Exploration of Kinesthetic Gaming for Enhancing Elementary Math Education using Culturally Responsive Teaching Methodologies

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Abstract

In this paper a novel computer-assisted culturally responsive teaching (CRT) framework is presented for teaching mathematics to 5th grade students. The curricular basis for this framework is Gloria Jean Merriex's award winning curriculum program, which uses music and body gestures to help students build associations between mathematical concepts and culturally inspired metaphors. The proposed framework uses low-cost kinesthetic sensors along with a embodied virtual reality gamimg environment that extends such proven CRT methodologies from a traditional classroom into a digital form. A pilot study was performed to investigate the efficacy of this framework in 5th grade students. A group of 35 students participated in this study and the results are discussed in detail.

1 Introduction

It is widely known in the education research community that there is a significant achievement gap between elementary schools with large population of African American students and schools predominantly populated with white (European American) students. Although this phenomenon is observed in most STEM areas (Science, Technology, Engineering, and Mathematics), reports show that this difference is more notable in mathematics classrooms [27, 28]. Similar findings have been reported for schools with students of color in general (African American, Hispanic, Native American, Pacific Islander etc.) and results show that schools with higher cultural diversity fall behind in standardized assessments in mathematics and sciences [26, 13, 20].

Furthermore, statistics published by the U.S. Census Bureau show that the cultural diversity in the U.S. population has been increasing significantly [4]. Data projections forecast that in 2060 the 'non-white' percentage will come close to 56% of the general population, which will also be reflected on the educational system. Consequently, the linguistic and cultural diversity in the nation's schools is increasing each year intensifying even more the aforementioned phenomenon of failing scores in standardized tests nationwide [20, 15].

This effect continues to diminish the United States' capacity to compete and innovate in the STEM areas at the international scale [11]. In this context, STEM should serve as a catalyst for the advancement of quality of life in general by investing in culturally responsive teaching (CRT) mathematics curricula that motivate students to develop significant fluency and interest in mathematics and science before entering middle school and provide them with the necessary foundation for following careers in Science, Technology, Engineering, and Mathematics.

The aforementioned facts strongly support the argument that there is a critical educational need for developing effective CRT techniques that promote equity and access to mathematical knowledge, which is the cornerstone of all STEM areas. Within such cultural responsive teaching frameworks, particular culturally-based pedagogies and effective styles of communication have been documented through the study of highly effective teachers of African American students [12, 17, 19, 20, 22, 25, 26], though very little of this work focuses on the unique work of mathematics teaching and learning [28, 18, 16].

The main goal of this study is to investigate computer-assisted CRT methodologies and contribute in filling the aforementioned gap by developing an effective interactive system for facilitating culturally responsive elementary math education. The curricular basis for this investigation is Gloria Jean Merriex's award winning curriculum program for 5th grade elementary students [9, 28] which has been documented as an open-access 70-page instructional booklet with strategies, work sheets, activities, and music [6]. In this paper we propose a novel gaming framework that adapt Gloria's award-winning curriculum using low-cost kinesthetic sensors along with a set of game rules in order to form a serious game.

The proposed interactive serious game platform blends Gloria's culturally responsive music and movements for learning geometric and other mathematical properties. Students can use gestures to exhibit geometric concepts, angles, line intersections, polygons, fractions, multiples, all while moving to the culturally inspired music of Gloria's curriculum and reciting mathematical knowledge. Serious games is a very successful and rapidly expanding area of learning research, which is driven by the fact that, according to data reported by the Pew Internet & American Life Project [5], 97% of teens in the U.S. play video games. Furthermore, there is a well documented theoretical basis that indicates that there is a significant increase in the learning outcomes when the students build associations between mathematical concepts and other real world equivalent metaphors [10, 23, 24, 30, 34, 36]. The link between action and cognition related to mathematical concepts has been well studied and this project is founded on the theoretical basis of the reported findings [21, 35, 37, 32, 33, 30].

In this paper we present a novel virtual reality game for teaching mathematics to 5th grade students by extending proven CRT methodologies from a traditional classroom into a digital form. The proposed framework intends to help the students build metaphors that correlate body motions and gesture mnemonics with mathematical elements from 5th grade. Multiple Microsoft Kinect Sensors have been used to track in real time the body motion of the students in a robust way that allows group learning sessions of up to 4 students at a time. A pilot study was performed to investigate the efficacy of the proposed framework in 5th grade students. A

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group of 35 students participated in this study and the results are discussed in detail.

Figure 1: A math lesson given in the classroom of Gloria Merriex in 2004 using gesture in mathematics learning. Source: [14]

2 Background

Gloria Merriex (1950-2008) was a teacher in a high-poverty and predominately minority school in the Southeastern United States [29]. Gloria developed an award winning curriculum program for 5th grade elementary students [9, 28], which combines music and body gestures to help students build associations between mathematical concepts and culturally inspired metaphors. Students can use gestures (Fig. 1) to exhibit geometric concepts, angles, line intersections, polygons, fractions, multiples, all while moving to the culturally inspired music of Gloria's curriculum and reciting mathematical knowledge.

Figure 2 presents results from the state of Florida accountability system, which indicate that her techniques improved student mathematics scores on standardized assessment, a success that was well-recognized by her colleagues [9, 28]. This curriculum took an under-achieving elementary school from an "F" on standardized math test to an "A", when applied in its original form during the academic years 2002-2008. Unfortunately, Gloria's successful techniques were not continued in practice after her unexpected death in 2008 and consequently, as the chart in Fig. 2 shows, the ratings of the school plummeted from an "A" back down to an "F" ranking.

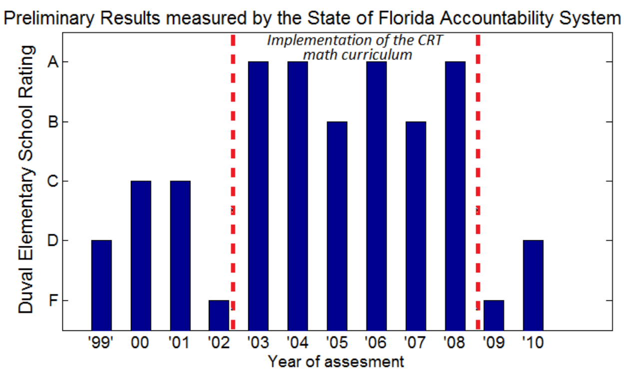

Figure 2: Bar plot of the C. W. Duval Elementary School Ratings measured by the State of Florida Accountability System based on the FCAT state system scores in accordance with the NCLB act. The plot shows a significant jump from 'F' rating to 'A' after the implementation of the CRT math curriculum during the school years 2002-2008 and then back to 'F', which demonstrates the efficacy of the introduced teaching methodology.[3]

Gloria's CRT methodologies have been documented by the University of Florida as an on-line open-access resource for elementary school teachers [6] and a documentary that describes her innovative work [14]. An example of her methodology for teaching geometric concepts is shown on the top row of Fig. 3. In this example a hip-hop metaphor was chosen to teach the students a sequence of moves and body gestures that have direct relationship with line intersections and angles from 5th grade curriculum. In the next sections we present a computer-assisted framework that trasformed several of the CRT methodologies from Gloria's curriculum into a digital interactive form for enhancing the traditional forms of learning.

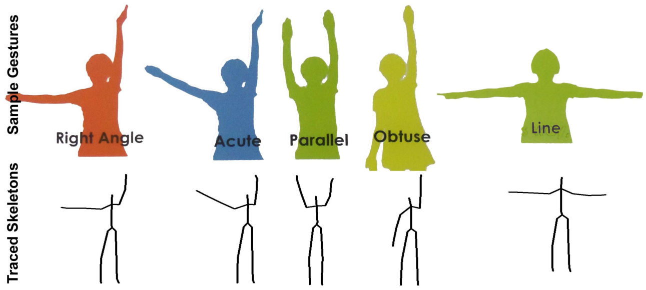

Figure 3: Upper row: Examples of gestures that can be associated with various geometric properties for 5th grade students such as 'right angle', 'acute', 'parallel', 'obtuse', and 'line' (Gloria's Hip Hop Math [6]). Lower row: Preliminary results of skeleton tracking using Microsoft's Kinect to capture a real student's motion.

3 Methods

Although camera-based gesture recognition and motion tracking are two mature and well-studied research topics in computer science, kinesthetic human-computer interaction using full body language, natural gestures, and expressions is a new commercial technological revolution, which has been massively welcomed by consumers, since it transforms computing from device-oriented to human-oriented. In this new technological reality, intelligent cameras with depth sensors are an essential tool for many applications including education and research. Some examples of research using kinesthetic devices include the use of full body kinesthetic technology for teaching angles to children [32, 34], locomotor training for children with neurological disorders [8], real-time 3d reconstruction of the articulated human body [7], and others.

The current available systems for kinesthetic interaction are based on depth sensors that can be used to detect the presence of a particular skeletal geometry 4, such as human skeletal geometry, by fitting to each acquired depth frame a skeletal model that consists of the following set of parameters:

$$\mathscr{S} = \{\mathbf{t}_j \in \mathbb{R}^3, \mathbf{R}_j \in SO(3) : j \in \mathscr{J}\} \quad (1)$$

where $\mathscr{J}$ is a set of indices of joints connected together in a tree structure of parent/children nodes. Each joint is defined by its location in the 3D space, which is expressed as a translation $\mathbf{t}_j$ from the origin of the coordinate system of the root joint, and its orientation in the 3D space is given as rotation matrix $\mathbf{R}_j$ with respect to the orientation of the root node. There are several algorithms that compute $\mathscr{S}$ from RGB-D, such as those implemented in the Microsoft Kinect SDK [1], in OpenNI library [2], and others [38, 31].

A distance metric between two elements of the space $\mathscr{S}$ can be defined as a function of the corresponding $\mathbf{t}_j$ vectors and $\mathbf{R}_j$ metrices according to the desired matching criteria. Examples of the tracked skeletons that correspond to the various body gestures/mnemonics from Gloria's CRT curriculum are shown on the bottom row of Fig. 3.

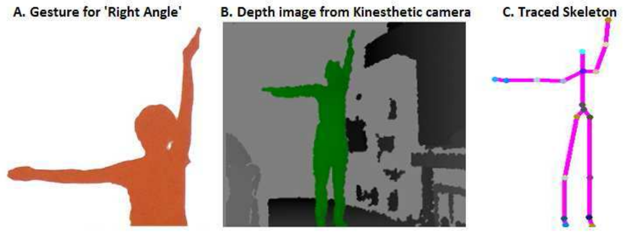

Figure 4: A. Gesture example for 'Right Angle' from Gloria's curriculum. B. A depth image captured by Microsoft's Kinect showing a student imitating the 'Right Angle' gesture. C. The corresponding result of the real-time skeleton fitting algorithm.

In order to create a user experience similar to the experience of the traditional CRT curriculum as it was applied in the classroom by Gloria (see Fig. 1), our system was designed to allow for multiple users to simultaneously participate in this virtual reality educational experience. For this reason, the tracking feedback from 2 sensors was utilized, which produced robust skeleton tracking for 4 users as shown in Fig. 5. Three topics from Gloria's curriculum were digitized as mini-games in our experimental framework: 1) lines and angles, 2) Polygons, and 3) Multiples. However, our pilot study focused primarily on the topic of lines and angles as it has clear CRT metaphor from urban dancing. In addition, there is a well founded theoretical framework on this subject [32, 34], that is also applicable to our particular topic of CRT methodologies.

Each of the mini games consisted of a short (6̃0 sec) challenge, in which the students compete with each other using an intuitive scoring mechanism, or worked collectively to achieve a higher group score. Part of our study focused on finding correlations between the type of multi-user interaction (i.e. compete vs. collaborate) and the learning outcomes. Two versions of each mini game were developed, one that focused on instruction, and the other one that focused on testing. For example, the first version of the angles and lines game presented to each student an image of a body posture (from Fig. 2) that they had to match with their own body by moving accordingly in front of the kinesthetic cameras. In the second version of this game, the students had to do the same task while they were presented with the type of the angle (acute, obtuse, etc.) instead of the body posture image. Differences on the scores achieved between the two versions of the games were correlated with the student's learning outcome. The next section presents our experimental setup and discusses the results from the pilot study that was performed in order to assess the efficacy of the proposed framework.

4 Experimental Results

In order to test and quantitatively evaluate the proposed framework, we performed a pilot study with the assistance of 5th grade student volunteers. For the purposes of this pilot user study we recruited 35 students who used the prototype framework and completed pre-test and post-test surveys.

In our experimental setup we used two Kinect^{TM}sensors by Microsoft connected via USB 2.0 to a single computer with Intel Core i7^{TM}CPU at 2.80GHz and 8GB RAM. The resolution of each depth sensor was 640×480 pixels at 30 frames per second and was calibrated so that it records depth in the range from 0.8m to 4.0m, which is adequate for capturing the body motions of the students. The sensors were placed in front of the projection screen in a distance from each other so that each of the sensors can capture the motion of two users as shown in Fig. 5.

Before the game session, each student completed a survey with questions regarding their gaming experience, their preference in culturally inspired music and dancing, personal preference on group user experience vs. single user experience, as well as competition vs. collaboration games. In addition each student answered mathematical questions from the 5th-grade curriculum in order to assess the prior knowledge level of each student. After that, the students played a sequence of three mini games in groups of four. Finally, the students completed an exit survey similar to the first survey.

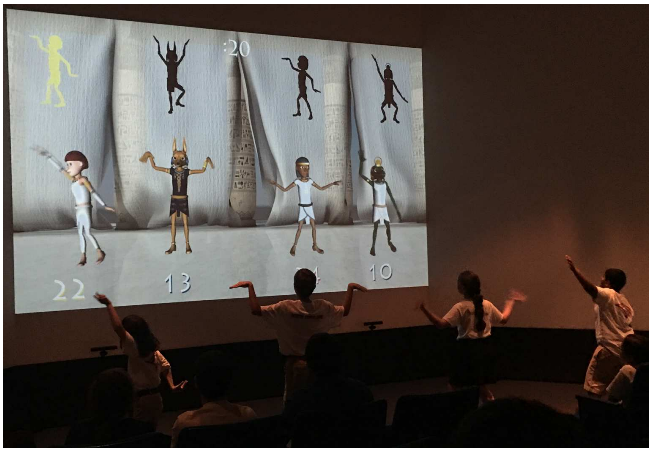

Figure 5: Picture from a group session of four 5th grade students while playing the developed virtual reality game.

By comparing the answers in the pre-test and post-test surveys, 73.53% of the students provided the correct answers to the mathematical questions before interacting with the game, and 82.35% after the game, which corresponds to 33.33% reduction in the number of incorrect responses that indicates a level of effectiveness of the proposed framework as an instructional tool.

A comparison between the game scores achieved in the 'angles and lines' game with and without body gesture image clues shows that score of 60% of the students dropped while playing the game without the image clues. It should be noted that a percentage of 5̃0% would indicate that there was no difference in the achieved scores between the two versions of the game, and the 50% drop is due to random gaming factors. Indeed, among the population of the students who had the mathematical knowledge before the game interaction, 54.17% of the students dropped their score, and the same result becomes 50% within the students who acquired new mathematical knowledge during the game experience. However the same result becomes 100% within the students who did not improve their responses in the exit surveys. This indicates that the differences in instructional modality between these two versions of the game only affect the students with higher learning difficulties.

Finally, in the pre-tests 68.96% of the students declared preference on urban dancing or singing in front of an audience vs. alone, while this percentage was increased to 75.8% after the gaming experience. Similarly, only 28.57% of the students preferred a collaborative game task vs. a typical competitive challenge, while this percentage became 37.03% after the gaming experience. It is interesting to see that after experiencing the developed gaming framework the students shifted their personal opinion regarding their participation in activities with others. This demonstrates that the current framework motivates the students to engage in culturally inspired urban dancing and singing in front of an audience and promotes learning as a collaborative process rather than a competitive one, which was one of the fundamental concepts in Gloria's CRT curriculum [9].

5 Conclusion

In this paper a computer-assisted cultural responsive teaching framwork was developed based on a proven methodology, which had been applied successfully by Gloria Merriex to diverse classrooms with underprivileged students. The proposed framework uses two Kinect sensors to track the body motions and gestures of four students who can simultaneously participate in a group learning session. A pilot study was performed in order to assess the efficacy of the proposed framework in 5th grade students. The results demonstrate correlations between the achieved game scores and their learning outcome and show improvement in their performance during the exit surveys. Future directions will include the development of the complete computer-assisted curriculum of Gloria Merriex and its term-long evaluation as a tool for enhancing the traditional in-classroom CRT methodologies.

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