Approximately 50.6% of the students received free or reduced price lunch. She had 3 years of formal teaching experience and 11 years of experience in informal school settings. Ms. Ayers taught robotics the first term and game design the second term during Year 2. She was one of the few teachers who taught before- and after-school clubs 4 days per week. Thus, she fulfilled her number of contact hours in 5 to 6 weeks.

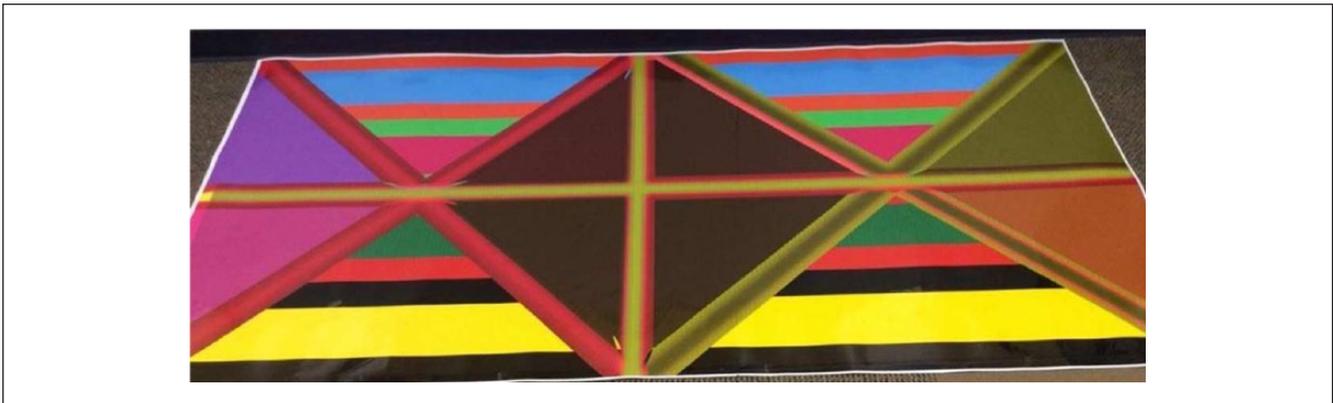
Excerpts from Ms. Ayers's reflections after teaching in the study reveal her teaching style and beliefs about student autonomy and individual agency:

There was one LEGO® EV3 kit per three students and at least one laptop per group for robotics. Students have the ability to take a complex situation and break it into smaller sections. As a facilitator, even though it may be challenging to give fourth and fifth graders agency, by doing so, students have deeper experiences and more meaningful conversations with their peers. Students take ownership of the project and work towards a common goal when the goal is presented clearly and they are given choice. Students are then allowed to immerse themselves in their preferred learning style and are capable of creating a climate where everyone is respected and welcome.

Video game design took place in the computer lab where each student had their own iMac and access to their own AgentCubes online account. The students paid really close attention to computational thinking patterns when they were important to making their game function. I could have given that information at the start, but it was more meaningful to hold off until it was relevant. The students discovered something that they did “not” program in their game (even though they did unintentionally) and felt that it was distracting enough and important enough that it needed to be fixed. I taught the kids that reaching out to the makers



**Figure 7.** Sample AgentCubes game.



**Figure 8.** Culturally relevant student game board.

of a program is something that can be accomplished and will help achieve their desired results. I still believe that allowing students to struggle a little and work through their own problems with each other creates an enhanced learning environment and experience.

Ms. Ayers considered herself to be a facilitator, and encouraged her students to take charge of their own learning during robotics and game design. She maintained a respectful environment where students were able to show leadership and work effectively with peers. She also used the SGD project team as a resource when debugging issues occurred. Allowing students to struggle with debugging helped them to develop CT skills during robotics and CT patterns during game design. The rubric developed to assess students' CT skills was used to rate each of the students' games. Field

notes revealed that student motivation and creativity were greater when students developed three-dimensional games (i.e., AgentCubes) compared with two-dimensional games (i.e., AgentSheets). Analysis of students' AgentCubes games ( $n = 12$ ) revealed that 33% were rated 1 for emergent, 50% were rated 2 for moderate, and 17% were rated 3 for substantive. Thus, 75% of the students exhibited moderate to substantive CT skills for designing AgentCubes games. Figure 7 shows an example of a game that received a moderate rating. This game shows the agents as well as some of the students' code. The primary agent that moved on the game board was called Lava Monster, which is an actual off-shelf game. Thus, this game design emulated pop culture, which supports field notes obtained during site visits to Ms. Ayers's before- and after-school clubs.

During the robotics term, students made game boards for the robots to move on. A few of the game boards reflected students' cultural backgrounds (see Figure 8). Ms. Ayers was one of two teachers in the study who used Photoshop for students to develop their own game boards. The lessons and challenges Ms. Ayers provided allowed students to engage in all levels of CT based on the modified learning progression model (i.e., sequencing, causal inference, proportional reasoning, conditional reasoning, and systems thinking). Thus, these students exhibited high levels of CT during robotics lessons. At the end of each term, students showcased their work during a family reception. This culminating event allowed parents and siblings to play their students' computer games. Finally, the students participated in the FIRST LEGO League (FLL) competition in nearby Utah.

In terms of her instructional practices (see Table 7), Ms. Ayers showed growth in each of the DoS categories when her initial and final robotics observations were compared (Activity Engagement:  $M_1 = 3.3$  to  $M_2 = 4.0$ ; STEM Knowledge and Practices:  $M_1 = 2.3$  to  $M_2 = 4.0$ ; Youth Development:  $M_1 = 3.3$  to  $M_2 = 3.7$ ). Because the final observation was on game design, it will not be compared with ratings on robotics. Nevertheless, the final scores reveal that Ms. Ayers had reasonable evidence of equitable STEM practices on all of the domains, including relevance.

Ms. Ayers was the only focal teacher who taught two terms during the 2014-2015 academic year. Therefore, we analyzed fourth-grade students' ( $n = 15$ ) Measures of Academic Progress (MAP) mathematics scores. Results show that MAP mathematics scores increased significantly from pretest ( $M = 207$ ,  $SD = 11.83$ ) to posttest ( $M = 224.6$ ,  $SD = 14.23$ ) for fourth graders in the treatment groups ( $t = -9.521$ ,  $p = .000$ ). Cohen's  $d$  shows a rather large effect size for this result ( $d = 1.35$ ). However, these data should be interpreted with caution due to the small sample size and lack of a comparison group. Many factors, such as self-selection and interest, may have influenced these results.

**Mrs. Cobb's case.** Mrs. Cobb is a female teacher who participated in the study during spring 2015 and fall 2015. She preferred not to identify herself by race/ethnicity. Mrs. Cobb had 12 years of teaching experience prior to participating in the study. She was a technology facilitator at a Title 1 elementary school and worked with fifth- and sixth-grade students ( $n = 8$ ) after school. Demographics revealed that the student population was 72% White, 25% Hispanic, 2% American Indian/Alaskan Native, and 1% two or more races. Thirty-three percent of the students were English as a second language (ESL), and 65.5% received free or reduced price lunch. Mrs. Cobb taught game design only in Year 2 and robotics/game design in Year 3 two days per week for 10 weeks each term.

After completing the study, Mrs. Cobb described the learning environment, pedagogical practices, and some of the students' activities by writing a reflective narrative:

Each student was assigned a Mac desktop computer in the computer lab, and the class was managed from Edmodo in Year 2 and Google Classroom in Year 3. This allowed students to go back and review instructions or lessons and work at their own pace. I used these digital platforms to upload text instructions, video tutorials, and "cheat sheets" with pictures and examples to get them started. This also gave them the opportunity to communicate with each other and me by asking questions or making comments to posts. This gave the club a sense of solidarity as they could share their work with each other within this digital platform. Once a task was completed, I awarded the student with a digital badge for successful accomplishment.

When introducing game design, we compiled a list of characteristics that made a good game, including characters, setting, colors and challenges. The first task I gave them was to create a basic game in AgentSheets. I gave them directions in the digital platform with screenshots on how to make agents, backgrounds, and perform simple behaviors. They each created a unique game that they were able to share on the Scalable Game Design Arcade and played their cohorts' games. The second task was to create a game within AgentSheets that followed the Frogger game model starting with one lane of traffic, then adding one river of logs and finally one river of turtles. Students then had the option of adding more if they had time. I was then able to introduce them to AgentCubes where they created a simple first person navigation, 3-D game. Most students really enjoyed this, as it looked more like the games they were familiar with and played at home.

Students worked with partners using MINDSTORMS® software and LEGO®NXT or EV3 robotics kits. Their first task was to decide who would be the designer and who would be the builder to ensure both students were equal contributors to the project. Their assignment was to design, build and program together a robot that functioned as an alarm for someone walking into a room. I was very impressed with their ingenuity. I had students create very unique robots that moved, sensed light, sensed motion, talked or had alarms. We began the tradition of everyone watching completed robots to celebrate successful projects. This became one of our favorite parts of the club. Everyone was very supportive and positive about each project that was demonstrated.

As described in the excerpts above, Mrs. Cobb tried to scaffold student learning using digital supports. She also assisted her students individually as needed. The instructions and screenshots were helpful to ESL students in the after-school club. Mrs. Cobb also provided a safe space for students to share their learning and ideas. Students were respectful as they shared their work and enjoyed receiving the rewards she provided.

During game design, students worked on AgentSheets and AgentCubes. They were observed working independently on AgentSheets without a great deal of teacher direction. Students downloaded instructions from a Wiki to complete their games and were observed playing each other's games. The rubric developed to assess students' CT skills was used to rate each of



**Figure 9.** Sample Frogger game.

the students' games. Results revealed that 25% of the games were rated 1 for emergent, 50% were rated 2 for moderate, and 25% were rated 3 for substantive evidence of CT. Thus, 75% of Mrs. Cobb's students could create functional games that exhibited moderate to substantive evidence of CT. The screenshot shown in Figure 9 illustrates a Frogger game where logs and ladybugs were generated on the left-hand side of the river and absorbed on the right-hand side. The frog had to get through the obstacles to the house to win the game. This game was rated 2 for moderate CT using the aforementioned rubric. While tutorials can be used as an equitable STEM practice to provide scaffolding, the prescriptive nature of tutorials may have limited student creativity and use of culture in this after-school club.

During robotics, students were observed working on real-world problems and challenges, such as programming the robot to work as a motion detector to protect entry into a room. When someone walked by the robot, it would sound off an alarm or repeat a message such as "You shall not pass!" The students were observed engaging in predictive thinking to debug the program (Falloon, 2016). During this lesson, students demonstrated all levels of the modified learning progression model: sequencing, causal inference, proportional reasoning, conditional reasoning, and systems thinking. Thus, these students exhibited high levels of CT during robotics lessons. At the end of each term, students also presented their work to parents. This culminating event allowed parents and younger siblings to see the robot perform specific functions, such as the motion detector activity described above, and to play the digital games created by their child or older sibling, respectively.

Mrs. Cobb's DoS observations reflect the prescriptive nature of her game design lessons. Initially, there was weak evidence of equitable STEM practices on six domains (see Table 7). However, ratings improved over time (Activity Engagement:  $M_1 = 2.7$  to  $M_2 = 4.0$ ; STEM Knowledge and Practices:  $M_1 = 2.0$  to  $M_2 = 3.0$ ; Youth Development:  $M_1 = 2.3$  to  $M_2 = 3.0$ ). Scores increased on all domains, except for relationships and interactions, which already had the maximum rating. Near the end of the game design club, Mrs. Cobb exhibited strong evidence of STEM practices on all domains, except for relevance. While we do not compare her DoS scores on robotics with game design, the data show that Mrs. Cobb excelled in the blended robotics/game design context. Given the rich description of student activities in this learning environment, it is easy to understand how Mrs. Cobb received the maximum rating on each domain.

### Summary

The results of this study reveal that teachers' beliefs about CRT, attitudes toward CT, and STEM practices were malleable but varied by the type of context. While the results of this study are promising, using culture to hook rural and underserved students to learn essential CT skills to prepare them for further study in computer science is virtually untapped. Implementation of CRT as well as innovative computer science curriculum is critical in preparing K-12 students for STEM/ICT careers (Moreno-León et al., 2016).

## Discussion

### Key Findings

The results of this study reveal four important findings as it relates to the research questions. The first finding is teachers' efficacy beliefs and outcome expectancy increased as a result of the study (Bandura, 1986; Siwatu, 2007). While Hattie (2009) contended that researchers can expect gains after interventions to show learning, we found that scores varied by the type of learning environment. CRT Self-Efficacy (i.e., CRTSE) was more malleable among teachers in the robotics only (Cohort 2) and robotics/game design (Cohort 4) treatment groups. Thus, teachers who participated in robotics had more robust CRTSE scores than teachers who did not. While increases in self-efficacy scores have been documented in science (Leonard, Barnes-Johnson, Dantley, & Kimber, 2011) and mathematics education (Newton et al., 2012) literature, outcome expectancy usually declined (Leonard et al., 2011; Newton et al., 2012). Yet, in this study, teachers in all learning environments had slight increases in CRT outcome expectancy, regardless of the treatment. While these results should be viewed with caution given the small samples, it appears that professional development and teaching robotics positively influenced teachers' CRTSE but was not that much of a factor in changing CRTSE beliefs. Further study with larger samples and a comparison group are needed to validate these findings.

The second finding is that teacher participants' CT understandings and dispositions increased as a result of the study (Yadav, Mayfield, Zhou, Hambrusch, & Korb, 2014). However, gain scores were greater for teachers in the game design only and blended robotics/game design treatment groups (Cohort 3: mean difference = 0.12; Cohort 4: mean difference = 0.10) than for teachers who participated in the robotics only treatment group (Cohort 2: mean difference = 0.02). This implies that CT attitudes were more robust for teachers who participated in game design. This is understandable, given that CT patterns are associated with game design (Repenning et al., 2015). Wing (2008) claimed that the abstraction process—"deciding what details we need to highlight and what details we can ignore"—is fundamental to CT (p. 3718). Perhaps teaching game design helped teachers to hone in on factors that influenced student success, and, as a result, their attitudes toward CT increased. Further study with larger samples and a comparison group is needed to validate this assumption.

The third finding is that reasonable evidence emerged to suggest that teachers in all of the learning environments exhibited equitable STEM practices (N. Shah et al., 2013). A score of 3 on the DoS constitutes what researchers document as reasonable evidence, whereas a score of 4 constitutes what would be considered compelling evidence that equitable STEM practices occurred (Papazian et al., 2013). While teachers in the game design only (Cohort 3) context had lower scores on the domains of STEM learning ( $M = 2.8$ ) and reflection ( $M = 2.8$ ), and teachers in the blended context (Cohort 4)

were slightly lower on the domain of inquiry ( $M = 2.9$ ), mean scores on the STEM Knowledge and Practices category provided reasonable evidence of equitable STEM practices (Cohort 2:  $M = 3.3$ ; Cohort 3:  $M = 2.9$ ; Cohort 4:  $M = 3.3$ ). Teachers in Cohort 2 had the highest mean score on the Youth Development category ( $M = 3.6$ ) and the highest score on the domains of relationships/interactions ( $M = 4.0$ ) and relevance ( $M = 3.3$ ). Teachers in Cohort 3 ( $M = 2.5$ ) and Cohort 4 ( $M = 2.0$ ) had scores that implied weak evidence for engaging students in relevance during our site visits. Nevertheless, teachers used ZPD to scaffold students' learning in each context (Vygotsky, 1978), and students exhibited moderate to high levels of CT during robotics and game design.

The fourth finding is that culture was evident in each of the three learning environments. Students used robots in races and for mechanical tasks. Use of pop culture and holidays was also evident as students embedded musical scores in the code for robotics and digital games. However, use of culture in digital games created challenges for two of the focal teachers in the case studies. First, Indigenous students may not want to include their culture in game design. Moreover, some symbols may not be appropriate to express in digital games (i.e., case of Mr. Gibbs). Thus, teachers who are outside of the students' culture should learn about the culture of the community to which the students belong, which is a hallmark of CRT (Gay, 2010; Ladson-Billings, 2009). Second, students may be restricted in their use of culture when tutorials are used to develop games. By looking at the examples in the tutorial, students are more likely to mimic them rather than come up with their own ideas. When teachers in this study relied less on tutorials and used the project-first approach, students' games had more cultural referents (Leonard et al., 2016). Nevertheless, the case studies contribute to the extant literature on rural teachers' CRT and equitable STEM practices.

### Implications for Practice

In this study, robotics and game design were used to broaden STEM participation in rural communities. We learned that robotics facilitated co-generative dialogue that allowed learners to use CT as evidenced by learning progressions. Students were able to take a familiar concept, such as building LEGOs, and apply it to a range of complex tasks that include different kinds of representations and models. Furthermore, game design not only facilitated CT applicable to STEM but also promoted the kinds of social engagement and collaboration that allowed students to communicate with peers as they played each other's games. Students' games showed evidence of CT strategies and some evidence of culture (i.e., Indigenous symbols, American holidays, pop culture, and music). As students built the layers of their games and integrated nonroutine features, their ability to take abstractions and symbols from their daily lives and apply them to a range of contexts revealed CT was evident.

### Recommendations for Future Research

Next Generation Science Standards (NGSS) Lead States (2013) and the Framework for Science Education (National Research Council, 2012) provide additional direction for future research. As more school districts adopt NGSS, greater integration of Engineering, Technology, and Applications of Science (ETS) can be expected. Preparing teachers to engage rural and underrepresented students in CT using robotics and game design is not a panacea. Building on this study, future research will provide teachers with sustained professional development on CRT to improve equitable STEM practices. Moreover, future research on game design will expand beyond SGD to include curriculum such as Tinkercad and Unity to promote 3-D modeling. We will also examine a wider range of student products across multiple school settings to show how diverse students' CT strategies develop within the context of CRT to promote equitable engineering and computer science education.

### Appendix A

#### *Culturally Responsive Teaching Self-Efficacy (CRTSE) and Culturally Responsive Teaching Outcome Expectancy (CTROE) Scales (Siwatu, 2007)*

*CRTSE scale (40 items).* Rate how confident you are that you can achieve each of the following statements by indicating a probability of success from 0 (*no chance*) to 100 (*completely certain*).

1. Adapt instruction to the needs of my students.
2. Obtain information about my students' academic strengths.
3. Determine whether my students like to work alone or in a group.
4. Determine whether my students feel comfortable competing with other students.
5. Identify ways that the school culture (e.g., values, norms, and practices) is different from my students' home culture.
6. Implement strategies to minimize the effects of the mismatch between my students' home culture and the school culture.
7. Assess student learning using various types of assessments.
8. Obtain information about my students' home life.
9. Build a sense of trust in my students.
10. Establish positive home-school relations.
11. Use a variety of teaching methods.
12. Develop a community of learners when my class consists of students from diverse backgrounds.
13. Use my students' cultural background to help make learning meaningful.

14. Use my students' prior knowledge to help them make sense of new information.
15. Identify ways how students communicate at home may differ from the school norms.
16. Obtain information about my students' cultural background.
17. Teach students about their cultures' contributions to science.
18. Greet English Language Learners with a phrase in their native language.
19. Design a classroom environment using displays that reflect a variety of cultures.
20. Develop a personal relationship with my students.
21. Obtain information about my students' academic weaknesses.
22. Praise English Language Learners for their accomplishments using a phrase in their native language.
23. Identify ways that standardized tests may be biased toward linguistically diverse students.
24. Communicate with parents regarding their child's educational progress.
25. Structure parent-teacher conferences, so that the meeting is not intimidating for parents.
26. Help students to develop positive relationships with their classmates.
27. Revise instructional materials to include a better representation of cultural groups.
28. Critically examine the curriculum to determine whether it reinforces negative cultural stereotypes.
29. Design a lesson that shows how other cultural groups have made use of mathematics.
30. Model classroom tasks to enhance English Language Learners' understanding of classroom tasks.
31. Communicate with parents of English Language Learners regarding their child's achievement.
32. Help students feel important members of the classroom.
33. Identify ways that standardized tests may be biased toward culturally diverse students.
34. Use a learning preference inventory to gather data about how my students like to learn.
35. Use examples that are familiar to students from diverse cultural backgrounds.
36. Explain new concepts using examples that are taken from my students' everyday lives.
37. Obtain information regarding my students' academic interests.
38. Use the interests of my students to make learning meaningful for them.
39. Implement cooperative learning activities for those students who like to work in groups.
40. Design instruction that matches my students' developmental needs.

*CTROE scale (26 items)*

1. A positive teacher–student relationship can be established by building a sense of trust in my students.
2. Incorporating a variety of teaching methods will help my students to be successful.
3. Students will be successful when instruction is adapted to meet their needs.
4. Developing a community of learners when my class consists of students from diverse cultural backgrounds will promote positive interactions between students.
5. Acknowledging the ways that the school culture is different from my students' home culture will minimize the likelihood of discipline problems.
6. Understanding the communication preferences of my students will decrease the likelihood of student–teacher communication problems.
7. Connecting my students' prior knowledge with new incoming information will lead to deeper learning.
8. Matching instruction to the students' learning preferences will enhance their learning.
9. Revising instructional materials to include a better representation of the students' cultural group will foster positive self-image.
10. Providing English Language Learners with visual aids will enhance their understanding of assignments.
11. Students will develop an appreciation for their culture when they are taught about the contributions their culture has made over time.
12. Conveying the message that parents are an important part of the classroom will increase parent participation.
13. The likelihood of student–teacher misunderstandings decreases when my students' cultural background is understood.
14. Changing the structure of the classroom so that it is compatible with my students' home culture will increase their motivation to come to class.
15. Establishing positive home–school relations will increase parental involvement.
16. Student attendance will increase when a personal relationship between the teacher and students has been developed.
17. Assessing student learning using a variety of assessment procedures will provide a better picture of what they have learned.
18. Using my students' interests when designing instruction will increase their motivation to learn.
19. Simplifying language used during the presentation will enhance English Language Learners' comprehension of the lesson.
20. The frequency that students' abilities are misdiagnosed will decrease when their standardized test scores are interpreted with caution.
21. Encouraging students to use their native language will help them to maintain their cultural identity.
22. Students' self-esteem can be enhanced when their cultural background is valued by the teacher.
23. Helping students from diverse cultural backgrounds succeed in school will increase their confidence in their academic ability.
24. Students' academic achievement will increase when they are provided with unbiased access to the necessary learning resources.
25. Using culturally familiar examples will make learning new concepts easier.
26. When students see themselves in the pictures that are displayed in the classroom, they develop a positive self-identity.

## Appendix B

### *Modified Computational Thinking Survey (Yadav, Zhou, Mayfield, Hambrusch, & Korb, 2011)*

1. Computational thinking is understanding how computers work.
2. Computational thinking involves thinking logically to solve problems.
3. Computational thinking involves using computers to solve problems.
4. Computational thinking involves abstracting general principles and applying them to other solutions.
5. I do not think it is possible to apply computing knowledge to solve other problems.
6. I am not comfortable with learning computing concepts.
7. I can achieve good grades (C or better) in computer courses.
8. I can learn to understand computing concepts.
9. I use computing skills in my daily life.
10. I doubt that I have the skills to solve problems by using computer applications.
11. I think computer science is boring.
12. The challenge of solving problems using computer science appeals to me.
13. I think computer science is interesting.
14. I will voluntarily take computing courses if I were given the opportunity.
15. Computational thinking can be incorporated in the classroom by using computers in the lesson plan.
16. Computational thinking can be incorporated in the classroom by allowing students to problem solve.
17. Knowledge of computing will allow me to improve my performance in my career.
18. My career does not require that I learn computing skills.
19. I expect that learning computing skills will help me to achieve my career goals.
20. I hope that as my career continues it will require the use of computing concepts.
21. Having background knowledge and understanding of computer science is valuable in and of itself.

## Appendix C

CT 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)
Abstraction	Agent and background resemble tutorial in Frogger game	Agent or background is nontraditional and created by the student	Agent and background are nontraditional 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 keep score and say, "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 Indigenous culture or pop culture	No evidence of including culture or elements from off-shelf games	Some evidence of culture or reference to current off-shelf games	Substantial cultural referents and/or to references to off-shelf games with improvements and/or significant modifications

Source. Leonard et al. (2016).

Note. CT = computational thinking.

### Authors' Note

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