Programming Moves: Design and Evaluation of Applying Embodied Interaction in Virtual Environments to Enhance Computational Thinking in Middle School Students

Dhaval Parmar* Clemson University
Joseph Isaac† Clemson University
Sabarish V. Babu‡ Clemson University
Nikeetha D'Souza§ Clemson University
Alison E. Leonard¶ Clemson University
Sophie Jörg‖ Clemson University
Kara Gundersen** University of Florida
Shaundra B. Daily†† University of Florida

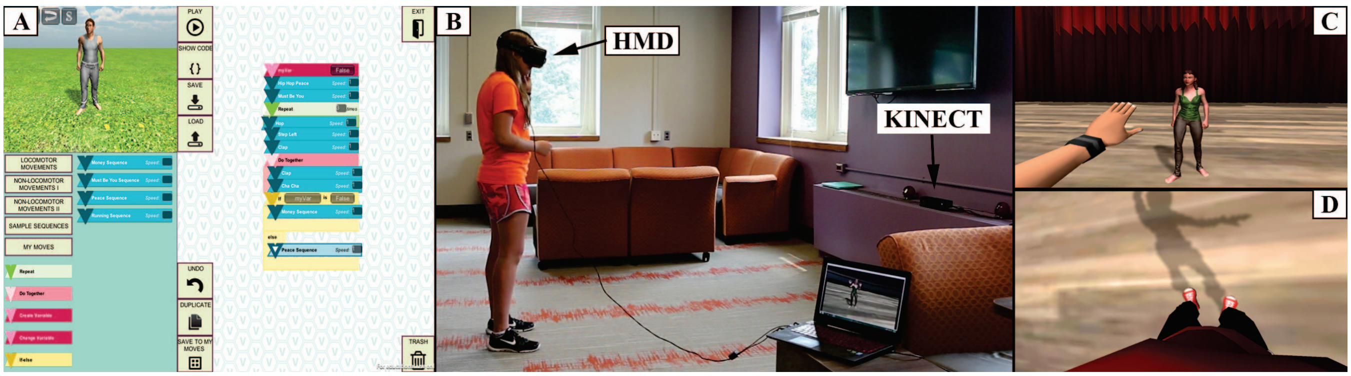

Figure 1: (A) The VEnvI user interface (B) The immersive embodied interaction experiment setup with the head-mounted display (HMD) on the user's head, and a Kinect sensor in front of the user. (C) Screen capture of the virtual character that dances in front of the user. (D) The first-person view of the user's virtual body.

Abstract

We detail the design, implementation, and an initial evaluation of a virtual reality education and entertainment (edutainment) application called Virtual Environment Interactions (VEnvI). VEnvI is an application in which students learn computer science concepts through the process of choreographing movement for a virtual character using a fun and intuitive interface. In this exploratory study, 54 participants as part of a summer camp geared towards promoting participation of women in science and engineering programmatically crafted a dance performance for a virtual human. A subset of those students (16) participated in an immersive embodied interaction metaphor in VEnvI. In creating this metaphor that provides first-person, embodied experiences using self-avatars, we seek to facilitate engagement, excitement and interest in computational thinking. We qualitatively and quantitatively evaluated the extent to which the activities of the summer camp, programming the dance moves, and the embodied interaction within VEnvI facilitated students' edutainment, presence, interest, excitement, and engagement in computing, and the potential to alter their perceptions of computing and computer scientists. Results indicate that students enjoyed the experience and successfully engaged the virtual character in the immersive embodied interaction, thus exhibiting high telepresence and social presence. Students also showed increased interest and excitement regarding the computing field at the end of their summer camp experience using VEnvI.

Index Terms: I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual Reality; K.3.2 [Computers and Education]: Computer and Information Science Education—Computer Science Education

1 Introduction

Even with the increasing demand for jobs in computer science and related STEM (science, technology, engineering and mathematics) fields, there is a lack of representation of minorities and women in western nations [22]. From the early stages of middle school, students can make decisions about courses of study and career paths that can affect their desire and ability to pursue careers in STEM [46]. The interest in STEM fields for girls is much lower compared to boys, and this interest is often lost during middle school [23]. Maltese et al. [19] found that interest in science began before middle school for a majority of their participants, and Sadler et al. [31] reported that students' initial specific career interests at the start of high school influenced the stability of their interest in a STEM career. Therefore, it is worthwhile to make an effort in broadening the participation of middle school students in computing fields.

Exploring the topic of computer programming through the context of dance is an innovative approach to reach our target audience. Dance has innate similarities with programming, with steps following one after the other in a sequential manner, or having repetitions similar to loops, and allowing even further complex struc-

*e-mail:dkparma@clemson.edu
†e-mail:jisaac@clemson.edu
‡e-mail:sbabu@clemson.edu
§e-mail:ndsouza@clemson.edu
¶e-mail:aleona2@clemson.edu
‖e-mail:sjoerg@clemson.edu
**e-mail:kgunder@ufl.edu
††e-mail:shanib@ufl.edu

IEEE Virtual Reality Conference 2016
19–23 March, Greenville, SC, USA
978-1-5090-0836-0/16/$31.00 ©2016 IEEE

tures such as conditionals and parallelization. Therefore, dance can be used as an active learning metaphor to learn about logic, programming, and computational thinking. "Computational thinking is taking an approach to solving problems, designing systems, and understanding human behavior that draws on concepts fundamental to computer science," as stated by Wing [47]. Additionally, virtual reality can be useful for developing an environment that is highly immersive and provides a feedback mechanism for the programming process. A completely virtual and immersive interface can be thought of, which lets students create, modify, and visualize the entire programming process within the immersive embodied interaction metaphor.

The motivation behind designing an immersive embodied VR experience was for students to develop computational thinking via embodied cognition. Varela et al. [41] define embodied cognition using two points: "first that cognition depends upon the kinds of experience that come from having a body with various sensorimotor capacities, and second, that these individual sensorimotor capacities are themselves embedded in a more encompassing biological, psychological and cultural context." This notion of applying body and motion in learning tasks is echoed in dance education, as Sklar [32] mentions, "rather than underline the fact that thinking can be abstracted and separated from corporeality, I am underlining the fact that thinking depends upon it". Dance inherently facilitates physically thinking with the body by using it as an instrument of cognition [15]. Dance choreography involves switching and translating between physical and mental sensory modalities, which helps choreographers be more creative, as reported by Kirsh [16].

This notion of learning computational thinking through dance and movement is tied into Virtual Environment Interactions (VEnvI). VEnvI is a software that uses a database of motion captured dance sequences and a feature-rich drag-and-drop interface to teach concepts of programming and computational thinking, such as sequences, loops, conditionals, variables, functions and even parallelization. VEnvI was designed and developed by our team through funding by a National Science Foundation (NSF) award in order to boost the interest of students, especially middle school girls, in the field of computing through employing embodied cognition in virtual reality.

We define success of the VEnvI initiative with the following three points:

1. VEnvI helps the students learn programming, logic, and computational constructs.

2. Students are willing to spend more time and learn using VEnvI.

3. We get insights on usability, satisfaction, and how well the students adopt the idea of VEnvI as a learning tool.

The results of the study were highly positive and students reported an enriching experience. VEnvI achieved our goals of motivating our target audience towards computer science, particularly through the immersive embodied interaction metaphor.

2 Related Work

2.1 VR in STEM Education

Virtual reality (VR) can be a powerful tool in supporting and facilitating STEM education. A study of VR alongside lab-based technologies showed that most students remembered what they saw in the VR context and concluded that VR is a more memorable learning experience than laboratory based demonstrations [25]. Researchers have used virtual reality based learning environments as an innovative approach to teaching engineering concepts [5]. Their study found an overall increase in student performance. Through user experience surveys, they also found that a majority of students (86%) preferred the virtual learning environment over traditional classroom lectures and discussions.

Multi-user virtual environments have also been used as a pedagogical vehicle, as seen in the study by Ketelhut et al. [14], where teams of middle school students collaboratively solved problems to study and cure diseases in a virtual town. The research results indicated that the students were able to conduct an inquiry in virtual worlds and were motivated by that process. Some researchers have used virtual technologies, specifically virtual reality, simulations and virtual field trips, in special education classrooms [33]. These researchers confer that there are numerous potential benefits of virtual technology use in special education classrooms, and "as educators become more aware of the power of virtual reality, simulations, and virtual field trips as instructional tools, they will be in the position to provide suggestions to developers as to what programs are needed and what works best with students with disabilities."

Warburton [45] discusses using Second Life, a popular multi-user virtual world platform, in higher education. This research states that for education to properly transfer to the virtual, it will require us to address how to best manage our virtual identities, improve our digital and cultural literacies, understand more fully the links between immersion, empathy, and learning, and develop design skills that could be used productively to exploit virtual spaces. Squire [34] examines the history of video games in educational research, and puts forth an argument in favor of video games in education. He highlights that the cognitive potential of games has been largely ignored by educators. Contemporary developments in gaming, particularly interactive stories, digital authoring tools, and collaborative worlds, suggest powerful new opportunities for educational media.

2.2 Environments for Computer Science Education

There is a large body of work related to environments for computer science education, as well as user studies related to their effectiveness. Cooper et al. [7] introduced Alice, a 3D tool for introductory programming concepts. Alice is a scripting and prototyping virtual environment for 3D object behavior, and aimed to teach programming concepts. Rodger et al. [30] integrated Alice 3D environment into a middle school context to engage teachers and students through a diverse set of school subjects. Their research found that both teachers and students were strongly engaged with Alice, and students used a large variety of computer science concepts in the worlds they built. Sykes [35] conducted a user study using the Alice 3D, comparing student performance in Computer Science I using an Alice-based coursework. The study found that the Alice Group exceeded the performance of a Comparison Groups. Cordova et al. [8] used Alice to engage high school teachers and students in programming and logical problem solving. Their study found significant improvements in students' attitudes towards computer science.

Wang et al. [44] conducted a study comparing programming classes taught using Alice to those taught using C++. An analysis of students' test scores revealed that the Alice group performed significantly better than the C++ group, indicating that Alice seemed to be more effective in facilitating students' comprehension of fundamental programming concepts. Mullins et al. [24] used Alice 2.0 in an introductory programming language course, and observed retention data and percentages of women enrolled when using Alice for the first semester compared to C++. They found that the incorporation of Alice into the programming sequence increased the number of students that passed the courses and decreased the number of withdrawals. Howard et al. [12] conducted a qualitative analysis of Alice and paired-programming, which indicated that students using Alice reported that they enjoyed programming, had confidence in their programming ability, understood basic programming concepts, and understood the relationship between algorithms and Alice stories.

Kelleher et al. [13] described Storytelling Alice, a version of Alice 3D programming environment that uses 3D animated stories to introduce middle school girls to computer programming. They also conducted a comparative evaluation of Storytelling Alice versus Generic Alice. They found that although the learning benefits were similar, users of Storytelling Alice were more motivated to program; they spent 42% more time programming, were more than 3 times as likely to sneak extra time to work on their programs, and expressed stronger interest in future use of Alice than users of Generic Alice.

Maloney et al. [18] introduced Scratch, which is a visual programming environment allowing users to learn computer programming while working on projects such as animated stories and games. The key design goal for Scratch was to support self-directed learning through tinkering and collaboration with peers. Radu et al. [29] introduced AR Scratch, which added augmented reality functionality to the Scratch programming platform.

Brown et al. [4] introduced computer-aided instruction using the Scratch programming environment for children as a context for problem-solving to engage and assess the skills of the students. They found that students in the treatment group showed improvement in their problem-solving skills at a rate greater than those in the control group.

Kolling [17] describes the Greenfoot programming environment as an integrated development environment aimed at learning and teaching programming. It is aimed at a target audience of students from 14 years old and is also suitable for college-level education. Utting et al. [40] compare and contrast three environments (Alice, Greenfoot, and Scratch), which aim to support the acquisition and development of computing concepts (problem-solving and programming). In their discussions, they concluded that the storytelling aspect of Scratch and Alice is a hook into middle school STEM education in the US. However, they have a potential appeal to non-STEM instruction in and outside the US. Storytelling is hard in Greenfoot, the framework of which is more geared towards user input and objects reacting to each other.

2.3 Contributions

Even though a variety of applications exist that employ immersive virtual reality for STEM education, the research literature on providing insight into children's acceptance of such technology on edutainment (education + entertainment), and outcomes of excitement and interest in learning, sense of telepresence and social presence are sparse. In one instance, Winn et al. [48] in their research titled "The virtual reality roving vehicle project" studied the enjoyment, learning and sense of presence of students in grades 4 through 12. The results showed positive learning outcomes and very high enjoyment, but enjoyment and sense of presence decreased with age. Students who built virtual worlds in their study also had consistently better attitudes towards science and computers after the experience.

We created a novel virtual reality application in teaching computational thinking via embodied cognition in which students programmatically created dance performances for a virtual human, and experienced an embodied interaction metaphor towards enhancing engagement, excitement, and interest in computing. Our user study highlights the desired outcomes of embodied cognition and interaction using VEnvI with students.

More specifically, this research intends to contribute in two ways:

1. We introduce and describe 'Virtual Environment Interactions' (VEnvI), a visual programming tool that marries dance, computational thinking and embodied interaction in pursuit of enhancing students' enthusiasm, excitement, and interest in computer science.
2. We present a user study of applying VEnvI and the immersive, first-person embodied interaction metaphor using a self-avatar, as an activity of a summer camp for middle school girls. We document the potential VEnvI and the embodied interaction metaphor have, to improve students' perceptions of computer science and computer scientists, as well as their interest and excitement in learning to program through embodied cognition. Students' telepresence, social presence, satisfaction, and acceptance of the embodied interaction metaphor in VEnvI are also discussed.

3 VEnvI User Experience and Construction

The design of VEnvI was inspired by technologies that already existed in the field of STEM education. Applications such as Alice [13], Looking Glass [10] and Scratch [18] are similar visual programming environments. These programming tools use poses and animations that are linearly interpolated between the poses. This causes the virtual character's movements to look robotic and unrealistic. In a pilot study conducted by Daily et al [9] students used Dancing Alice, a visual programming environment built using Alice. Although the students enjoyed seeing their characters perform, they desired smoother and more fluid movements.

VEnvI improves upon the user experience provided by Alice and Looking Glass by utilizing motion captured animations and the Unity3D game engine [39] to create fluid and smooth movements for the virtual character. The motion captured sequences were obtained by recording trained dancers, and the sequences were then split up into motion segments. Students access these motion segments in the form of move blocks and programmatically assemble them together to create the choreography, as opposed to creating step-by-step animations by positioning and orienting joints. The speed or rate of animation for each move block can be modified to synchronize with music. Due to the high fidelity of animations through the motion captured sequences, the movements of the virtual character look believable and realistic. For the past two years, VEnvI has been iteratively designed and developed through a combination of subject matter experts in CS education, arts education, VR application development, and character animation, as well as user testing with 4th - 7th grade students.

3.1 The VEnvI Programming Interface

Figure 2: The character customization screen in VEnvI. The controls for modifying the character can be seen on the left.

Avatar customization positively impacts participants' identification with their avatars, as shown in the research by Turkay et al. [37]. In VEnvI, students customize the virtual agent that they program the choreography for, giving it a personality and attributes, eventually forming an association with the character. In the process of creating the virtual agent, a sense of belonging with the character can result in creating better-programmed choreography for the character than if we provided them with an agent. Bailey et al. [1] showed that avatar customization can affect both subjective feelings of presence and psychophysiological indicators of emotion, thus making the gameplay experience more enjoyable. The work by Teng [36] indicated that increased customization can better foster gamer loyalty. Students using VEnvI can feel connected with their customized avatars and be willing to spend more time programming within VEnvI.

VEnvI greets the student starting a new game with the character customization interface, as shown in Figure 2, where attributes such as gender, height, weight, skin tone, clothing, and eye color can be customized. In a preliminary study, students expressed the desire to personalize the virtual character with quotes like "Why can't the character look more like me?" Students specifically wanted the ability to choose gender, skin tone, and body size of the character, which led to the implementation of the character customization section within VEnvI. Following this, the VEnvI programming interface is presented to the student (Figure 3). This interface has three major areas: the virtual environment (VE) window on the top-left with the customized virtual human, the movement database and selection area on the bottom-left, and the drag-and-drop area on the right.

Figure 3: The VEnvI user interface. The VE window is on the top left, the move selection area is on the bottom left, and the drag-and drop area is on the right.

The VE window is where the virtual character performs the choreography programmed by the student. A play button triggers the virtual character in the VE to perform all the moves in the programmatic sequence specified by the learner. To create the program, the student can choose from a database of moves in the move selection area and drop it into the drag and drop area on the right. The animation database currently has 37 unique motion captured segments based on moves from the line dance 'Cha-Cha slide', hip-hop style sequences, and various dance primitives. New motions are continually being captured and added. These moves are categorized into 'locomotor movements', 'non-locomotor movements' and 'sample sequences'. Locomotor movements are those that end up displacing the character from its starting position, such as 'slide left' or 'step forward'. Non-locomotor movements such as 'clap' or 'stomp' do not displace the character. This category has 24 unique motions. In addition to these, students can mix and match any number of moves and save the group of moves as a custom move block under 'My Moves', and this new move is designed to behave as a callable function.

The move selection area also has the building blocks for computational constructs which can be used to create complex choreography and form the basis of computer programming education using VEnvI. Any blocks placed within the 'repeat' block will be repeated or looped a set number of times, which can be entered in a text box within the repeat block. The 'do together' block provides

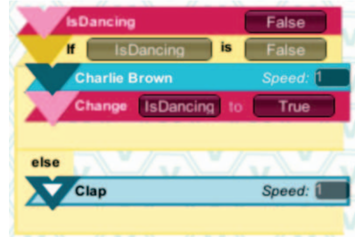

Figure 4: The Create Variable block is shown at the top, with the 'IsDancing' variable initialized to False. This block is followed by an if-else block, which checks if 'IsDancing' is False. The change variable block will change 'IsDancing' to True.

a construct to parallelize two different moves and execute them simultaneously. 'Create Variable' (Figure 4) lets students create a new Boolean variable, assign a name to it, and set its initial value to either true or false. 'Change Variable' can be used at multiple points within the program to change the value of an already created variable. This is similar to assigning a new value to an existing variable. Finally, the 'if-else' block lets you divide the flow of the program into two branches. The 'If-else' block can check for the value of an existing variable, equate it to either true or false as required, and choose one of the two branches of execution, just like in computer programming.

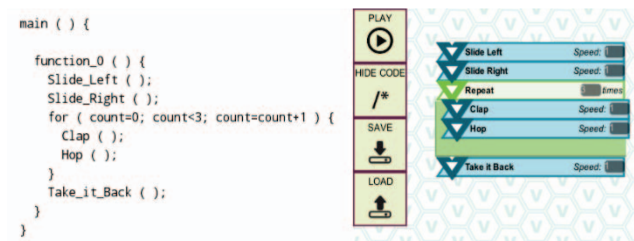

Figure 5: The show code window. The generated pseudo-code for the movement sequence on the right can be seen in the show code window.

Finally, a button named 'show code' generates and shows pseudo-code based on the move sequences in the drag-and-drop area (Figure 5). This functionality is an effort to tie the visual programming language of the move blocks to traditional pseudo-code language and demonstrate similarities between them.

3.2 Immersive Embodied Interaction Metaphor

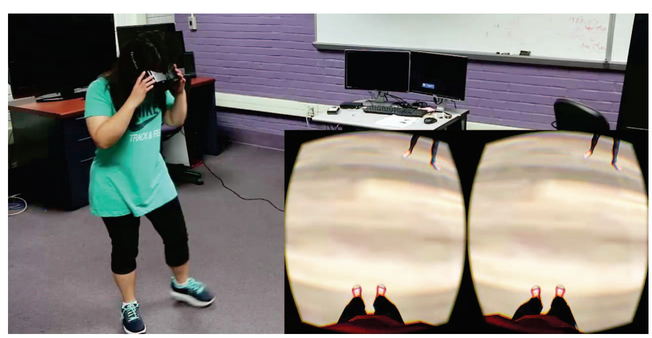

Figure 6: A student experiencing the immersive embodied interaction metaphor within VEnvI, with the HMD view shown on the bottom right corner.

As part of this study, we created an immersive embodied experience within VEnvI, to augment the visual programming model with immersive virtual reality, in an effort to make it more appealing and engaging. The principal goal is to provide the users with the opportunity to be present with the virtual character they are programming, have a first-person perspective of the choreographed performance, be able to visualize and even follow by dancing with the programmed character, and by doing so, get motivated to make changes, correct mistakes or even come up with new ideas for their programs. Students could look at time synchronization of the moves, and even match their own dance moves to synchronize with those performed by the virtual character.

To facilitate the highly immersive embodied experience, we made use of the Oculus Rift head-mounted display [27]. The Rift has a resolution of 960x1080 per eye and a 100°diagonal field of view. We also used the Microsoft Kinect V2 motion sensor [21] to track the user's position and movements. Efforts were made to keep the VR technology low cost by using current or soon-to-be commercially available off-the-shelf hardware. The system was running on a machine having the Microsoft Windows 8.1 operating system, Intel Core i7-4710HQ processor, NVidia GeForce GTX 860M graphics, and 16GB RAM.

The immersive VR setup is shown in Figure 1. Figure 6 shows a student within the immersive embodied interaction metaphor, wearing the Oculus Rift HMD, and the student's view from the HMD is shown in the inset. Special modifications were made to the VEnvI software to enable it for first-person immersive viewing. A new virtual character was added to serve as the co-located virtual avatar for the user. Since all the participants were females, a female avatar was chosen. Tracking data from the Kinect was applied to this avatar so that it follows the user's movements.

Data obtained from the Kinect and the Oculus Rift's sensor was used to calibrate the body size and proportions of the virtual self-avatar and the eye height for each participant. For the head orientation, tracking data from the Oculus Rift was used instead of the Kinect, to enable users to freely look around the environment. The virtual self-avatar's head was removed from the body, to avoid occlusion issues when looking through the Oculus Rift. The participants were oblivious to this fact, as they could only see the self-avatar from the neck and downwards.

Within the immersive virtual environment, participants were able to see a virtual body co-located with their real body, which mimicked the movements of their real body. They could also see a shadow of their body, which added to the immersion. The environment was set in a grassy field, with a dance stage in the middle of the field. The participants started on the stage, and could see another virtual character in front of them on the stage. The participants could look and move around the field, and could see a virtual sky when they looked above. Music was played using speakers, and the participants would see the virtual character in front of them dancing with the music using pre-programmed dance choreography.

VEnvI was built using Unity [39], which is a cross-platform game engine developed by Unity Technologies (http://unity3d.com/). The code is written using the C# programming language. The virtual characters were created using Unity Multipurpose Avatar (UMA) [38], which is a framework within Unity to create customizable avatars. All the dance motions for the category of moves were captured using a 14 camera Vicon optical motion capture system [42] and then integrated into VEnvI using Unity's Mecanim animation system (Figure 7).

4 Research Questions

We conducted an initial explorative user study as part of the summer camp to examine the following research questions on the impact of students' interactions with VEnvI:

Figure 7: (Left) A trained dancer in a motion capture suit performing a hip-hop move, with the animation skeleton overlaid. (Right) The captured animation applied to a virtual character in VEnvI.

1. To what extent does the pedagogical activity of using VEnvI to programmatically create performances for a virtual human impact their perceptions of computing and computer scientists?

2. How do students' experiences of the immersive embodied interaction in VEnvI of performing with a virtual human for whom they programmatically choreographed a dance sequence affect their telepresence, social presence, usability, satisfaction, and enthusiasm?

3. What are the impressions and behavioral effects of the immersive embodied interactions in VEnvI on students? To what extent are they engaged, excited, and compelled in dancing with the virtual human?

5 Methodology

5.1 Setting

For this research, we had parallel activities occurring as a part of a larger camp hosted by the university's science and engineering program for middle school girls. This program is dedicated to meeting the needs of today's women in science and engineering. Its mission is to increase retention and graduation rates of qualified female students in the College of Engineering and Science; with outreach to younger students as an important component of it efforts. During this one-week outreach program, girls had short sessions in material science, electrical engineering, microbiology, environmental engineering, civil engineering, mathematics, chemistry, art, and computer science. During the evenings, they engaged in social and recreational events, such as game night and pottery painting.

5.2 Participants

54 girls between the ages of 11 through 14 were a part of the program. Of the participants, demographically, 61.1% were White, 28.8% African American, 5.1% Non-White Latina, 3.3% American Indian or Alaskan Native, and 1.7% Asian. 36% of the students have someone in their family who works in science, technology, engineering, or math as a career, and 35% have participated in previous robotics activities. Of these participants, 16 participants volunteered, 8 on each day, to participate in the immersive embodied interaction metaphor. Prior to volunteering, they were asked if they wanted to participate in an activity using the Oculus Rift goggles. Our research team for the camp consisted of 2 White females, 1 African American female, 3 Asian females, and 2 Asian males who interacted with students during various parts of the camp. Six team members work in computer science or a closely related field (e.g., digital production arts, human-centered computing).

5.3 Procedure: Overall Camp

Students spent 2 days in the computer science session for a total of 2.5 hours. During this time, students were introduced to VEnvI as well as programming concepts: sequencing, loops, and variables. They also spent time practicing dance techniques to learn some of the movements in VEnvI and talked through different aspects of VEnvI software including motion capture and Unity 3D Development. The latter conversations were couched in relation to being a computer scientist.

5.4 Procedure: Immersive Experience

1. The experiment was set up in a room separate from the main VEnvI camp activities. Students were escorted one at a time by a student coordinator to this room.

2. A researcher greeted the student, verbally introduced the experiment and clearly explained the safety guidelines and the risks involved with participation in the experiment. The researcher then asked for her consent for participation.

3. Upon receiving consent, the Oculus Rift HMD was placed on the student's head, tightened and adjusted. The student was positioned at the center of the room in the line of sight of the Kinect sensor.

4. Once inside the VEnvI environment, the student was asked to perform certain calibration steps, such as moving forward, backward and side to side, squatting and jumping, and moving each of their hands and legs in order to acclimate to the self-avatar and natural motion inside the virtual environment.

5. When the student was comfortable with the environment, the experiment was started. The student would see a virtual character in front of them performing pre-programmed choreography (a popular social line dance, the Cha-Cha slide) with music playing in the background. The student was informed that she could do whatever they liked in the virtual environment. The student's activities were recorded using a video camera.

6. The simulation was stopped at the end of the song (approximately 4 minutes and 30 seconds), and the HMD was taken off the participant's head. The student was then directed to another room for a debriefing interview.

5.5 Measures

At the beginning and end of the VEnvI activities, each student (n=54) was given a piece of paper that only contained a code corresponding to her. The instructions were to write, "What do computer scientists do?" on one side of the page, and to draw a picture of a computer scientist on the back. Asking what computer scientists do was influenced by Grover et al [11] who asked this question to middle school and collegiate students. Draw-a-"something" technique is a solidly grounded technique developed in the field of psychology to determine attitudes and stereotypical beliefs about whatever the "something" is [6]. Martin [20] utilized the "something" as a computer scientist, uncovering a perception of "various degrees of 'geekiness'".

Selected volunteers from the larger group experienced dancing with a virtual human through the embodied interaction metaphor. Their reactions were recorded in a debriefing interview at the end of the immersive portion of the study to obtain qualitative and quantitative insights into the experience of the immersive embodied interaction metaphor in VEnvI. Using statements made during the debriefing interview, we measured participants' telepresence, social presence, enjoyment, and satisfaction, as well as the impact and usability of the technology. The presence questions were an adaptation of the questionnaire designed by Nowak and Biocca [26]. The language was simplified for the target audience of middle school students, and only a subset of the questions were asked due to time constraints. For six questions, we asked the participants to rate their experience based on a 10 point Likert scale (0 = the lowest and 10 = the highest on the scale).

6 Results

In the following sections, we discuss the results from both the overall VEnvI camp, and the immersive metaphor study.

6.1 Computer Science Perceptions

Only 47 students' pre-post-data gathered are included due to incomplete surveys (some girls were pulled out at various times). Thematic analysis was utilized to generate emergent themes from the pre and post questions, "What do computer scientists do?" Thematic analysis is "an accessible and theoretically-flexible approach to analyzing qualitative data" [3]. Thematic analysis, a method widely used in psychology, calls for the demarcation of a qualitative data corpus into themes. All data were also analyzed using thematic analysis procedures which include building familiarity, generating codes, identifying features, and finding, confirming, and defining themes for reporting.

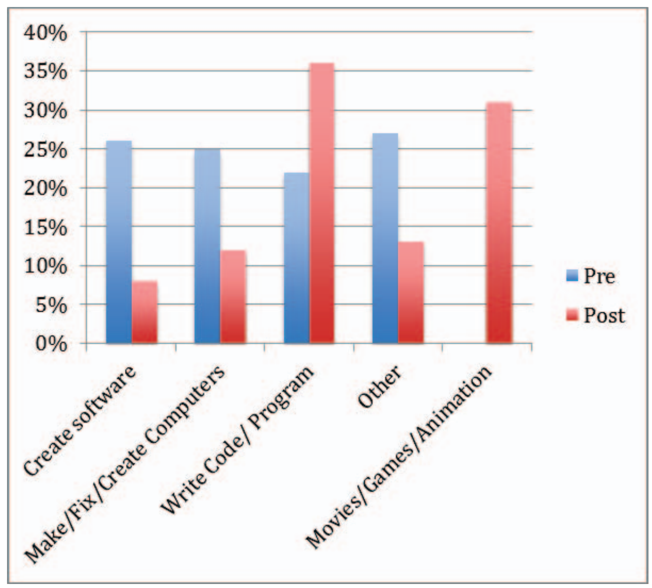

Figure 8: Results from the thematic analysis performed on the pre and post questions on "What do computer scientists do?"

Since some student responses included multiple answers to the question, "What do computer scientists do?" seventy-two total items were coded for the pre-test and sixty-one responses were coded for the post-test. As shown in Figure 8, 26]% say create applications, software, website (n=18), 22% say write code or program (n=16), 25% say work on, make, fix computers (n=19). Of the remaining response answers included: do science with computers (n=6), solve problems (n=5), teach people how to use computers (n=1), help people (n=2), animation/video games (n=1), I don't know (n=4). For the post-test, 31% mentioned movies, games, animation (n=19), 8% create applications, software, website (n=5); 36% write code or program (n=22); 12% say work on, make, fix computers (n=7). The remaining 13% of the responses included: helping people (n=4), do science with computers (n=2), solve problems (n=2).

6.2 The Immersive Embodied Interaction Metaphor

6.2.1 Telepresence

Immersion is a key factor for VR to have a pivotal effect in keeping the students engaged and inspire them to learn. The sense of being present in the environment and experiencing the programmed choreography that they created using VEnvI first-hand is the crux of this research. To measure this sense of "being there", we asked various questions such as "Did you feel like you were inside and surrounded by the environment?" and "How did it feel seeing your own body in there?"

Responses such as "it was cool to take video games to the next level ... it was cool not only being able to see yourself, but all around you as well" showed the students' excitement of being immersed in the virtual world. Similarly, "It felt weird because I actually thought I was there", "it just felt real", and "that was so much fun that I forgot where I really was" indicated that the students felt a high sense of presence.

When asked about their virtual body, they replied with "it actually felt like this is my body ... it's doing the exact movements that you're doing" and "in a regular game you can just see the person walking and in this one you could like see yourself ... that made it even more real". Upon asking why it felt so real, many students mentioned seeing their own shadow and how it added to the immersion, with statements like "even the shadow was matching my arm and my elbows and my knee bends." When asked if it would be any different if the virtual body was not there, they said, "that wouldn't be as much fun. It'd be like you're a ghost, and you're just standing there."

Not all responses were positive, however. Some students felt their immersion break because the "grass and the ground didn't feel real". Some were conscious about "feeling the HMD on their face" and feared tugging on the wires and breaking something. Some experienced occasional tracking glitches with body parts going through each other which felt "creepy".

Overall, we learned that immersion is a highly desirable feature which gave the students a feeling of novelty, excitement, realism and provided a fun experience. Further, the shortcomings of the simulation can be ironed out by having higher fidelity of models and textures, better handling of tracking errors, and longer cables or possibly employing a wireless strategy.

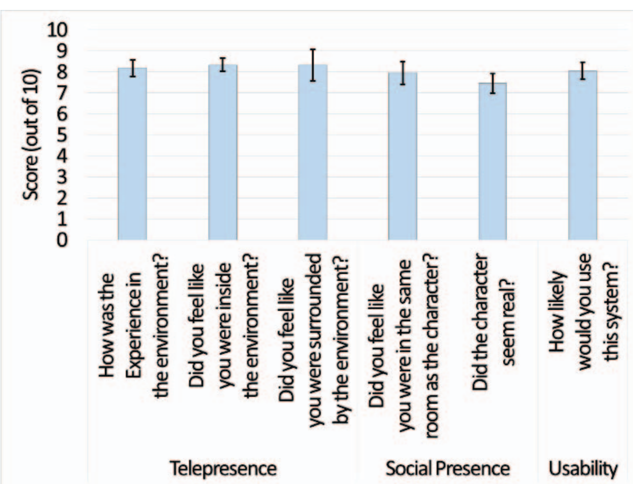

Figure 9: Descriptive statistics of the quantitative responses for telepresence, social presence and usability of the immersive embodied interaction metaphor.

6.2.2 Social-presence

Another important factor we wanted to measure was social-presence. Our intent was for the participants to feel socially attached to the virtual character performing in front of them. We believed this social attachment would, in turn, foster engagement and learning. We hypothesized that seeing the virtual character, in first-person, perform the moves created using VEnvI would provide the students with exuberance, and motivate them to make improvements, correct mistakes, and ultimately program more. To measure the students' feeling of social connection with the virtual character, we asked questions such as "Did you feel like you were in the same room as the character?", "Did the character feel real?", and "Did you feel like dancing with the character?"

They felt they occupied the same space as the virtual character because they "felt the need to back up and give her more space". "She looked like she was right in front of me ... it felt like I could just reach out and touch her", said another student. Upon asking if she felt like dancing with the virtual character, she replied, "I danced because it felt comfortable and real". Some students had the sentiment that dancing with the virtual character was comfortable because the virtual character would not criticize the way they dance by saying "oh my god you suck at dancing, please stop!"

What was lacking, according to the students, was true interaction with the character. They felt like the character did not know they existed in the VE, as if she was ignoring the participant. They wished that the virtual character acknowledged their presence, by "looking and smiling, or simply saying hey". Some of the students found the animations to be patchy at times and felt that the character model was not of the best quality.

Responses about true interactivity with the virtual character provided us with a highly interesting result. This study wasn't aimed at providing true interaction with the character, but it became evident that such a feature was highly desired. These features can be incorporated by implementing interactivity, refining the animations, and improving the fidelity of the virtual character model.

6.2.3 Usability, satisfaction, and enthusiasm

Finally, we were highly interested in the usability and acceptance of VEnvI and the immersive simulation. Knowing if the students were satisfied with and had the enthusiasm for the simulation would give us a reason for pursuing the development of such an application. We asked the students "How likely you are to use this system?", "What would you change in this system?", and "Do you think this immersive experience would help you learn better?"

Most students said that they would use this simulation very often, comparing it to activities such as watching TV or playing video games. They would use it "whenever they have free time", or "when they are bored", or "at parties and when friends come over". The students really liked the idea of an educational game with an immersive VE that surrounds you and having the ability to program how the virtual character moves.

The students had great ideas about improving the current simulation. Some students wanted "more objects and more people" in the environment because it felt like they were "in the middle of nowhere". Some suggested we add the ability to change where the character dances. Another important suggestion was to implement "easy, medium, and hard" difficulty levels to appeal to differently skilled individuals. It was also suggested to gamify VEnvI, so you could "unlock new outfits and moves" to add motivation to keep playing.

Students thought that the immersive experience would help them learn better because it was similar to going to a class, and one could learn by looking at the virtual character and repeating the steps. In real life, the person teaching may have limited time, "might get irritated" by a slow pace of learning, or could even give up in the worst case. However, in the virtual world, "you have as much time as needed, and you could do it whenever you want, and you don't have to go to a class."

Therefore, we learned that the students highly appreciated VEnvI and the immersive embodied interaction experience, thought it was highly usable, and showed great enthusiasm towards the idea. Furthermore, the students presented us with great ideas of improving the system, demonstrating an ardor for critical thinking.

We also asked the students to rate their experiences on a 10-point Likert scale. Figure 9 shows the means and standard deviations of these quantitative responses. Overall, the telepresence, social presence, and usability were rated highly by the participants.

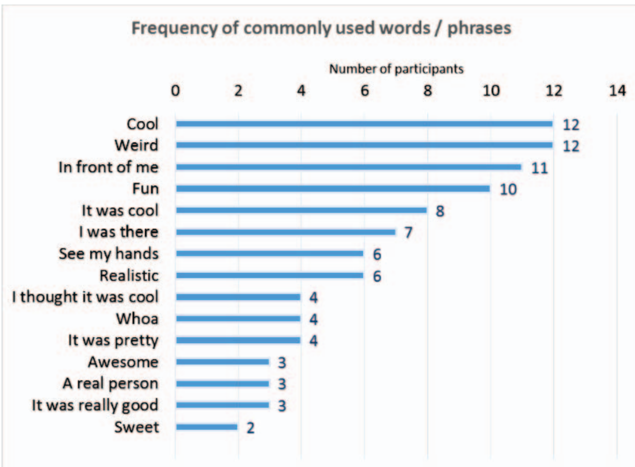

Figure 10: A chart showing frequency of words and phrases used commonly by the participants.

We conducted a frequency analysis on a subset of words and phrases of interest that were commonly used by the participants (n=16). As shown in Figure 10, a large number of participants used the words 'cool' and 'weird' to describe their experience (n=12), indicating the experience to be novel and unexpected. The students were aware of their surroundings, and frequently described what they saw "in front of them" (n=11), and even the ability to see their own hands in the virtual environment (n=6). As seen from the results, the students felt a high sense of presence, and many explicitly stated the feeling as "I was there" (n=7). Many students (n=6) used the word "realistic" for describing the environment and the virtual character in front of them, and some thought of the character as a real person (n=3). Overall, a positive trend was depicted in the student responses.

6.3 Observations of participant behavior within the embodied interaction metaphor

We recorded each participant's performance during the immersive embodied experience. We analyzed these recordings to make observations on the participants' behavior while they were engaged within the virtual environment. Almost all the participants exclaimed "this is so cool" and some said "this is awesome" while in the environment. When the virtual character came too close to the participants while dancing, most participants tried to move back, some participants tried to push the virtual character away from them, and some said, "this is creepy".

A majority of the participants (12 out of 16) started dancing in the immersive environment without any prompt or being told to do so. The Cha-Cha slide is a line dance, in which the song instructs the participants to execute a repeated sequence of steps. The students could either choose to follow the music, or to follow the dancing virtual character. Out of the 12 participants who danced, 6 followed the music, 4 followed the steps of the virtual character, and 2 switched from following the virtual character to following the music upon realizing that the two weren't in sync. Some of the participants even moved around enough to either come close to a wall or feel the tug of the HMD cord.

7 Discussion

VEnvI leverages the strengths of other successful CS environments like Alice, Looking Glass and Scratch, but also presents many novel improvements over the prior tools. Aspects drawn from other environments include an intuitive drag-and-drop interface, customizable characters, actions within a virtual environment that follow and correspond to the user created program, and the use of computational techniques to foster creativity and learning.

The first major difference is the representation of animation towards a more realistic and user-friendly medium of interaction. Alice, Looking Glass, and Scratch are designed for the purpose of storytelling, simple games, and animations. They use pose-based motion primitives that require modifying joint angles and positions to move the various body parts, a method similar to keyframing animations. While this works for simple storytelling and games, dance primitives created in Alice look highly unrealistic and robotic. Additionally, programming of dance animations within Alice and Looking Glass [9] proved to be very time-consuming. To capture the complexity of dance, we developed VEnvI to be specialized for dance representation using the Unity3D game engine and motion captured animations. The result is a faster and easier method of creating programmed choreography with realistic animations of higher fidelity.

The second major difference in VEnvI is the virtual reality component that follows and complements the programming interface. Since dance is an embodied activity, providing a unique first-person perspective that places the students in the same space as the virtual character facilitates natural embodied thinking and cognition. The result is an enhanced creation process that allows students to critically think via physical actions and apply this feedback to the programming interface. We wish for students to view the VR metaphor as an integral part of the programming process, through which they visualize their programmed choreography, use embodied cognition to validate their choreography, and return to the creation process to perhaps make changes and improve the choreography further. This two-stage approach inspires students to continue learning and allows us as researchers to analyze the creation process.

Overall, the activities within the VEnvI camp altered students' perceptions of computer science and computer scientists and broadened their perspectives. We learned that activities within the WISE camp in conjunction with programming within VEnvI proved to have a positive impact on students' perceptions on the field of computer science.

Furthermore, virtual reality proved to be successful in grabbing the attention of middle school students. Students had a lot of fun within the immersive environment. The ability to see a co-located virtual self-avatar that mimics the movements of the real self, and to be able to look around in the virtual world, just like in the real world, seemed to be the major factors in experiencing high telepresence with the middle school children. The shadow of the virtual body played an important role in establishing telepresence. The students cared about the surroundings in the environment and desired more objects and people inside the virtual world. They also preferred having a virtual self-avatar over no self-avatar. The students did have the fear of running over things or walking into walls, which caused them to be more cautious within the virtual environment. For the participants who did want to move around more, the short cable of the HMD proved to be a hindrance.

The feeling of high social presence was attributed to the virtual character moving around in the environment and coming close to the participants. The use of 3D stereo and the feeling of being able to touch the virtual character positively impacted social presence. The virtual character seemed like a real person to the students, even though they faced some technological limitations with the character. However, there was great desire for the virtual character to acknowledge the participant's presence and interact with them, in the form of looking at, smiling at, or greeting the user. Participants either danced or wanted to dance with the virtual character even when they were not prompted to do so by the researchers. Some participants felt too shy to dance in the presence of researchers but mentioned that they would dance if they were alone or with close friends.

The students rated the virtual environment high in usability as it was a novel experience and was different from traditional games. They expressed a desire to buy the software and wanted to know if it would be commercially available soon, indicating high satisfaction and enthusiasm for the technology. The students envisioned using this technology alone at home as well as with siblings or friends. They also provided great suggestions for improving the software and also adding new functionalities. Some students wanted the option to choose the background where the virtual character dances. It was also suggested to add facial expressions and interactions to the virtual character. Thus, going through the VR experience and thinking about improving the system provoked the students to think like computational scientists and come up with critically thought out propositions.

Most students thought that such an immersive experience would help them learn better, and one student especially wanted more of the programming features from VEnvI in the embodied interaction metaphor. Through the interview responses and behavioral analysis, we found that the immersive embodied interaction metaphor motivated dancing, movement and learning thereby facilitating embodied cognition. The user study also highlighted the need for a larger operational area and longer cables in future implementations of the immersive embodied interaction in VEnvI.

8 Conclusion and Future Work

The camp activities, programming with VEnvI, and the immersive embodied interaction together proved to be successful in sparking an interest in computer science within middle school students. The pedagogical activity of using VEnvI positively altered their perceptions of computing and computer scientists. It was a defining moment when one of the students exclaimed:

Student: "What career do I have to do to invent this kind of stuff?"

Researcher: "A computer scientist"

Student: "I'm gonna be a computer scientist"

Not much work has been done in studying middle school students' attitudes towards virtual reality, namely through studying their sense of telepresence and social-presence, usability of the application, and enthusiasm towards virtual reality in general, especially in the field of education. Our broader aim is to advance the knowledge by examining how virtual reality systems can be integrated into a technology based STEM education curriculum to enhance the pedagogical outcomes, and test children's acceptance and use of such technology towards learning. Some research can be found in medical VR applications, such as the study comparing neurological differences in adults versus children in the feeling of presence [2] or studies in using VR technologies with children in the autism spectrum [28]. Virvou and Katsionis [43] studied the usability and likeability of VR games in education and suggested that further research on virtual reality educational games is warranted.

Our initial exploratory research reveals that middle school students are greatly interested in educational VR applications that make learning programming fun, and show great enthusiasm towards the state-of-the-art immersive and interactive VR technologies. These observations seem to be promising and ripe for exploration in further empirical analyses.

Unlike the procedure followed in the current research, it is envisioned that the embodied interaction metaphor is not just used towards the end, but students rather use it constantly to view and iteratively improve their programmed choreography, and it forms a part of the formative evaluation of the choreography. Eventually, students should be able to author the programmed choreography and even the dance animations from within the immersive VR experience, but many technical hurdles need to be crossed to achieve this end goal. Challenges such as interaction with the programming interface within the virtual environment in an intuitive and non-cumbersome manner and legible rendering of GUI elements within the HMD environment need to be tackled.

For the next iteration, students will utilize the programming interface and the immersive VR metaphor side-by-side as an integrated process. We plan to conduct a comparative empirical evaluation investigating the effects of immersive embodied viewing versus non-immersive desktop viewing of the students programmatic dance simulations on presence, engagement, enthusiasm, and learning of computational thinking in VR. We also plan to empirically examine the impact of shared virtual reality experiences of having multiple users occupying the immersive virtual environment, dancing with one another and the virtual character, on students' presence, engagement, and pedagogical outcomes in computational thinking.

Acknowledgements

The authors wish to thank our university partners and summer program participants for their involvement in and support of the project. This material is based upon work supported by the National Science Foundation under Grant No. 1344228.

References

[1] R. Bailey, K. Wise, and P. Bolls. How avatar customizability affects children's arousal and subjective presence during junk food–sponsored online video games. *CyberPsychology & Behavior*, 12(3):277–283, 2009.

[2] T. Baumgartner, D. Speck, D. Wettstein, O. Masnari, G. Beeli, and L. Jäncke. Feeling present in arousing virtual reality worlds: prefrontal brain regions differentially orchestrate presence experience in adults and children. *Frontiers in Human Neuroscience*, 2, 2008.

[3] V. Braun and V. Clarke. Using thematic analysis in psychology. *Qualitative research in psychology*, 3(2):77–101, 2006.

[4] Q. Brown, W. Mongan, D. Kusic, E. Garbarine, E. Fromm, and A. Fontecchio. Computer aided instruction as a vehicle for problem solving: Scratch programming environment in the middle years classroom. *Retrieved September*, 22, 2013.

[5] J. Cecil, P. Ramanathan, and M. Mwavita. Virtual learning environments in engineering and stem education. In *Frontiers in Education Conference, 2013 IEEE*, pages 502–507. IEEE, 2013.

[6] D. W. Chambers. Stereotypic images of the scientist: The draw-a-scientist test. *Science education*, 67(2):255–265, 1983.

[7] S. Cooper, W. Dann, and R. Pausch. Alice: a 3-d tool for introductory programming concepts. In *Journal of Computing Sciences in Colleges*, volume 15, pages 107–116. Consortium for Computing Sciences in Colleges, 2000.

[8] J. Cordova, V. Eaton, and K. Taylor. Experiences in computer science wonderland: a success story with alice. *Journal of Computing Sciences in Colleges*, 26(5):16–22, 2011.

[9] S. B. Daily, A. E. Leonard, S. Jörg, S. Babu, and K. Gundersen. Dancing alice: Exploring embodied pedagogical strategies for learning computational thinking. In *Proceedings of the 45th ACM technical symposium on Computer science education*, pages 91–96. ACM, 2014.

[10] P. A. Gross, M. S. Herstand, J. W. Hodges, and C. L. Kelleher. A code reuse interface for non-programmer middle school students. In

Proceedings of the 15th international conference on Intelligent user interfaces, pages 219–228. ACM, 2010.

[11] S. Grover, R. Pea, and S. Cooper. Remedying misperceptions of computer science among middle school students. In *Proceedings of the 45th ACM technical symposium on Computer science education*, pages 343–348. ACM, 2014.

[12] E. V. Howard, D. Evans, J. Courte, and C. Bishop-Clark. A qualitative look at alice and pair-programming. In *Proceedings of ISECON 2006*, 2006.

[13] C. Kelleher, R. Pausch, and S. Kiesler. Storytelling alice motivates middle school girls to learn computer programming. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 1455–1464. ACM, 2007.

[14] D. J. Ketelhut, B. C. Nelson, J. Clarke, and C. Dede. A multi-user virtual environment for building and assessing higher order inquiry skills in science. *British Journal of Educational Technology*, 41(1):56–68, 2010.

[15] D. Kirsh. Thinking with the body. *Proceedings of the 32nd Annual Conference of the Cognitive Science Society.*, pages 2864–2869, 2010.

[16] D. Kirsh. Creative cognition in choreography. *Proceedings of 2nd International Conference on Computational Creativity*, 2011.

[17] M. Kölling. The greenfoot programming environment. *ACM Transactions on Computing Education (TOCE)*, 10(4):14, 2010.

[18] J. Maloney, M. Resnick, N. Rusk, B. Silverman, and E. Eastmond. The scratch programming language and environment. *ACM Transactions on Computing Education (TOCE)*, 10(4):16, 2010.

[19] A. V. Maltese and R. H. Tai. Eyeballs in the fridge: Sources of early interest in science. *International Journal of Science Education*, 32(5):669–685, 2010.

[20] C. D. Martin. Draw a computer scientist. In *ACM SIGCSE Bulletin*, volume 36, pages 11–12. ACM, 2004.

[21] Microsoft. Kinect for Windows - Voice, Movement and Gesture Recognition Technology. `https://www.microsoft.com/en-us/kinectforwindows/meetkinect/default.aspx`, 2015. [Online; accessed 15-September-2015].

[22] T. J. Misa. *Gender codes: Why women are leaving computing*. John Wiley & Sons, 2011.

[23] K. Modi, J. Schoenberg, and K. Salmond. Generation stem: What girls say about science, technology, engineering, and math. *A Report from the Girl Scout Research Institute. New York, NY: Girl Scouts of the USA*, 2012.

[24] P. Mullins, D. Whitfield, and M. Conlon. Using alice 2.0 as a first language. *Journal of Computing Sciences in Colleges*, 24(3):136–143, 2009.

[25] T. Nadan, V. Alexandrov, R. Jamieson, and K. Watson. Is virtual reality a memorable experience in an educational context? *International Journal of Emerging Technologies in Learning (iJET)*, 6(1), 2011.

[26] K. L. Nowak and F. Biocca. The effect of the agency and anthropomorphism on users' sense of telepresence, copresence, and social presence in virtual environments. *Presence*, 12(5):481–494, 2003.

[27] OculusVR. Oculus Rift Development Kit 2 (DK2). `https://www.oculus.com/en-us/dk2/`, 2015. [Online; accessed 15-September-2015].

[28] S. Parsons and S. Cobb. State-of-the-art of virtual reality technologies for children on the autism spectrum. *European Journal of Special Needs Education*, 26(3):355–366, 2011.

[29] I. Radu and B. MacIntyre. Augmented-reality scratch: A tangible programming environment for children. In *Proceedings of Conference on Interaction Design for Children, Como, Italy*, 2009.

[30] S. H. Rodger, J. Hayes, G. Lezin, H. Qin, D. Nelson, R. Tucker, M. Lopez, S. Cooper, W. Dann, and D. Slater. Engaging middle school teachers and students with alice in a diverse set of subjects. In *ACM SIGCSE Bulletin*, volume 41, pages 271–275. ACM, 2009.

[31] P. M. Sadler, G. Sonnert, Z. Hazari, and R. Tai. Stability and volatility of stem career interest in high school: A gender study. *Science Education*, 96(3):411–427, 2012.

[32] D. Sklar. Can bodylore be brought to its senses? *Journal of American Folklore*, pages 9–22, 1994.

[33] T. M. Smedley and K. Higgins. Virtual technology: Bringing the world into the special education classroom. *Intervention in School and Clinic*, 41(2):114, 2005.

[34] K. Squire. Video games in education. *Int. J. Intell. Games & Simulation*, 2(1):49–62, 2003.

[35] E. R. Sykes. Determining the effectiveness of the 3d alice programming environment at the computer science i level. *Journal of Educational Computing Research*, 36(2):223–244, 2007.

[36] C.-I. Teng. Customization, immersion satisfaction, and online gamer loyalty. *Computers in Human Behavior*, 26(6):1547–1554, 2010.

[37] S. Turkay and C. K. Kinzer. The effects of avatar-based customization on player identification. *Gamification: Concepts, Methodologies, Tools, and Applications: Concepts, Methodologies, Tools, and Applications*, page 247, 2015.

[38] UMA. Unity Multipurpose Avatar. `http://uma.unity3d.com/wiki/index.php/Main_Page`, 2015. [Online; accessed 15-September-2015].

[39] Unity. Unity - Game Engine. `http://unity3d.com/`, 2015. [Online; accessed 15-September-2015].

[40] I. Utting, S. Cooper, M. Kölling, J. Maloney, and M. Resnick. Alice, greenfoot, and scratch–a discussion. *ACM Transactions on Computing Education (TOCE)*, 10(4):17, 2010.

[41] F. J. Varela, E. Thompson, and E. Rosch. *The embodied mind*. CogNet, 1992.

[42] Vicon. Vicon Motion Capture Systems. `http://www.vicon.com/`, 2015. [Online; accessed 15-September-2015].

[43] M. Virvou and G. Katsionis. On the usability and likeability of virtual reality games for education: The case of vr-engage. *Computers & Education*, 50(1):154–178, 2008.

[44] T.-C. Wang, W.-H. Mei, S.-L. Lin, S.-K. Chiu, and J. M.-C. Lin. Teaching programming concepts to high school students with alice. In *Frontiers in Education Conference, 2009. FIE'09. 39th IEEE*, pages 1–6. IEEE, 2009.

[45] S. Warburton. Second life in higher education: Assessing the potential for and the barriers to deploying virtual worlds in learning and teaching. *British Journal of Educational Technology*, 40(3):414–426, 2009.

[46] C. R. Warren. An exploration of factors influencing the career preferences of junior high students. 1990.

[47] J. M. Wing. Computational thinking and thinking about computing. *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences*, 366(1881):3717–3725, 2008.

[48] W. Winn. The virtual reality roving vehicle project. *THE Journal (Technological Horizons in Education)*, 23(5):70, 1995.