Evaluating the effects of immersive embodied interaction on cognition in virtual reality

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Dhaval Parmar
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Accepted by:
Dr. Sabarish V. Babu, Committee Chair
Dr. Larry F. Hodges
Dr. Donald H. House
Dr. Alison E. Leonard

Abstract

Virtual reality is on its advent of becoming mainstream household technology, as technologies such as head-mounted displays, trackers, and interaction devices are becoming affordable and easily available. Virtual reality (VR) has immense potential in enhancing the fields of education and training, and its power can be used to spark interest and enthusiasm among learners. It is, therefore, imperative to evaluate the risks and benefits that immersive virtual reality poses to the field of education.

Research suggests that learning is an embodied process. Learning depends on grounded aspects of the body including action, perception, and interactions with the environment. This research aims to study if immersive embodiment through the means of virtual reality facilitates embodied cognition. A pedagogical VR solution which takes advantage of embodied cognition can lead to enhanced learning benefits.

Towards achieving this goal, this research presents a linear continuum for immersive embodied interaction within virtual reality. This research evaluates the effects of three levels of immersive embodied interactions on cognitive thinking, presence, usability, and satisfaction among users in the fields of science, technology, engineering, and mathematics (STEM) education. Results from the presented experiments show that immersive virtual reality is greatly effective in knowledge acquisition and retention, and highly enhances user satisfaction, interest and enthusiasm. Users experience high levels of presence and are profoundly engaged in the learning activities within the immersive virtual environments.

The studies presented in this research evaluate pedagogical VR software to train and motivate students in STEM education, and provide an empirical analysis comparing desktop VR (DVR), immersive VR (IVR), and immersive embodied VR (IEVR) conditions for learning. This research also proposes a fully immersive embodied interaction metaphor (IEIVR) for learning of computational concepts as a future direction, and presents the challenges faced in implementing the IEIVR metaphor due to extended periods of immersion. Results from the conducted studies help in formulating guidelines for virtual reality and education researchers working in STEM education and training, and for educators and curriculum developers seeking to improve student engagement in the STEM fields.

Dedication

I dedicate this work to my parents, Khushal and Jashoda. Thank you so much for your unconditional love and support and for always being there for me.

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I would like to express the deepest appreciation to my advisor and committee chair Dr. Sabarish V. Babu, who continually and convincingly conveyed a spirit of adventure in regard to research and scholarship, and an excitement in regard to teaching. Without his guidance and persistent help this dissertation would not have been possible.

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Chapter 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 [86, 17]. 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 [133]. The interest in STEM fields for girls is much lower compared to boys, and this interest is often lost during middle school [87]. Maltese et al. [79] found that interest in science began before middle school for a majority of their participants, and Sadler et al. [111] 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.

The field of virtual reality (VR) has gained immense popularity in recent years. From its earliest conceptions in science fiction stories, and bulky, expensive hardware in earlier applications, VR today is on its way to become a household name. Commercialization of virtual reality by companies such as Facebook/Oculus, HTC, Samsung, and Google is making VR ever more accessible and affordable. VR is also being popularized on the mobile platform, where an inexpensive mount houses a mobile phone and lenses, creating a highly portable head-mounted display. Gaming companies are heavily advocating for virtual reality on desktop, mobile, and console platforms using the popularity of VR to drive sales. VR is well on its way to transitioning from existing only in research labs into an everyday household commodity.

A key goal of this research is to utilize embodied processes of inquiry to help students engage in computational thinking. Literature suggests that learning is a grounded and embodied process. The brain's sensory modalities, states of the body, and actions with respect to the situation form the basis of cognition [8]. Embodiment forms a foundation for cognition, and that learning is greatly enhanced through an embodied approach [42]. Embodied cognition proposes viewing the learning process as "not a mind working on abstract problems, but a body that requires a mind to make it function" [134]. Varela et al. [127] state that "cognition depends upon the kinds of experience that come from having a body with various sensorimotor capacities, and these individual sensorimotor capacities are themselves embedded in a more encompassing biological, psychological and cultural context." Anderson [2] indicates cognition to be a situated activity, and that "thinking beings ought therefore be considered first and foremost as acting beings." There have been various ways in which the notion of embodied cognition has been successfully applied in teaching and classroom education [71, 35]. Examples include physics [66], chemistry [104], mathematics [95, 93, 54], geology [14], neuroscience [37], psychology [45], language acquisition [4, 105, 76], gesture instruction [92], arts education [20, 113], and computational thinking [41, 40]. The idea of learning computer programming via embodied cognition builds upon the work of Papert [98], which showed that the learning and understanding of mathematical concepts while programming was more efficient among students when their active engagement with the programming knowledge was associated with their knowledge of self, culture, and the body.

The idea of using dance as a medium of embodying and teaching computer science concepts has been introduced in the research by Leonard, Daily, et al. [70, 34]. Dance is an inherently embodied activity. Dance and arts education research echoes the concept of embodied cognition, suggesting the inextricable nature of mind and body in the learning process [38, 22, 50, 67]. Warburton [132] makes the connection between dance and embodied cognition by using the example of dance marking, which helps dancers in conserving physical energy and relieving cognitive load when memorizing, recalling, and performing dance movements. Dance marking is an informal representation of dance movements, such as using a finger movement to represent a turn while not actually turning the whole body. Warburton states, "Through the process of dance marking the dancer uses her own cognitive mapping of somatic, kinesthetic, and mimetic knowledge to automatize the effortful process of learning a new move." Further, concepts within dance and programming mirror each other [59]. For example, dance has sequences of steps executed one after the other, just like code sequences. Repetitions exist in dance choreography just as loops in programming. Performing dance steps in unison is similar to parallelism. Following and leading in a dance partnership uses concepts similar to conditional branching. Likewise, the choreographic process of reusing and reordering dance sequences mirror computational practices of code reuse and recycling.

Virtual reality has the ability to provide a sense of embodiment via virtual self-avatars [121]. Self-avatars refer to the self-representations of the user in immersive virtual reality experiences. Through self-avatars, users obtain a sense of self-location, global motor control, and body ownership [64]. Embodiment within virtual worlds has shown to have a strong effect on the sense of physical presence, social presence, and self-presence, causing inter-sensory conflict when a mismatch is encountered between the virtual and the real body [13]. Slater et al. [115] showed how a first-person perspective of a virtual human female body in substitution of male subjects own bodies was sufficient to generate a body transfer illusion. Embodiment within virtual worlds has also shown to reduce implicit racial bias and produce a change in negative interpersonal attitudes [103]. Llobera et al. state, "a full body ownership illusion within VR results in unification of the virtual and real bodies into one overall entity" [74]. Such an immersive embodied experience afforded by virtual reality can be used to couple dance and programming, where learners get to actually perform moves instead of simply programming them. As stated in the work by Leonard et al. [70, 72], this will in turn enable the students to form cognitive associations between programming and physical movement within the real and virtual worlds, making virtual reality a perfect platform for facilitating embodied cognition.

Researchers in STEM (science, technology, engineering, and mathematics) fields have explored the benefits of virtual reality to motivate learning. A combination of storytelling and gaming concepts within virtual learning environments has been used to facilitate K-12 STEM learning. Applications such as Alice 3D [31] and Looking Glass [46] use virtual characters and objects within a virtual storytelling environment to teach programming. Students drag-and-drop code blocks to program the actions within the virtual environment. Similarly, in the Scratch learning environment [78], students use block programming to solve puzzles and games. Code.org's Hour of Code [58] and Google's Made with Code [39] use similar virtual environments, and concepts of games and puzzles, to teach programming to K-12 students. VR has led to increased motivation for learning and kindled interest towards STEM fields.

The virtual world is a highly customizable space where the experiences can be tailored to the task and to the individual. VR can reduce operational hazards in performing the tasks, provides real-time feedback, and allows skills to be developed at the individual's own pace. VR provides the user with a sense of being in the environment, and allows the user to substitute the real world with the virtual world by affording immersive embodied interactions. An immersive system is one which can deliver an "inclusive, extensive, surrounding, and vivid illusion of reality the senses of a human participant" [116]. An embodied system utilizes a virtual body to provide the user with a sense of "self-location", a sense of having "global motor control", and a sense of "body ownership" [64]. An interactive system allows the user to "modify the environment", and the environment in turn "responds to the user's actions" [110]. Immersion, embodiment, and interacivity together play a vital role in the suspension of disbelief within the virtual world, and the levels of each of these factors can affect the level of believability.

Within the realm of education and training, immersive embodied VR applications can provide great benefits for knowledge acquisition and skills learning. Research, however, is lacking in understanding this relation between learning and immersive embodied interaction. VR solutions exist for the purpose of education ranging from low fidelity, non-immersive desktop applications to high fidelity, immersive, head-mounted display based applications. These applications include education domains such as computer programming [31, 46, 78], mathematics [60], science and technology [44], engineering [25], chemistry [83, 28], and physics [136, 75]. However, the lack of embodiment through the means of virtual self-avatars and its effects on education and learning reveals a gap in the literature.

1.1 The immersive embodied interaction continuum

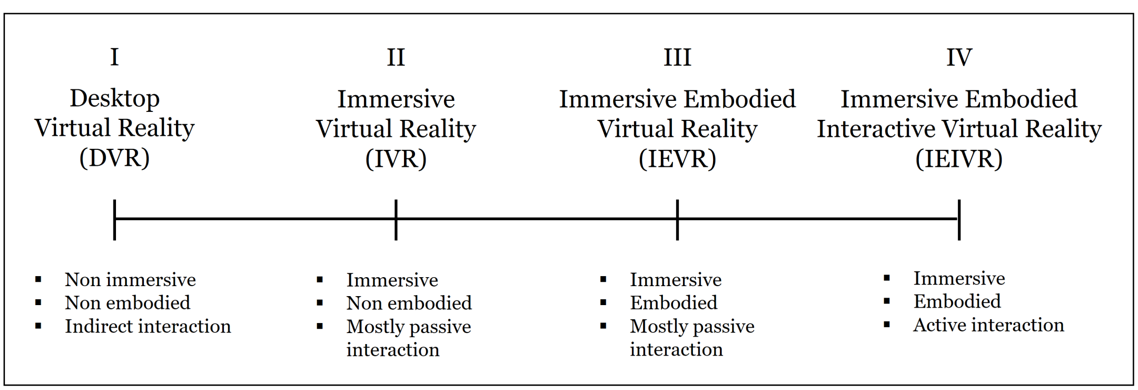


Figure 1.1: The immersive embodied interaction continuum, increasing in fidelity from left to right.

This research presents a linear continuum for immersive embodied interaction within virtual reality applications (Figure 1.1). This continuum focuses on the active embodiment that exists across immersive virtual experiences, from exploratory visualizations on one end, such as viewing a virtual museum or an art gallery [130], to active immersive experiences with self-avatars on the other end, allowing direct interaction with objects in the VR world in a natural manner [129].

At the lowest level is the low fidelity desktop virtual reality (DVR), which is non-immersive and non-embodied, and has an indirect mode of interaction. User actions can directly affect and modify the virtual environment, however this interaction is not natural as it is enabled via a keyboard and mouse setup.

At the next level is immersive virtual reality (IVR) which provides immersion via a head-mounted display, but is non-embodied. Interaction is mostly passive as the user is a mere viewer in the virtual environment and cannot directly affect the environment. Some active interactions include using bodily movements to change viewing parameters such as position, direction, and scaling. This level involves simple exploration activities to view the virtual environment by means of joystick controlled movement, pointing and teleporting, and natural or redirected walking [19, 107].

Embodiment is minimal between immersive virtual reality (IVR) and the immersive embodied virtual reality (IEVR) levels. At the IVR level there is no body representation, and various ways of body representation are introduced as we increase embodiment fidelity from IVR towards IEVR. Simple representation in the form of end-effectors shown as points or spheres can be used to denote body parts [99, 10]. Increasing the fidelity from point-based representations, inverse-kinematic or forward-kinematic skeletons can be used in the virtual environment to represent hands, feet, or the body [119]. Going further, realistic looking floating body parts are employed to add to the effect of embodiment [68]. Finally, a full body self-avatar leads to the next level of the continuum.

At the third level is the immersive embodied virtual reality (IEVR) which is immersive as well as embodied by means of a virtual self-avatar. Interaction is, yet, mostly passive at this level. Having a complete body representation in the virtual environment allows for various benefits including self-location, global motor control, and body ownership [64]. Having a body allows for path integration [61]. The virtual body acts as an egocentric ruler within the virtual world. Embodied self-avatars can be altered by making them smaller or larger or by having shorter or longer limbs to affect the perceived sizes, distances, and weights within the virtual environment [7, 73]. Having a virtual body also allows the user to gauge the space around them and helps with distance estimation

[108, 88].

At the final level is the immersive embodied interactive virtual reality (IEIVR), which provides immersion, embodiment, and passive as well as active interaction by means of 3D spatial controllers and trackers, such as hand-held 6-DOF controllers, VR gloves, or even non-intrusive optical tracked interaction. These VR controllers and trackers afford direct interaction and manipulation of objects in the virtual environment via natural body-based actions [18, 85, 80].

1.2 Objectives

The goal of this research is to evaluate the ability of virtual reality in increasing student interest within the STEM fields, and how the various levels of the VR continuum help in learning and broadening participation among the minority population. This dissertation addresses the first three levels of the immersive embodied interaction continuum by studying the effects of each level on cognition and gain of abstract knowledge.

1.2.1 Objective 1: Initial Evaluation of IEVR

The first objective of this research was to design and implement an immersive embodied virtual reality metaphor (IEVR) for an educational tool that teaches middle-school students computational concepts. Later chapters provide a detailed description of Virtual Environment Interactions (VEnvI), which a pedagogical VR software designed to train students in computer programming concepts. The immersive embodied metaphor built as an extension to VEnvI to provide benefits of embodied cognition and get students interested in learning programming is also described. An exploratory evaluation was conducted for a preliminary analysis of the effects of immersive embodied viewing within VR on enhancing computational thinking in middle-school students. The goals of this exploratory study were:

- To understand the impact of the pedagogical activity of using VEnvI to programmatically create performances for a virtual human on students' perceptions of computing and computer scientists.
- To guage students' experiences of the IEVR metaphor in VEnvI of performing with a virtual human for whom they programmatically choreographed a dance sequence and how they affect

their telepresence, social presence, usability, satisfaction, and enthusiasm.

- To assess the impressions and behavioral effects of the IEVR metaphor in VEnvI on students in terms of their engagement, excitement, and proclivity to dance with the virtual human.

1.2.2 Objective 2: DVR vs. IEVR

The second objective of this research was to perform a thorough empirical evaluation comparing immersive embodied VR viewing within VEnvI (IEVR) against desktop viewing (DVR). A cognitive test was created for this study to assess student knowledge regarding programming concepts based on various categories of established cognitive taxonomies, namely the revised Bloom's taxonomy and the Structure of Observed Learning Outcomes (SOLO) taxonomy. In addition to the cognitive questionnaire, student self-reports on presence, engagement, and satisfaction, and student behavior were statistically analyzed to answer the following questions:

- Does immersive embodied viewing of programmed dance choreographies in VEnvI facilitate embodied cognition for learning programming concepts in middle school children?
- To what extent does immersive embodied viewing within VEnvI affect presence, engagement, and computational thinking among middle school children?
- How do the factors of gender and age of middle school students affect learning and engagement when performing educational activities within VEnvI?

1.2.3 Objective 3: DVR vs. IVR vs. IEVR

The third objective of this research was to understand the effects of embodiment in the form of self-avatars within immersive VR for computer science education. While the previous objective focused on teasing out the factor of immersion, this objective focused on teasing out the factor of embodiment and its effects on learning computer programming concepts. A carefully constructed empirical analysis was performed to compare a desktop-based VEnvI interaction (DVR) with the IEVR condition within VEnvI, implemented using co-located self-avatars which mimicked the movement of students in the virtual environment, with the IVR condition lacking the self-avatar component. This study aimed at answering the following questions:

- Is embodied immersion an important factor for facilitating embodied cognition?

- Does embodied immersion elicit greater presence as compared to immersive VR alone?
- Do immersive embodied experiences within VR have greater impact on students' attitudes towards dance and computing as compared to immersion alone?

This research is organized in eight chapters. Chapter 1 provides the introduction, motivation, and objectives for this research. Chapter 2 outlines the background research for VR applications in education and training. Chapter 3 presents the design and implementation of virtual environment interactions (VEnvI), a desktop virtual reality application at the first level of the continuum (DVR) for the purpose of computational thinking education. An extension of VEnvI in the form of an immersive embodied viewing metaphor at the third level of the continuum (IEVR) is then presented, detailing its design and implementation. Chapter 4 describes the first objective of this research in detail with the initial evaluation of the IEVR metaphor within VEnvI. In chapter 5, a comparative empirical evaluation between the DVR and IEVR levels of VEnvI is presented. Chapter 6 presents an overall analysis in terms of comparing DVR vs. IVR vs. IEVR and looking at the potential of immersive embodiment facilitating embodied cognition. Chapter 7 provides a detailed discussion on the implications of the results from the previously described studies. Finally, chapter 8 concludes this research with a discussion on lessons learned, contributions of this research, significant impact on the research community, limitations of this research, and future directions.

Chapter 2

Background and Related Work

2.1 Virtual Reality Applications for Training

With the ability of virtual reality to spark motivation and interest, VR has been a powerful tool for skills training. Seymour et al. [112] used the Minimally Invasive Surgical Trainer - Virtual Reality (MIST-VR) system to train skills pertinent to the operating room environment. It was found that the use of VR significantly improved the operating room performance among the surgical residents. In another study, Armstrong et al. [3] demonstrated the use of VR in military training. Their research evaluated the Virtual Reality Stroop Task (VRST), which measures reaction time in a military convoy scenario with simulated combat threats. Validity of VRST was established and the system proved to be on par with computerized and traditional tests of attention and executive functioning. Bertrand et al. [11] showed the use of immersive virtual reality for bimanual psychomotor skills training in metrology. They found that immersive VR training significantly improved learning outcomes. Chan et al. [27] created a dance training system using virtual reality and 3D motion capture. Users observed a virtual trainer and mimicked the trainer's movements to learn how to dance. The users reported that the VR system increased their interest in dancing and motivated them to learn. Utilizing the potential of immersive embodied virtual reality to empower education by exposing new knowledge, encouraging retention, and positively altering student perspectives is ripe for exploration within VR research.

2.2 Virtual Reality in STEM+C Education

The use of virtual reality to impart science, technology, engineering, mathematics, and computing (STEM+C) education has been heavily explored and supported in literature. Hew et al. [52] conducted a strong survey on the use of 3D immersive virtual worlds in K-12 and higher education. They found that virtual world research mainly focused on the affective domain, learning outcomes, and social interaction among the participants. Students preferred learning in the virtual worlds because of the ability to move freely within the environment, the ability to meet and interact with virtual agents and peers, and the ability to experience the simulated 3D environment. Students, however, disliked the exclusivity of virtual reality to higher-end computer systems and the lower accessibility of VR on public systems. The review of the studies suggested that virtual worlds can be helpful in stimulating social behavior among participants through the use of avatars.

Kaufmann et al. [60] introduced Construct3D, an application for teaching mathematics and 3D geometry construction using virtual reality. The participants visualized the environment through a head-mounted display and interaction was done using a two-handed 3D augmented-reality interaction tool called the Personal Interaction Panel (PIP). Through an initial evaluation, they found that Construct3D was an effective educational tool which made learning mathematical and geometry concepts easier and encouraged experimental learning. Giarratani et al. [44] created Click!, a mixed-reality role-playing game for pre-teen girls to learn science and technology concepts, and found that Click! helped in increasing confidence, interest, and knowledge towards science and technology among the girls.

Johnson-Glenberg et al. [56] conducted a review of existing research on semi-virtual environments having video-game elements, and analyzed the effects on embodied STEM learning and assessment. Their analysis found significant improvements in learning of STEM concepts within the embodied, semi-virtual environments when compared to regular classroom instruction, and suggested embodiment to be a vital component in game-based learning. Dalgarno et al. [36] analyzed 3D virtual learning environments to identify the affordances impacting learning outcomes. These affordances are comprised of enhanced spatial knowledge representation tasks, experiential learning opportunities, increased motivation and engagement, enhanced contextualization of learning, and richer collaborative learning possibilities as compared to 2D alternatives.

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 [91]. Researchers have used virtual reality based learning environments as an innovative approach to teaching engineering concepts [25]. 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. [63], 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 [117]. 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." Virtual reality has the power to enhance traditional modes of instruction, but it is essential to incorporate VR into the school curriculum in a way that augments the curriculum and provides additional learning benefits.

2.3 Environments for Computational Thinking Education

There is a large body of work related to environments for science, technology, engineering, mathematics, and computing (STEM+C) education, as well as user studies related to their effectiveness. Cooper et al. [31] 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. [109] 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 [120] 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. [32] 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. [131] 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. [90] 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. [53] 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. [62] 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. [78] 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. [106] introduced AR Scratch, which added augmented reality functionality to the Scratch programming platform.

Brown et al. [24] 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 [65] 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. [125] 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.

2.4 Immersive vs. Non-Immersive Interaction

Comparative studies pitching immersive virtual learning environments against traditional non-immersive training methods are crucial in understanding the impact of virtual reality on learning. Coulter et al. [33] compared the effects of a fully immersive head-mounted display (HMD) based learning environment to a desktop-based learning environment for medical education, and found that participants in the HMD condition had significantly higher knowledge gains as compared to the desktop condition. Patel et al. [102] found that in relation to learning of physical tasks, participants learned more in the immersive virtual environment as compared to a 2D video system, and they experienced higher social-presence. Chittaro et al. [29] found that HMD-based immersive learning was better than traditional card-based learning for airline safety education among passengers. Participants reported that the immersive environment more engaging and fear-inducing than the safety cards, which possibly contributed to higher knowledge retention.

Moreno et al. [89] compared HMD-based instruction methods with a desktop-based method for learning about botany. Though students experienced higher sense of presence in the immersive learning method, the results did not indicate any effect on performance in either condition. Juan et al. [57], too, did not find any significant differences in immersive versus desktop training in their research where students learned about the interior of the human body. However, the children enjoyed learning via either training method, suggesting that immersive VR did not have negative effects on learning. Therefore, immersive virtual learning environments can provide learning benefits on par with, if not better than the traditional methods, and exceed in performance gains when interactivity is essential. Immersive VR can be developed in conjunction with existing teaching methods to augment the learning experience. Research exploring the effects of immersion and presence among children within virtual learning environments is sparse, and it is important to conduct empirical studies to gain better insight into children's reactions, attitudes, and expectations of immersive embodied VR.

Chapter 3

System Design and Implementation

Exploring the topic of computer programming through the context of dance is an innovative approach to reach the 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 structures 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 [135].

The notion of learning computational thinking through dance and movement is tied into Virtual Environment Interactions (VEnvI). VEnvI is an application through which students learn computer science concepts through the process of choreographing movement for a virtual character using a fun and intuitive interface. VEnvI 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 with an aim to boost the interest of students, especially middle-school girls, in the field of computing through employing embodied cognition in virtual reality.

3.1 Dancing Alice

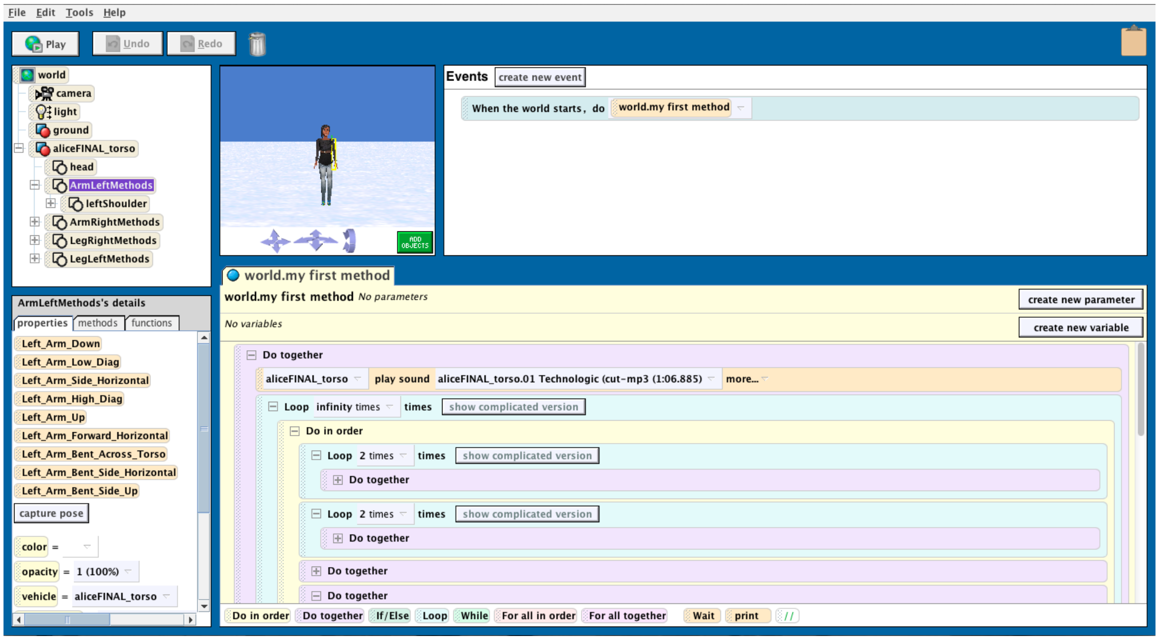


Figure 3.1: User interface for the Dancing Alice programming environment.

The first iteration of VEnvI was built using Storytelling Alice [62], a 3D interactive graphics programming environment, and was named Dancing Alice [34]. The programming interface of Dancing Alice is shown in figure 3.1. In building Shannon, the female virtual character within Dancing Alice, "an individual piece of geometry had to be modeled for every joint that needed to move", as described by Daily et al. "Then, rigging through parenting created a hierarchy to control the limbs. Once this was accomplished, Shannon was textured (i.e., given a visual appearance) and exported to a format that Alice accepts. Once in Alice, left and right arm, left and right leg, and head positions were captured using the native pose command in Alice. Shannon could be posed to move her limbs in a variety of horizontal, vertical, and diagonal positions" (Fig. 3.2). "In order to actuate Shannon, various commands were utilized including Alice's control structures 'DoTogether', 'DoinOrder', and 'Loop'. Motion commands could also be used to move within the world (e.g., Move) and rotate the limbs about their 3-D axes (e.g., Turn and Roll). Poses were created and named similar to a procedure, and then assembled to create full dance movements."

From the initial evaluation [34], Daily et al. found that students were "put-off" by the disjointed appearance of the character. When asked what should be changed about the program,

Figure 3.2: Few basic arm and leg positions built into Shannon that can be put together to create movements.

Figure 3.3: The rigid skinning of the dancer results in a disjointed and unappealing look.

one student said, “I would figure out how to make the movements smoother.” The necessity of creating a simplified version of a character with a rigid body animation within Alice led to an effect of Shannon looking as though her hips were detached from her body or she was missing knees (Fig. 3.3). Finally, students immediately wanted to change the characteristics of the dancer to be male, to change her clothes, to change her ethnicity, and to change her body shape, often replicating their own identifying characteristics. This feedback warranted the design and implementation of VEnvI as a separate software with realistic characters, fluid movements, and the ability to customize the characteristics of the dancer.

3.2 Virtual Environment Interactions (VEnvI)

Lessons from the initial evaluation of Dancing Alice indicated that the software to be used to teach programming concepts by means of dance needed to have fluid and realistic dance movements, appealing virtual characters, and an intuitive user interface. Therefore, Virtual Environment Interactions (VEnvI) was conceptualized, built from the ground up using the Unity3D [124], which is a crossplatform game engine developed by Unity Technologies. The code was written using the C# programming language.

3.2.1 VEnvI design process

The design process for VEnvI started with the software engineering process of modeling the high-level system structure using a UML class diagram (Fig. 3.4). Once the system structure was finalized, an interface design mock-up was created using Microsoft Powerpoint. A slide from the design mock-up is shown in figure 3.5. This design mock-up was shared with various subject-matter experts who then provided feedback and guidance on improving the system. After multiple iterations of feedback and improvements, the system was ready to be built.

3.2.2 Motion-captured animation

Since one of the requirements within VEnvI was to have fluid and realistic movements for the virtual characters, motion-captured animations were used for this purpose. Professional dancers donned a motion-capture suit covered with reflective markers, while a 14-camera Vicon optical motion-capture system recorded their dance movements and converted them to 3D animation

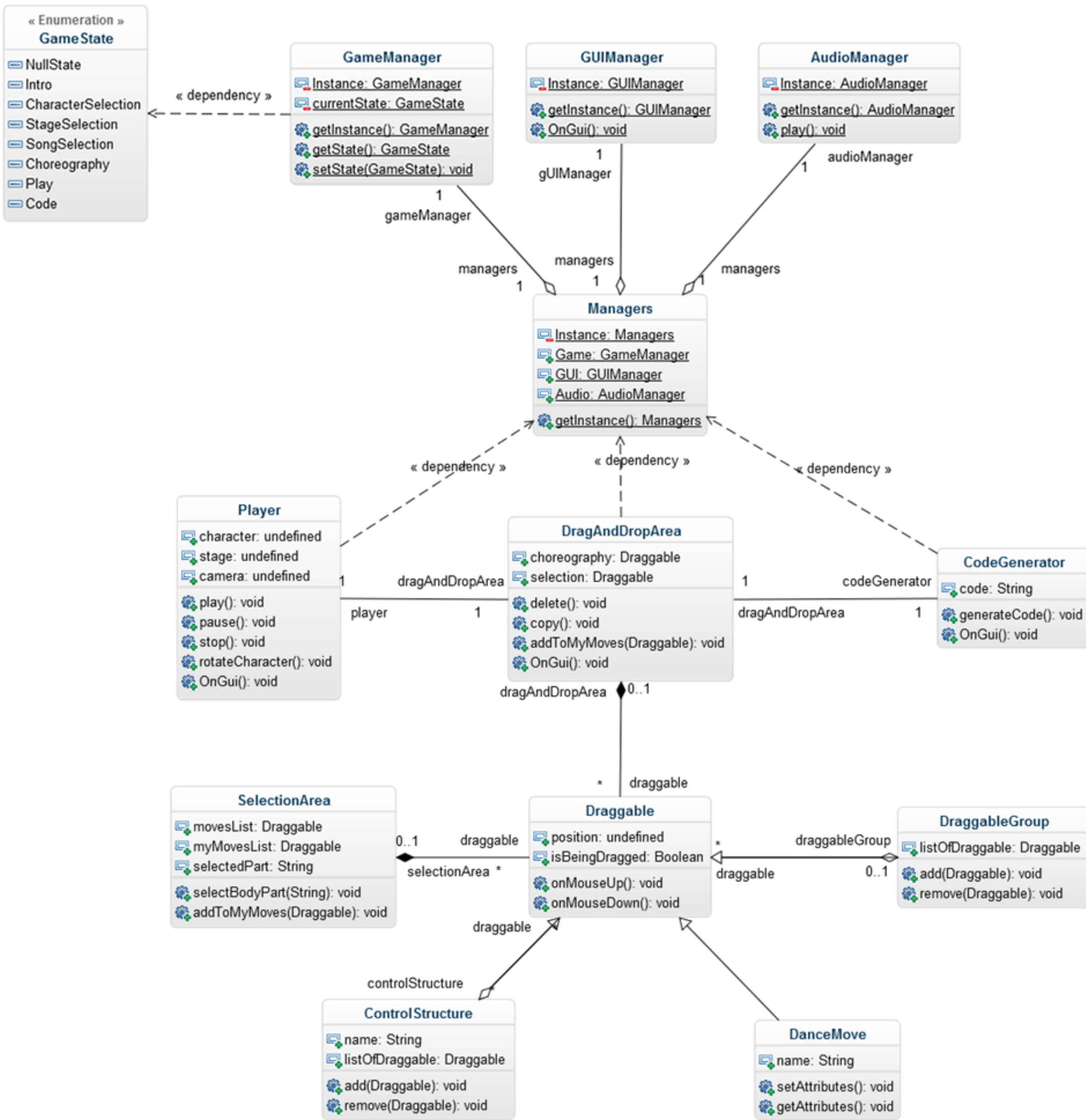


Figure 3.4: UML class diagram for VEnvI.

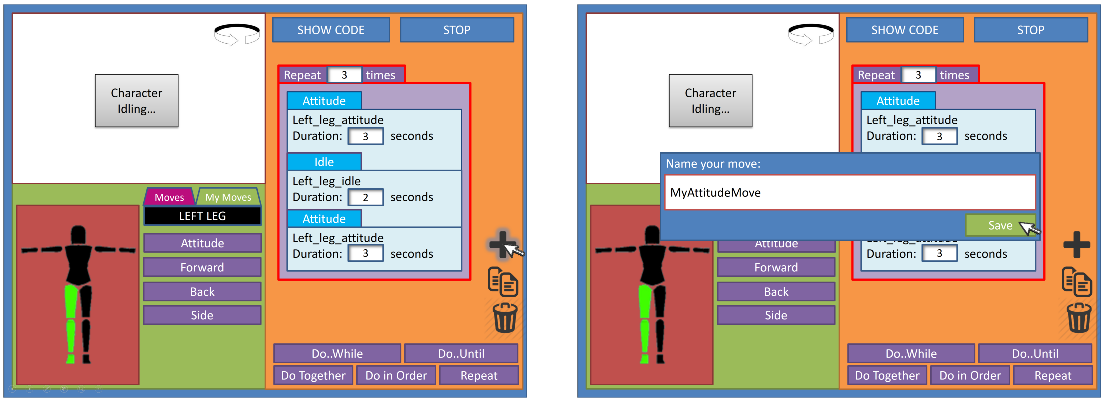


Figure 3.5: Slides taken from the interface design mock-up for VEnvI.

Figure 3.6: (Left) A professional dancer wearing the motion capture suit and performing a hip-hop move, with the animation skeleton overlaid on the dancer's body. (Right) The captured animation applied to a virtual character in VEnvI.

files (Fig. 3.6). These animation files then went through a process of digital clean-up where any animation errors were manually corrected, and then the animations were split up into individual dance movements, such as ‘clap’, ‘hop’, ‘cha-cha’, or ‘charlie brown’. These animations were then integrated into VEnvI using Unity’s Mecanim animation system (Fig. 3.7).

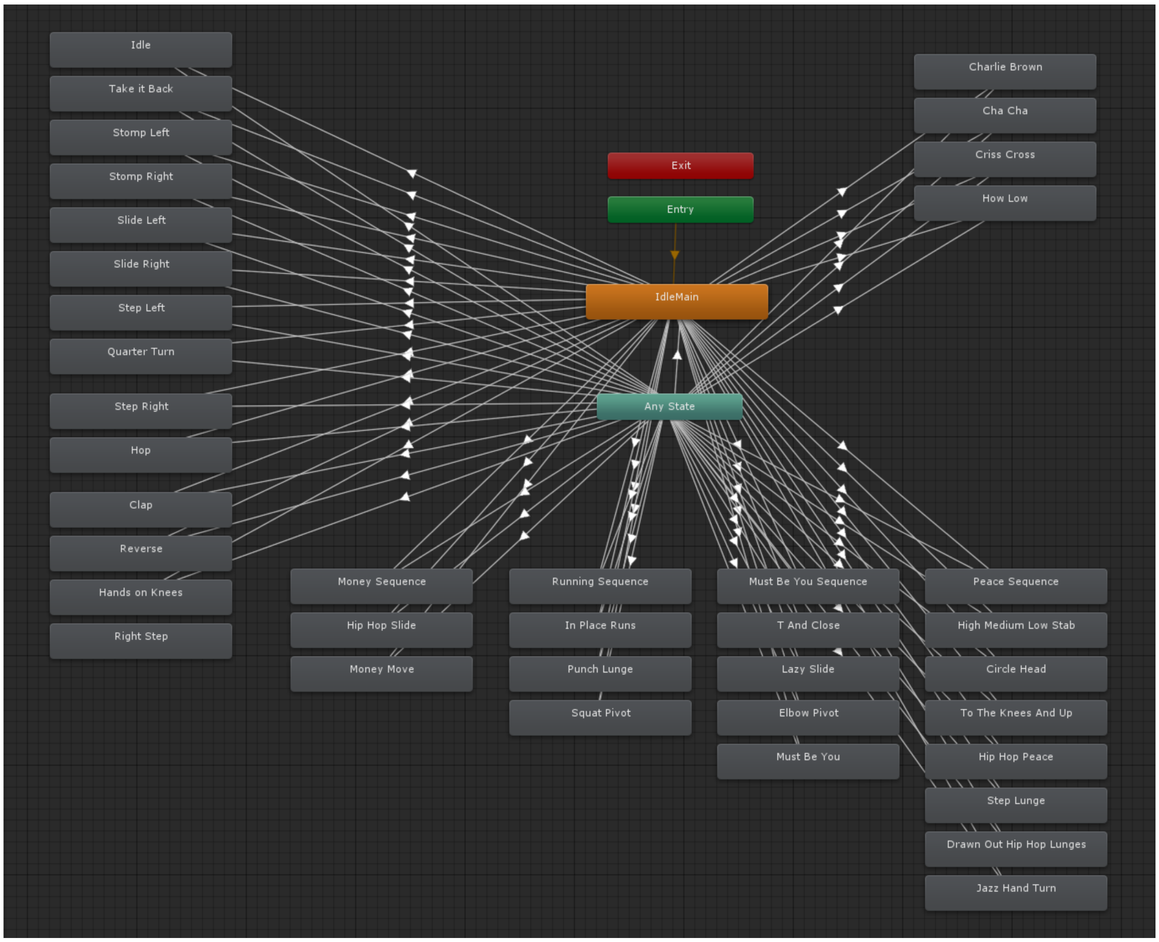


Figure 3.7: The Unity3D Mecanim animation state machine.

3.2.3 Character customization

Avatar customization positively impacts participants’ identification with their avatars, as shown in the research by Turkay et al. [123]. 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

[34]. Character customization options were added to VEnvI, such that students could customize the virtual character that they programmed the choreography for. This enabled the students to give a personality to their virtual character, leading to eventually forming an association with the character. In the process of creating the virtual character, a sense of belonging with the character can result in creating better-programmed choreography for the character than if they were provided with a pre-customized character. Bailey et al. showed that avatar customization can affect both subjective feelings of presence and psychophysiological indicators of emotion, thus making the gameplay experience more enjoyable [6]. The work by Teng indicated that increased customization can better foster gamer loyalty [122]. With the inclusion of character customization, students using VEnvI would feel connected with their customized characters and would be willing to spend more time programming within VEnvI.

Figure 3.8: The customization screen, where the user can select the gender of their character, and body parameters of height, upper weight, and lower weight from within the 'basic' section. Here the user is customizing a male character.

The VEnvI interface greeted the student starting a new game with the character customization screen. Figure 3.8 shows shows the initial customization screen where the user is customizing a male character. On this screen, the user has the option to select either the male or the female gender, and some basic body parameters such as the height of the character, and separately the

Figure 3.9: The customization screen with the user customizing a female character.

upper body weight and the lower body weight. These parameters were important for providing the virtual character a body identity that the users could identify with. Figure 3.9 shows the same screen with a female character.

The next section of character customization was labelled 'body', where the users could customize additional parameters of the character's body, namely the skin tone and the clothing colors. Students could choose from six diverse skin tones ranging from light to dark. Students could also choose from five colors for the upper clothing and five colors for the lower clothing for their characters. Figure 3.10 shows this section of the customization screen.

Finally, students had the ability to customize hair and eye colors by choosing from five different hair colors and three choices for eye color, as shown in figure 3.11. The customization options provided to the users were kept limited so that the users are not overwhelmed by them. The limited options also kept the amount of time spent in customizing the characters short. When the users were satisfied with their customizations, they would provide an identifiable name to their character.

Figure 3.10: The 'body' section of the character customization screen where the user can customize skin tone and upper and lower clothing color.

Figure 3.11: The 'face' section of the customization screen where the user can customize hair color and eye color.

Figure 3.12: The VEnvI user interface showing the virtual environment window on the top left, the move selection area on the bottom left, and the drag-and-drop area on the right.

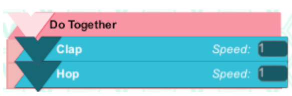
3.2.4 VEnvI user interface

Following this, the VEnvI programming interface was presented to the student (Fig. 3.12). This interface is divided into three major areas: the virtual environment (VE) window on the top-left where the user-customized virtual human appears, the movement database and selection area on the bottom-left, and the drag-and-drop area on the right where the user creates all the programmed choreographies.

The VE window is where the virtual character performs the choreography programmed by the student. A play button triggers the virtual character in the virtual environment 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', hiphop 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'.

This category contains nine unique motions. Non-locomotor movements such as 'clap' or 'stomp' do not displace the character. This category has twenty-four unique motions. The 'sample sequences' contains four special dance moves which are longer and are a hybrid of locomotor and non-locomotor movements. 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.

Table 3.1: The six programming concepts afforded by VEnvI.

<table>
<tr><th>VEnvI element</th><th>Concept</th><th>Functionality</th></tr>
<tr><td>
</td><td>Sequence</td><td>Perform dance moves in a sequence</td></tr>
<tr><td>
</td><td>Loop</td><td>Repeat a sequence of moves a set number of times</td></tr>
<tr><td>
</td><td>Parallelization</td><td>Perform an upper-body and a lower-body movement simultaneously</td></tr>
<tr><td>
</td><td>Variable</td><td>Create a boolean variable and modify its value</td></tr>
<tr><td>
</td><td>Conditional</td><td>Conditional branching of choreography based on a variable check</td></tr>
<tr><td>
</td><td>Function</td><td>Modularize a set of moves as a reusable function</td></tr>
</table>

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. The various affordances provided by VEnvI for teaching programming concepts are shown in table 3.1. Attaching blocks one after another creates sequences. 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 a construct to parallelize two different moves and execute them simultaneously. ‘Create Variable’ 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.

```
main ( ) {
  bool MyVar = False;

  function_0 ( ) {
    Lazy_Slide ( );
    Reverse ( );
    Squat_Pivot ( );
    for ( count=0; count<3; count=count+1 ) {
      Money_Move ( );
      Charlie_Brown ( );
      do together {
        Cha_Cha ( );
        Clap ( );
      }
    }
    for ( count=0; count<10; count=count+1 ) {
      MyVar = True
      Drawn_Out_Hip_Hop_Lunges ( );
      if (MyVar == True) {
          Elbow_Move ( );
        else
          MyVar = True
      }
      MyVar = False
    }
    Slide_Left ( );
    Elbow_Pivot ( );
  }
}
```

Figure 3.13: The show code window. The generated pseudo-code for the movement sequence on the right can be seen in the show code window on the left.

Finally, a button named ‘show code’ generates and shows pseudo-code based on the move sequences in the drag-and-drop area (Figure 3.13). 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.

Figure 3.14: (A) The immersive embodied metaphor experiment setup with the head-mounted display (HMD) on the user's head, and a Kinect sensor in front of the user. (B) Screen capture of the virtual character that dances in front of the user. (C) The first-person view of the user's virtual body.

3.3 The Immersive Embodied Metaphor

As an extension to VEnvI, an immersive embodied experience within VEnvI was created to augment the visual programming model with immersive virtual reality, in an effort to make it more appealing and engaging. The principal goal was 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. This embodied immersion within VEnvI was hypothesized to facilitate embodied cognition among the students, leading to learning benefits.

To facilitate the highly immersive embodied experience, the Oculus Rift development kit 2 head-mounted display [96] was used. The Oculus Rift DK2 has a resolution of 960x1080 per eye and a 100° diagonal field of view. Also, the Microsoft Kinect V2 motion sensor [84] was used 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 immersive VR setup is shown in Figure 3.14. Figure 3.15 shows a student within the immersive embodied interaction metaphor, wearing the Oculus Rift HMD, and the student's view

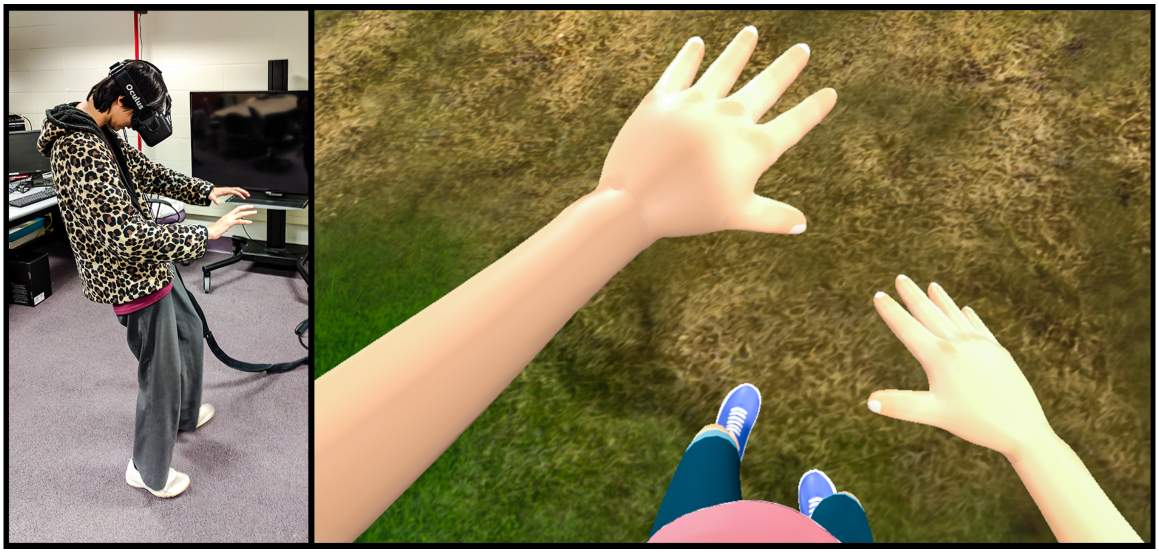


Figure 3.15: A student in VEnvI's immersive embodied interaction metaphor examining her virtual body (left), and her embodied point of view within VEnvI showing her self-avatar (right).

from the HMD is shown on the right. 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. Separate male and female self-avatars were created to embody the users based on their gender. 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 up. Music was played using speakers, and the participants would see the virtual character dancing to the music in front of them.

3.4 Summary

VEnvI leverages the strengths of other successful CS environments like Alice [62], Looking Glass [46] and Scratch [78], 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 [34] proved to be very time-consuming. To capture the complexity of dance, VEnvI was developed 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 can facilitate 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. The VR metaphor is an integral part of the programming process, through which students can 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 researchers to analyze the creation process.

Using VEnvI and the immersive embodied metaphor as the base, multiple studies were conducted to evaluate the system for its efficacy in imparting computer science education and motivating learning, and also to analyze the ability of immersive embodiment in virtual reality to facilitate embodied cognition, as discussed in the following chapters.

Chapter 4

Objective 1: Initial Evaluation of IEVR

4.1 Motivation

The first objective of this research was to explore the feasibility of using VEnvI and the immersive embodied metaphor to motivate students in learning computer programming concepts [100]. Exploring the topic of teaching computer programming through the means of dance is an innovative approach, and it was important to obtain the initial reactions over this approach from the target audience.

The design of VEnvI was inspired by visual programming environments that already existed in the field of STEM education, such as Alice [62], Looking Glass [46] and Scratch [78]. These programming tools use poses and animations that are linearly interpolated between the poses, causing the virtual character's movements to look robotic and unrealistic. VEnvI improves upon the user experience provided by Alice, Looking Glass, and Scratch by utilizing motion captured animations and the Unity3D game engine to create fluid and smooth movements for the virtual character. Users 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.

The goal was to introduce students to the VEnvI software and to the IEVR condition within VEnvI and gather subjective responses on various aspects such as presence, usability, satisfaction, and enthusiasm towards VEnvI and the field of computer science. The study and its results are described in the following sections.

4.2 Research Questions

The following research questions were examined on the impact of students' interactions with VEnvI:

1. How do students' experiences of the immersive embodied interaction in VEnvI of performing with a virtual human affect their telepresence, social presence, usability, satisfaction, and enthusiasm?
2. 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?
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?

4.3 Study Design

4.3.1 System

The VEnvI software, as described in chapter 3, was installed on Macbook Pro laptop computers for the students to access. The immersive embodied metaphor (IEVR) within VEnvI was set up on a Lenovo Ideapad laptop running the Microsoft Windows 8.1 operating system, Intel Core i7-4710HQ processor, NVidia GeForce GTX 860M graphics, and 16GB RAM.

4.3.2 Setting

For this study, parallel activities were being conducted as a part of a larger camp hosted by the university's science and engineering program for middle school girls. This program was dedicated to meeting the needs of today's women in science and engineering. The mission of the program was 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 its 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.

4.3.3 Participants

54 girls between the ages of 11 through 14 were a part of the program. Of the participants, demographically, 61.1% identified as White, 28.8% African American, 5.1% Hispanic, 3.3% American Indian or Alaskan Native, and 1.7% Asian. 36% of the students had someone in their family who worked in science, technology, engineering, or math as a career, and 35% had participated in robotics activities previously. Of these participants, 16 participants volunteered across two days (8 on each day) to participate in the IEVR metaphor. Prior to volunteering, they were asked if they wanted to participate in an activity using the Oculus Rift VR 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 worked in computer science or a closely related field (e.g., digital production arts, human-centered computing).

4.3.4 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 [48] 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 [26]. Martin [81] 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 immersive embodied metaphor (IEVR). 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 IEVR metaphor within VEnvI. Using statements made during the debriefing interview, participants' telepresence, social presence, enjoyment, satisfaction, as well as the impact and usability of the technology were measured. The presence questions were an adaptation of the questionnaire designed by Nowak and Biocca [94]. 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, the participants were asked to rate their experience based on a 10-point Likert scale (1 = the lowest and 10 = the highest on the scale).

4.3.5 Procedure

Overall, the students spent two days in the computer science session for a total of two and a half 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 Unity3D Development. The latter conversations were couched in relation to being a computer scientist.

The students were then asked if they would like to participate in a virtual reality activity related to VEnvI, and volunteers were enlisted. Due to the limited time, a maximum of sixteen participants were able to try the IEVR metaphor, eight on each day. The procedure for this activity is as follows:

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 co-located 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 called the Cha-Cha slide) with music playing in the background. The student was informed that she was free to do whatever she preferred 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.

4.4 Results

4.4.1 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" [21]. 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 includes building familiarity, generating codes, identifying features, and finding, confirming, and defining themes for reporting.

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 4.1, 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

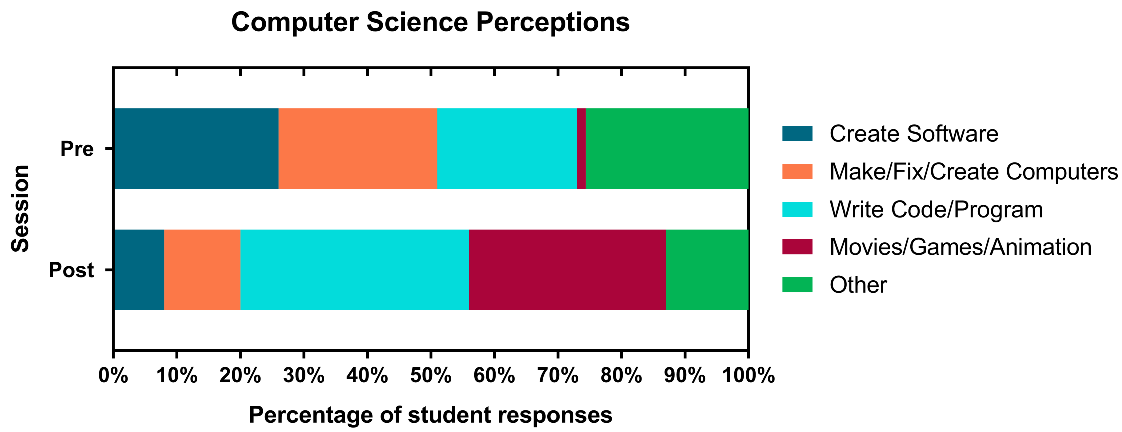


Figure 4.1: Results from the thematic analysis performed on the pre and post questions on "What do computer scientists do?"

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).

4.4.2 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 was the crux of this study. To measure this sense of "being there", the participants were 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, it was 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 needed to 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.

4.4.2.1 Social-presence

Another important factor to be measured was social-presence. The intent was for the participants to feel socially attached to the virtual character performing in front of them. Such a social attachment would, in turn, foster engagement and learning. It was hypothesized that seeing the virtual character in first-person performing 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, 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?"* were asked.

The students 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 a student 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 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 desired. These features can be incorporated by implementing interactivity, refining the animations, and improving the fidelity of the virtual character model.

4.4.2.2 Usability, satisfaction, and enthusiasm

Finally, it was interesting to gather responses related to the usability and acceptance of VEnvI and the IEVR simulation. Knowing if the students were satisfied with and had the enthusiasm for the simulation would provide a reason for pursuing the development of such an application. The students were asked, *"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 adding 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, it was revealed that the students highly appreciated VEnvI and the immersive embodied interaction experience, thought that it was highly usable, and showed great enthusiasm towards the idea. Furthermore, the students presented great ideas of improving the system, demonstrating an ardor for critical thinking.

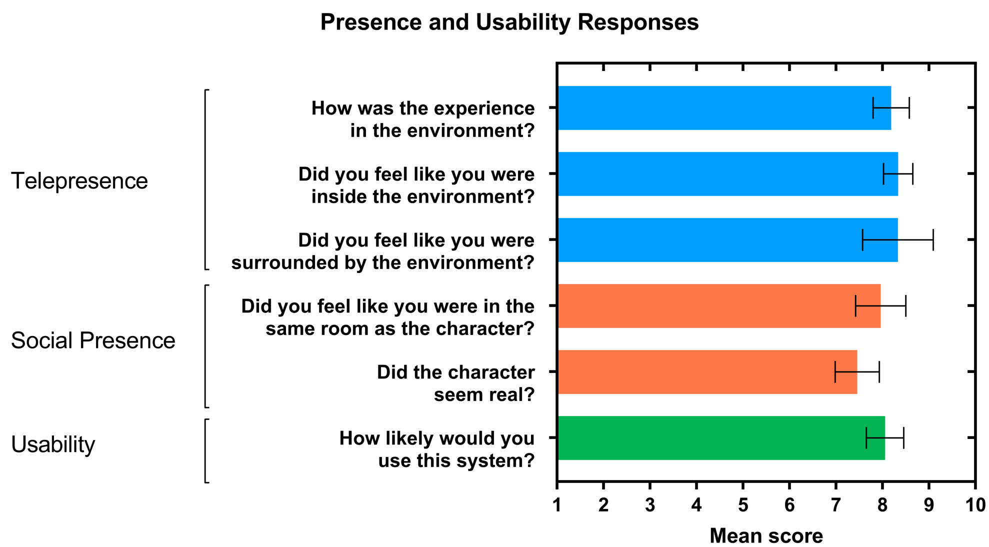


Figure 4.2: Descriptive statistics of the quantitative responses for telepresence, social presence and usability of the immersive embodied interaction metaphor. (Error bars represent standard error of the mean).

The students were also asked to rate their experiences on a 10-point Likert scale. Figure 4.2 shows the means and standard deviations of these quantitative responses. Overall, the telepresence, social presence, and usability were rated highly by the participants.

A frequency analysis was conducted on a subset of words and phrases of interest that were commonly used by the participants (n=16). As shown in graph 4.3, 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.

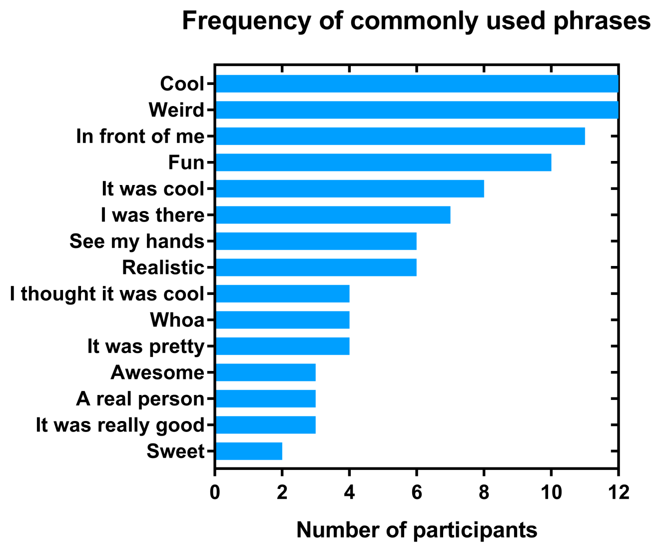


Figure 4.3: A chart showing frequency of words and phrases used commonly by the participants.

4.4.3 Observations of participant behavior within IEVR

Each participant's performance was recorded during the immersive embodied experience. These recordings were analyzed 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 were not synchronous. Some of the participants even moved around enough to either come close to a wall or feel the tug of the HMD cord.

4.5 Conclusion

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.

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

Chapter 5

Objective 2: DVR vs. IEVR

5.1 Motivation

The immersive embodied virtual reality (IEVR) metaphor within VEnvI provides the crucial situated sense of immersion and engagement for motivating students to learn. User actions are embodied using a self-avatar, allowing them to physically enact their programmed choreographies in a grounded learning process, in a way that is not possible in a desktop-only environment. Immersive embodied VR within VEnvI is a powerful tool for providing critical cognitive benefits and enhancing user experience. In the initial exploratory study discussed in chapter 4, it was anecdotally found that the IEVR metaphor within VEnvI provided a compelling experience, and showed potential to facilitate embodied cognition [100]. The aim of this study was to empirically evaluate the effectiveness of immersive virtual reality (IEVR) in teaching core programming concepts to middle school students, and compare it with a non-immersive and non-embodied (DVR) learning approach through a carefully constructed between-subjects user study. The primary goal of this study was to determine if active learning within VEnvI via immersive embodied viewing of student's performances in virtual reality would facilitate embodied cognition. The secondary outcomes involved studying the effects of immersive embodiment on presence within VR, usability of VEnvI, and interest and satisfaction among students for education in computer programming, when compared to the absence of immersion and embodiment (DVR condition) within VEnvI.

5.2 Research Questions

In conducting this comparative evaluation, it was hypothesized that the IEVR experience would significantly improve learning within VEnvI by facilitating embodied cognition, and would result in higher telepresence, social presence, and engagement as compared to the control condition. Further, it was interesting to measure the effects of age and gender of the participants, with the hypothesis that male students would respond differently to the VEnvI activities as compared to female students, and that younger students (ages 11 and 12) would respond differently to the VEnvI activities as compared to older students (ages 13 and 14), in terms of presence, engagement, and computational thinking. Finally, the success of the VEnvI program in imparting computer science education and in positively changing the attitudes of middle school students towards the field of computer science needed to be measured. With these goals, this research study attempted to answer the following research questions:

1. Does immersive embodied viewing of programmed dance choreographies in VEnvI facilitate embodied cognition for learning programming concepts in middle school children?

2. To what extent does immersive embodied viewing within VEnvI affect presence, engagement, and computational thinking among middle school children?

3. How do the factors of gender and age of middle school students affect learning and engagement when performing educational activities within VEnvI?

5.3 Study Design

5.3.1 System

Virtual Environment Interactions (VEnvI), the system used for this study, is described in detail in chapter 3. Figure 5.1 shows the system setup. The VEnvI software was installed in a number of Apple Macbook Pro laptops which were assigned to the students. Once assigned, the students used the same system every time. A separate virtual reality kiosk was set up which contained the immersive embodied (IEVR) metaphor of VEnvI. The IEVR system ran on a machine with Windows 8.1 operating system, Intel Xeon E5 2.8 GHz processor, NVidia GeForce GTX 980 graphics, and 32 GB RAM. Music was played using speakers. The goal of this immersive, self-avatar based metaphor

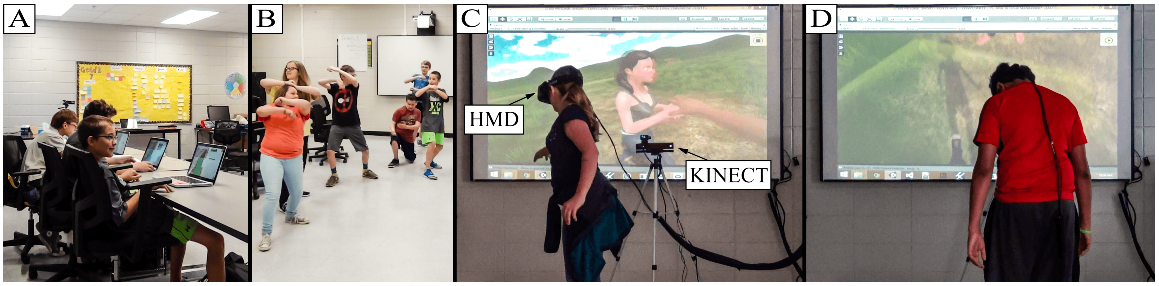


Figure 5.1: (A) Students using VEnvI on a laptop. (B) Students performing a dance activity. (C) System setup for the immersive embodied viewing metaphor. (D) Student looking at his virtual body and shadow.

was to allow students to look at their characters and their programmed choreographies in a first-person perspective, letting them examine their dances in an immersive manner, and encouraging active embodied learning. At any point during the VEnvI program, students could bring their programs into the embodied VR metaphor, evaluate their programs, think about modifications, to dance with and even learn from their characters.

5.3.2 Setting

With the aim of integrating VEnvI into the school curriculum, a local middle school was approached to be a partner in this study. The VEnvI program was created as part of the graphics communication class for the 6th and 7th grade students at the middle school. One of the goals of this class was to introduce the students to new technologies in a manner that enhanced their learning. The VEnvI program was structured around 6 weeks of activity, learning, and entertainment.

5.3.3 Participants

50 middle-school students between the ages of 11 and 14 participated in the VEnvI program (26 male, 24 female). Age was one of the factors in the analyses, where younger students (age 11/12, n=36) were compared with older students (age 13/14, n=14). Demographically, 64% of the participants identified as White, 14% identified as African American, 10% identified as Hispanic, 4% identified as Asian, and 8% as Multiracial/Other. In a between-subjects fashion, students were categorized into the two experiment conditions based on grade. The 6th grade students (n=28) were assigned to the non-immersive control condition (DVR), and the 7th grade students (n=22) were assigned to the immersive embodied VR condition (IEVR).

5.3.4 Measures

Various measures were employed in this study to obtain quantitative and qualitative insights regarding the participants in the VEnvI program.

Pre and post cognitive questionnaires were administered to the students in each of the two conditions to test their knowledge gain from the VEnvI activities. The test questions were inspired by and analyzed using the revised Bloom's and SOLO (Structure of Observed Learning Outcomes) taxonomies. Bloom's taxonomy is an established framework for educational goals [1, 16], and the SOLO taxonomy measures the degree of complexity to which a student understands a concept [12]. Using both taxonomies addresses not only the type of cognition but also the types of connections made between various concepts [82]. Leonard et al. describe this questionnaire in detail in their research [72]. Following are a few example questions:

- The first block below (Figure 5.2, Picture A) will cause the character to clap twice. How many times will the character clap with the second set of blocks (Figure 5.2, Picture B)?

Figure 5.2: Cognitive question to test the concept of loops.

- Based on the blocks below (Figure 5.3), will the character perform the "Cha Cha" or "Clap"?

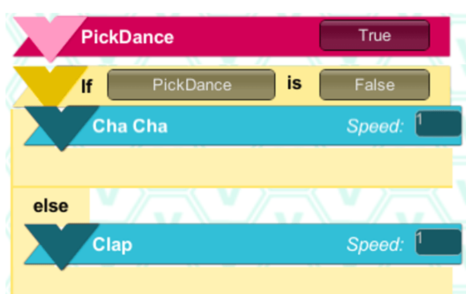


Figure 5.3: Cognitive question to test the concept of conditionals.

A presence survey was administered to measure the students' telepresence and social-presence, adapted from the Nowak and Biocca presence questionnaire. The presence questions were rated on a 10-point Likert scale (0=lowest and 10=highest on the scale), and the survey also asked the students to elaborate on their responses to gain further qualitative insights. Example questions included:

- Did you feel like the environment in which the character was dancing was real? Why?
- To what extent did your character seem real? Why?

A debriefing questionnaire was used to gather qualitative responses regarding students' overall experience, system usability and satisfaction. Example questions included:

- Did you think it was easy to learn and use VEnvI? Explain.
- What did you like/not like about VEnvI? Why?

Pre and post survey asking the students questions about their views on the field of computer science, to assess if the VEnvI program had any impact on changing their perceptions regarding computing and computer scientists.

- Do you believe that being able to make a computer program is an important skill? Why?
- Do you see yourself as a computer programmer? Why?

A demographic survey was administered to gather general information about the participants.

Video recordings of the sessions were collected to analyze the behaviors of the participants while using VEnvI.

5.3.5 Procedure

The weekly progression of activities is shown in Table 5.1. Both study groups (IEVR and DVR) received the same instructions and performed the same activities. However, students in the IEVR group additionally were able to visualize their programmed choreography in the immersive embodied virtual environment. Students in the IEVR condition were introduced to the Oculus Rift and the Kinect motion sensor, and were informed about the benefits and risks involved when using the VR equipment. In either condition, students were encouraged to dance with their characters.

Table 5.1: Weekly plan of activities for the VEnvI outreach program.

Week	Activity
1	• Introductions and pre-surveys. • Warm-up activities and introduction to dance.
2	• Introduction to programming. • Learning sequences and performing physical activities to demonstrate sequences. • Introduction to the VEnvI software. • Introduction to the immersive embodied metaphor (IEVR group). • Programming sequences in VEnvI.
3	• Learning loops and performing physical activities to demonstrate loops. • Learning parallelization and performing physical activities to demonstrate parallelization. • Programming loops and parallelization in VEnvI. • Students in the IEVR condition alternate between programming and viewing their programmed choreography in the immersive embodied metaphor.
4	• Learning variables and performing physical activities to demonstrate variables. • Learning conditionals and performing physical activities to demonstrate conditionals. • Learning functions and performing physical activities to demonstrate functions. • Programming variables, conditionals, and functions in VEnvI. • Students in the IEVR condition alternate between programming and viewing their programmed choreography in the immersive embodied metaphor.
5	• Programming for a dance challenge. • Students in the IEVR condition alternate between programming and viewing their programmed choreography in the immersive embodied metaphor.
6	• Viewing dance challenge performances on classroom projection display (DVR group) or HMD + classroom projection (IEVR group). • Post-surveys.

5.4 Results

5.4.1 Quantitative Results - Cognition

The questions in the cognition questionnaire were classified into two different categories: one based on Bloom's cognitive taxonomy and the other based on the Structure of Observed Learning Outcomes (SOLO) taxonomy. In analyzing the data gathered on the mean scores in each of the categories, a 2x2x2x2 mixed model repeated measures ANOVA was employed. The within-subjects factors were the mean pre and post cognition scores in each of the dimensions of a taxonomy, and the between subjects factors were gender (male vs. female), viewing metaphor (IEVR vs. DVR), and age category (younger 11/12 year old vs. older 13/14 year old students). Parametric tests have been used heavily on Likert scale data gathered in several human factors studies in prior HCI/VR research due their powerful nature of systematically investigating main and interaction effects in multi-factorial experiments. Here too, parametric ANOVA analyses have been conducted on the data, after carefully verifying that the underlying assumptions were met—namely the data in the samples were normally distributed and error variance between samples were equivalent. Thus, it was ensured that Box's test of equality of covariance matrix was not significant, Levene's test was conducted to verify homogeneity of variance, and Mauchly's test of sphericity was conducted to ensure that error variance in groups of samples are equivalent. Pairwise post-hoc tests for levels of the between subjects variables were conducted using Tukey HSD method, and between levels of the within subjects variable was conducted using the Bonferroni adjusted alpha method.

The significant main effects and interaction effects revealed by the ANOVA analysis for the cognitive results are shown in Table 5.2. Table 5.3 shows results from the post-hoc analyses. Figure 5.4 shows mean scores for the pre and post cognitive tests categorized by the various levels of Bloom and SOLO taxonomies.

5.4.1.1 Bloom's Taxonomy

- Remembering and Understanding

The ANOVA analysis revealed a significant main effect of session $F(1, 43) = 143.68$, $p < 0.001$, $\eta^2 = 0.77$, and a main effect of gender $F(1, 43) = 6.88$, $p = 0.012$, $\eta^2 = 0.14$. Post-hoc Tukey HSD pairwise comparisons revealed that older 13 and 14 year old students (M=48.21%, SD=22.92)

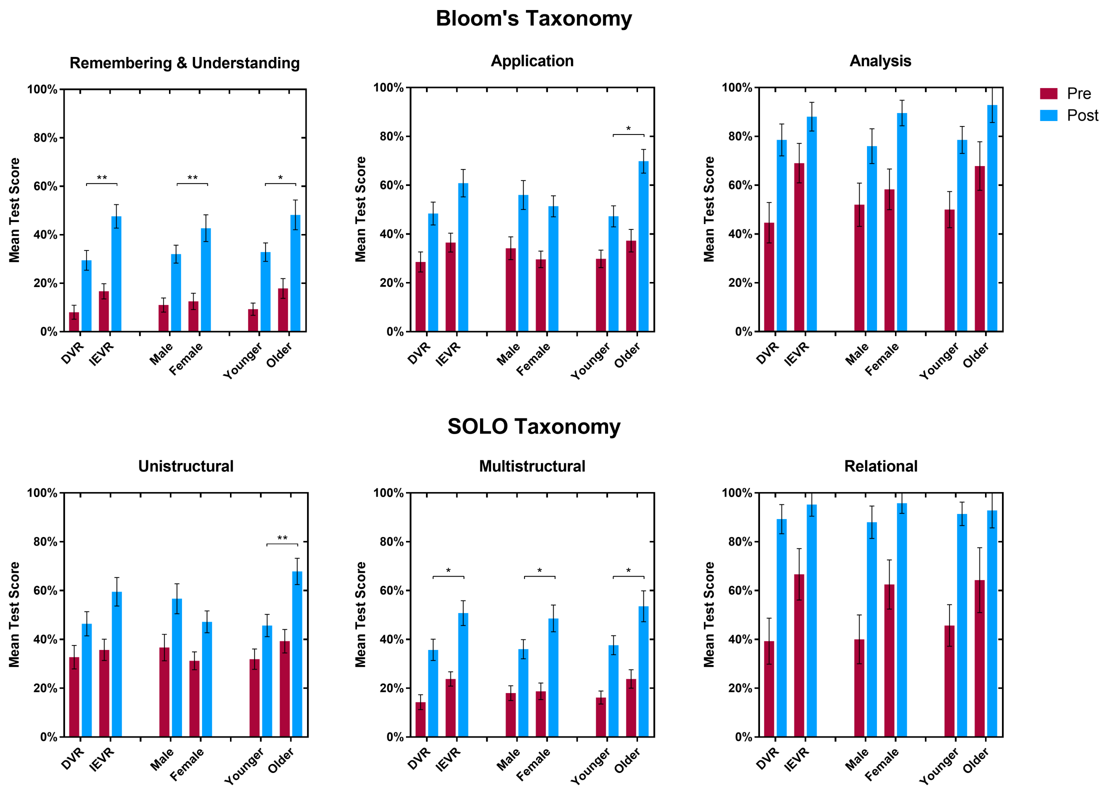


Figure 5.4: Mean cognitive test scores (pre and post) for the remembering and understanding (top-left), application (top-center), and analysis (top-right) categories of the Bloom's taxonomy, and the unistructural (bottom-left), multistructural (bottom-center), and relational (bottom-right) categories of the SOLO taxonomy. Scores were analyzed across the three factors of viewing metaphor, gender, and age. ** indicates a significant statistical difference with $p < 0.01$; * indicates a significant statistical difference with $p < 0.05$. Error bars represent standard error of the mean.

Table 5.2: Significant main and interaction effects from the ANOVA analysis for the cognitive questionnaire. *** indicates a significant statistical difference with $p < 0.001$; ** indicates a significant statistical difference with $p < 0.01$; * indicates a significant statistical difference with $p < 0.05$.

Bloom's Taxonomy									
Factors	Application			Analysis			Remembering & Understanding		
	F	p	η^2	F	p	η^2	F	p	η^2
Session	33.78	<0.001***	0.44	16.76	<0.001***	0.28	143.68	<0.001***	0.77
Gender							6.88	0.012*	0.14
Session x Age	5.85	0.02*	0.12						
Session x Gender							10.1	0.003**	0.19
Gender x Display	4.11	0.049*	0.068						
Session x Age x Gender	4.73	0.035*	0.053				6.39	0.015*	0.13
Session x Gender x Display	6.4	0.015*	0.13						

SOLO Taxonomy									
Factors	Unistructural			Multistructural			Relational		
	F	p	η^2	F	p	η^2	F	p	η^2
Session	18.795	<0.001***	0.3	118.12	<0.001***	0.73	20	<0.001***	0.32
Gender				6.08	0.018*	0.124	5.3	0.026*	0.11
Session x Age				5.11	0.029*	0.11			
Session x Gender				15.213	<0.001***	0.26			
Session x Display				4.18	0.047*	0.089			
Age x Gender	4.34	0.043*	0.092						
Gender x Display	5.25	0.027*	0.11						
Session x Age x Gender	8.21	0.006**	0.16						
Session x Gender x Display	8	0.007**	0.16						

Table 5.3: Descriptive statistics and post-hoc results from the quantitative analysis of the cognitive questionnaire. *** indicates a significant statistical difference with $p < 0.001$; ** indicates a significant statistical difference with $p < 0.01$; * indicates a significant statistical difference with $p < 0.05$.

Taxonomy	Level	Session	Gender	Age	Condition	N	μ	SD	p
Bloom	Application	Pre-test				50	33.20%	3.6	<0.001***
		Post-test				50	52.10%	4	
		Post-test		11-12		36	44.20%	4.8	0.035*
				13-14		14	68.10%	4.5	
	Analysis	Pre-test				50	55.10%	42.38	<0.001***
		Post-test				50	82.65%	31.54	
	Remembering & Understanding	Post-test	Female			24	42.71%	27.06	0.009**
			Male			26	32.00%	18.43	
		Post-test		11-12		36	32.85%	22.5	0.023*
				13-14		14	48.21%	22.92	
					IEVR	22	47.62%	22.22	0.005**
					DVR	28	29.46%	21.57	
SOLO	Unistructural	Pre-test				50	34.00%	23	<0.001***
		Post-test				50	52.04%	26.92	
		Post-test		11-12		36	26.91%	26.91	0.008**
				13-14		14	68.00%	20.11	
	Multistructural	Post-test	Female			24	48.61%	26.88	0.011*
			Male			26	36.00%	19.6	
		Post-test		11-12		36	37.61%	22.98	0.032*
				13-14		14	53.57%	23.73	
		Post-test			IEVR	22	50.79%	23.25	0.028*
					DVR	28	35.71%	23	
	Relational	Pre-test				50	51.00%	50	0.027*
		Post-test				50	91.83%	27.66	
			Female			24	79.15%	34.5	0.027*
			Male			26	64.00%	41.5	

scored significantly higher as compared to younger 11 and 12 year old students (M=32.85%, SD=22.50) in the post test session with regards to mean remembering and understanding scores, p = *0.023*. Also, female participants (M=42.71%, SD=27.06) scored significantly higher as compared to male participants (M=32%, SD=18.43) in the post test session, p = *0.009*. Further, participants in the VR viewing condition (M=47.62%, SD=22.22) scored significantly higher as compared to participants in the control condition (M=29.46%, SD=21.57), p = *0.005*. Overall, students were able to remember and understand cognitive information acquired from the VEnvI experience, and this effect was higher in older students, female participants, and those who experienced the VR condition.

- Application

For the main effect of session, post-hoc Bonferroni tests revealed that overall participants scored significantly higher in the post-test session (M=52.1%, SD=4.0) as compared to the pre-test session (M=33.2%, SD=3.6) in application scores, p <*0.001*. Post-hoc Tukey HSD tests revealed that in post-test application scores slightly older 13 and 14 year old students (M=68.10%, SD=4.5) scored significantly higher than slightly younger 11 and 12 year old students (M=44.2%, SD=4.8), p = *0.035*. Overall, students were able to learn how to apply their cognitive knowledge acquired from the VEnvI experience, and this effect was higher in older students.

- Analysis

The ANOVA analysis revealed a significant main effect of session F(1, 43) = 16.76, p <*0.001*, $\eta^2 = 0.28$. Overall mean analysis scores revealed that participants scored significantly higher in the post-test session (M=82.65%, SD=31.54) as compared to the pre-test session (M=55.10%, SD=42.38). Students were able to learn how to analyze and examine various cognitive ideas post VEnvI experience.

5.4.1.2 SOLO Taxonomy

- Unistructural

For the main effect of session, participants scored significantly higher in the post-test session (M=52.04%, SD=26.92) as compared to the pre-test session (M=34%, SD=23) with respect to mean unistructural scores, p <*0.001*. In the post-test session, older participants (M=68%, SD=20.11) scored significantly higher than younger participants (M=26.91%, SD=26.91), p = *0.008*. Overall, students were able to learn simple cognitive procedures post VEnvI experience, and this effect was higher in older students.

- Multistructural

The ANOVA analysis revealed a main effect of session F(1, 43) = 118.12, $p < 0.001$, $\eta^2 = 0.73$, and a main effect of gender F(1, 43) = 6.08, $p = 0.018$, $\eta^2 = 0.124$. Pairwise post-hoc analysis revealed that older students (M=53.57%, SD=23.73) scored significantly higher than younger students (M=37.61%, SD=22.98) in the post-test session with regards to mean multistructural scores, $p = 0.032$. Also, female participants (M=48.61%, SD=26.88) scored significantly higher than male participants (M=36%, SD=19.6) in the post-test session, $p = 0.011$. Further, participants in the VR conditions (M=50.79%, SD=23.25) scored significantly higher with respect to multistructural scores as compared to participants in the control condition (M=35.71%, SD=23), $p = 0.028$. Overall, students learned to use a combination of cognitive skills post VEnvI experience, and this effect was higher in older students, female participants, and those who experienced the VR condition.

- Relational

The ANOVA analysis revealed a significant main effect of session, F(1, 43) = 20, $p < 0.001$, $\eta^2 = 0.32$, and a significant main effect of gender, F(1, 43) = 5.30, $p = 0.026$, $\eta^2 = 0.11$. Overall, participants scored significantly higher in the post-test session (M=91.83%, SD=27.66) as compared to the pre-test session (M=51%, SD=50), $p = 0.027$. Generally, female participants (M=79.15%, SD=34.5) scored significantly higher as compared to male participants (M=64%, SD=41.5), $p = 0.027$ respect to the Solo Relational questions. Students were able to relate to the cognitive knowledge acquired from the VEnvI experience, and this effect was higher in female students.

5.4.2 Quantitative Results - Presence

The three independent factors that were considered for analysis were age of the students (younger students were 11 and 12 years old, and older students were 13 and 14 years old), Condition (IEVR vs. DVR), and the gender of the participants. The presence dependent variables consisted of five questions related to telepresence, four questions related to social-presence, one question related to identity, and one related to embodiment. Each of the questions assessed a sub-dimension of the presence factors they measured, and were rated by the students on a 1 (Not Intense) to 10 (Very

Intense) scale. The quantitative results were treated with a univariate 2x2x2 Independent Samples ANOVA on factors of Age (2 levels), Condition (2 levels) and Gender (2 levels) on each dependent measure of presence. In each of the tests, Levene's test of equality of error variances was tested to insure that error variances in the groups of samples were statistically equivalent before the ANOVA analysis was further conducted.

The significant main effects and interaction effects revealed by the ANOVA analysis for the presence results are shown in Table 5.4. Table 5.5 shows results from the post-hoc analysis.

Table 5.4: Significant main and interaction effects from the ANOVA analysis for the presence questionnaire. *** indicates a significant statistical difference with $p < 0.001$; ** indicates a significant statistical difference with $p < 0.01$; * indicates a significant statistical difference with $p < 0.05$.

Category	Question	Factor	F	p	η^2
Telepresence	How intense was your experience using VEnvI?	Age x Gender	4.75	0.036*	0.12
	Did you feel like you were inside the environment you saw?	Condition	2.5	0.013*	0.06
	Did you feel like you were immersed in the environment you saw?	Condition	4.031	0.05*	0.086
Social-presence	To what extent did you feel like you were in the same room as your character?	Condition	8.76	0.005**	0.169
	To what extent did your character seem real?	Condition	3.31	0.046*	0.071

With regards to the telepresence question *"How intense was your experience using VEnvI?"* the 3-way ANOVA analysis revealed a significant interaction effect of age by gender, $F(1, 43) = 4.75$, $p = 0.036$, $\eta^2 = 0.12$. Post-hoc analysis performed using Tukey HSD revealed that among female students, older students (M=9.5, SD=0.41) rated the intensity of the VEnvI experience significantly higher than younger students (M=6.45, SD=2.62), $p = 0.033$. Among older students, female students (M=9.50, SD=0.41) rated the intensity of the VEnvI experience significantly higher than male students (M=7.05, SD=0.64), $p < 0.001$.

With regards to the telepresence question *"Did you feel like you were inside the environment you saw?"* the 3-way ANOVA analysis revealed a significant main effect of condition, $F(1, 43) = 2.5$, $p = 0.013$, $\eta^2 = 0.06$. Post-hoc pairwise analysis performed using Tukey HSD revealed that

Table 5.5: Descriptive statistics and post-hoc results from the quantitative analysis of the presence questionnaire. *** indicates a significant statistical difference with $p < 0.001$; ** indicates a significant statistical difference with $p < 0.01$; * indicates a significant statistical difference with $p < 0.05$.

Category	Question	Gender	Age	Condition	N	μ	SD	p
Tele-presence	How intense was your experience using VEnvI?	Female	11-12		20	6.5	2.62	0.033*
			13-14		4	9.5	0.41	
		Female	13-14		4	9.5	0.41	<0.001***
		Male			10	7.05	0.64	
	Did you feel like you were inside the environment you saw?			IEVR	22	6.43	2.51	0.033*
				DVR	28	4.75	3.14	
	Did you feel like you were immersed in the environment you saw?			IEVR	22	6.7	2.71	0.026*
				DVR	28	5.071	2.78	
Social-presence	To what extent did you feel like you were in the same room as your character?			IEVR	22	6.524	2.71	0.002**
				DVR	28	4.089	3.08	
	To what extent did your character seem real?			IEVR	22	5.57	2.47	0.4*
				DVR	28	4.21	2.67	

participants in the VR viewing condition (M=6.43, SD=2.51) scored higher than participants in the control condition (M=4.75, SD=3.14), p = *0.033*.

With regards to the telepresence question *"Did you feel like you were immersed and surrounded by the environment you saw?"* the 3-way ANOVA analysis revealed a significant main effect of condition, F(1, 43) = 4.031, p = *0.050*, $\eta^2 = 0.086$. Post-hoc pairwise analysis performed using Tukey HSD revealed that participants in the VR viewing condition (M=6.70, SD=2.71) rated the feeling significantly higher than participants in the control condition (M=5.071, SD=2.78), p = *0.026*.

With regards to the social presence question *"To what extent did you feel like you were in the same/room as your character?"* the 3-way ANOVA analysis revealed a significant main effect of condition, F(1, 43) = 8.76, p = *0.005*, $\eta^2 = 0.169$. Post-hoc pairwise analysis performed using Tukey HSD revealed that participants in the VR viewing condition (M=6.524, SD=2.71) rated the feeling significantly higher than participants in the control condition (M=4.089, SD=3.08), p = *0.002*.

With regards to the social presence question *"To what extent did your character seem real?"* the 3-way ANOVA analysis revealed a significant main effect of condition, F(1, 43) = 3.310, p = *0.046*, $\eta^2 = 0.071$. Post-hoc pairwise analysis performed using Tukey HSD revealed that participants in the VR viewing condition (M=5.57, SD=2.47) rated the realism of their character significantly higher than participants in the control condition (M=4.21, SD=2.67), p = *0.40*.

The 3-way ANOVA analysis did not reveal any significant effects in the participants' scores on the identity dimension of *"Did you feel like the character was yourself?"* or in the embodiment dimension of *"How much did you feel like dancing with the character?"* between any of the levels of the independent factors.

5.4.3 Attitude towards programming

In a pre and post fashion, the students were asked whether they knew what a computer programming language is and whether they saw themselves as a computer programmer (Figure 5.5). A majority of the students (n=37) reported not knowing what a computer programming language is, and only a few students (n=18) identified themselves as a programmer. After finishing the VEnvI program, fewer students reported that they did not know what a computer programming language is (n=20), and a majority of students identified themselves to be a computer programmer (n=28). Thus, VEnvI was able to alter students' attitudes towards programming.

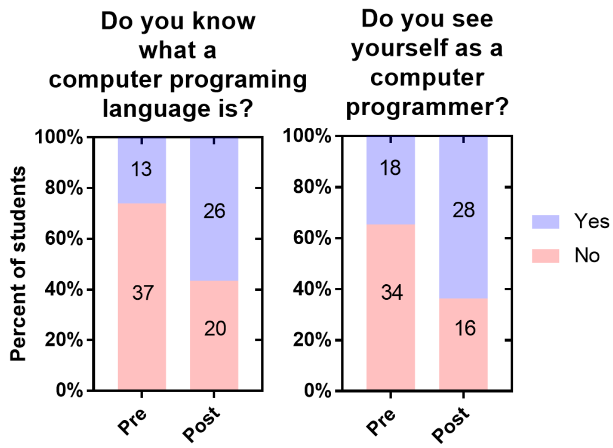


Figure 5.5: Students' pre and post reports on their knowledge and attitude towards programming.

5.4.4 Qualitative Results

The students were asked open ended questions to gain further insights on their experiences within VEnvI. Overall, the students responded positively towards VEnvI. Most of the students specifically used words such as *fun, engaging, interesting, exciting, enjoyable, great, and cool* to describe their experience (n=41). One student quoted saying *"It was fun while having the people dancing like the music was their life."* This positive experience can be attributed to the multi-modal VEnvI curriculum, supported by quotes such as *"We did a lot of dancing and activities out of our seats. I got to answer and ask questions and I was very involved in the activities."* and *"I felt like I was being prioritized as a student."*

Immersion within VR played an important role in the student's experiences, eliciting expressions such as *"It did feel like I was very much so there. Because my arms moved and then the character's arms moved, it felt real."* This was the goal of developing the immersive embodied viewing metaphor within VEnvI. Students expressed experiencing high telepresence with quotes such as *"Because when we used the Oculus it made me feel like I was actually in a new environment"* and *"I felt like I was walking in (the environment)."* One student commented on the realism of the virtual grassy environment by saying *"I'd get allergies from being around all that pollen."* On the other hand, students in the control condition expressed mixed reactions regarding the realism of the environment, with students expressively mentioning *"when I see the environment I can't be inside,"* and *"It looked like I was playing a videogame."* Social presence experiences were also reported high by the students in the immersive VR condition, with quotes such as *"I felt like I was touching her"* and *"she was right in front of me."* The students in the control condition, however, reported lower telepresence in their qualitative responses stating *"Your character is in a computer. We are inside (the classroom) and they are outside (in the grassy field)"* and that viewing the character on the desktop screen *"was like facetime (video conferencing) but they were being controlled by me."*

Negative feedback for immersion within the immersive VR viewing resulted from limited tracking capabilities of the Kinect tracker and being able to see screen pixels due to the resolution of the Oculus Rift DK2. The Kinect would sometimes lose tracking of the students, and one student exclaimed *"You can't move individual fingers."* Students desired more variation within the environment by suggesting additions of more arenas to dance in and more objects within the environment to interact with. Students desired the ability to manipulate objects within the VR world and use them as props for the dance sequences. Students also desired the ability to program multiple characters in order to choreograph partner or group dances.

Overall, students reported that VEnvI was very intuitive and easy to use, and the *"block programming helped in building confidence in programming, because you didn't need the actual code."* The VEnvI environment was *"easy to navigate around"* and they liked how they *"get to play games and listen to music while programming."* The immersive virtual metaphor was greatly influential in providing an engaging experience to the students with students saying *"I forgot it was a computer program"* and that with VR *"you watch your creation come to life!"*

5.5 Conclusion

VEnvI was successful in developing computational thinking in middle-school students and enhancing their interest in the field of computer science. Results showed that immersive embodied virtual reality (IEVR) has significant potential in enhancing learning of science, technology, engineering, and math (STEM) concepts, and VR can be propitiously integrated into the middle-school curriculum in order to augment existing teaching methodologies. VEnvI's IEVR metaphor was able to provide the pedagogical benefits of embodied cognition, which has rich support in literature for enhanced learning. One limitation of this study was to determine if a virtual self-avatar is essential in facilitating embodied cognition, which is tackled in the next chapter via an empirical analysis comparing VEnvI in a desktop-only system (DVR) to VEnvI's immersive VR metaphor with a virtual self-avatar (IEVR) and no self-avatar (IVR).

Chapter 6

Objective 3: DVR vs. IVR vs. IEVR

6.1 Motivation

Objective 1 introduced the VEnvI pedagogical software and the immersive embodied viewing metaphor (IEVR) built as an extension to VEnvI. It also described an initial exploratory analysis to anecdotally determine the feasibility of the IEVR metaphor, and showed that students were excited about this novel technology. Objective 2 introduced the VEnvI curriculum which brings dance, programming, and immersive VR into the middle-school classroom. A desktop-only version of VEnvI (DVR) was compared with the immersive embodied metaphor (IEVR) in a thorough empirical analysis. It was shown that the immersive embodied VR (IEVR) within VEnvI achieved higher success in enhancing computational learning among the students as compared to the DVR condition, evidenced by the higher scores in the remembering and understanding level of the Bloom's taxonomy, and the multistructural level of the SOLO taxonomy. Objective 3 aims to uncover the effects of self-embodiment by means of a self-avatar on cognition by comparing the immersive embodied metaphor (IEVR) within VEnvI to the IVR version lacking self-embodiment. The goal of this study is to determine if embodied immersion leads to embodied cognition. This chapter provides an overall analysis of the immersive embodied continuum (DVR vs. IVR vs. IEVR) to provide insights on the role of immersion and embodiment on cognition and computational thinking.

6.2 Research Questions

This study aimed to answer the following research questions:

1. Is embodied immersion an important factor for facilitating embodied cognition?
2. Does embodied immersion elicit greater presence as compared to immersive VR alone?
3. Do immersive embodied experiences within VR have greater impact on students' attitudes towards dance and computing as compared to immersion alone?

6.3 Study Design

6.3.1 System

The VEnvI DVR and IEVR systems are described in detail in chapter 3. To create the IVR metaphor without the self-embodiment, the self-avatar was removed from the VR version of VEnvI. Students' bodies were still tracked using the Microsoft Kinect tracker to enable the students to walk around the virtual environment, however, the body-tracking data was not applied to a virtual body. Just like the IEVR metaphor, students could see the grassy floor, the dance stage, and their customized character dancing on a stage, as well as a virtual sky. However, when they looked down in the IVR metaphor they would not see a co-located virtual body or a shadow of their virtual body.

6.3.2 Setting

This study was conducted at a partnering middle school in four groups: sixth and seventh grade students from a graphics communication class, and students in the same two grades from a dance aerobics class. There was no overlap in students between the two classes. The study was offered as an opt-in activity for the graphics communication class and was mandatory for all students of the dance aerobics class. Informed consent was obtained from all students whose data was used in this study and from their parents following the guidelines approved by the Institutional Review Board.

6.3.3 Participants

40 middle-school students from the 6th and 7th grade (22 from 6th grade, 18 from 7th) between the ages of 11 and 14 (28 aged 11/12, 12 aged 13/14) participated in the VEnvI program (6 male, 34 female). From the four groups of students, each group was randomly assigned to either the immersive VR condition with self-embodiment (IEVR, N=15) or the immersive VR condition without self-embodiment (IVR, N=25). Demographically, 27 students identified as White, 5 as African American, 2 as Asian, 1 as Hispanic, 4 as Multiracial, and 1 as Other/Unspecified.

The data from this study was combined with student data from the previous study (chapter 5) to increase the power of the analysis and to be able to compare all three conditions (DVR vs. IVR vs. IEVR), leading to a total of 90 participants. The distribution of students is shown in table 6.1.

Table 6.1: Distribution of students across the three conditions of DVR, IVR, and IEVR, and according to gender and age.

Condition	Age		Gender		Total
DVR	11-12	28	Female	16	28
	13-14	0	Male	12	
IVR	11-12	16	Female	26	26
	13-14	10	Male	0	
IEVR	11-12	20	Female	17	36
	13-14	16	Male	19	
Total	11-12	64	Female	59	90
	13-14	26	Male	31	

6.3.4 Measures

The measures employed were the same as objective 2 (chapter 5). To measure knowledge gain, pre and post cognitive tests based on various levels of Bloom and SOLO taxonomies were administered to the students. Presence was measured using a questionnaire adapted from the Nowak and Biocca presence inventory. A debriefing questionnaire was used to gather qualitative responses regarding students' overall experience, system usability and satisfaction. A pre and post survey was administered asking the students questions about their views on the field of computer science, to assess if the three conditions within the VEnvI program had any impact on changing their perceptions regarding computing and computer scientists. A demographic survey was administered to gather general information about the participants. Finally, video recordings of the sessions were collected to analyze the behaviors of the participants while using VEnvI.

6.3.4.1 Creativity

An additional measure in this objective was to assess performance of the students in the form of creativity by analyzing students' programmed choreographies within VEnvI. The scoring criterion for this purpose was developed via an adaptation of the system created by Isaac and Babu [55]. Elements such as number of unique and repeated move blocks, number of unique and repeated programming concept blocks (CS blocks), highest level in the hierarchy of nested blocks, and the duration (in seconds) were extracted from the saved VEnvI files of the final programmed performance for each student. Unique blocks within the programmed choreography represented variety. Therefore, each unique occurrence of a movement block or a CS block was awarded twice as many points as those gained when using the same blocks repeatedly. Nested blocks within the program represented complexity, and the highest level in the nesting hierarchy showed the maximum complexity reached by the student when creating the programmed choreography. Finally, the duration of the choreography was also taken into account with longer running programs getting more points. Students were awarded 10 points for every 30 seconds of the program (calculated as 1/3 points per second). The scoring criterion for calculating the creativity score from the programmed performances is shown in table 6.2.

Table 6.2: Scoring criterion for creativity within VEnvI.

Scoring Element	Points
Move block	1 per block
Unique move block	2 per block
CS block	5 per block
Unique CS block	10 per block
Highest level in hierarchy	5 per level
Duration	1/3 per second

Table 6.3: Weekly plan of activities for the VEnvI outreach program.

Week	Activity
1	• Introductions and pre-surveys. • Warm-up activities and introduction to dance.
2	• Introduction to programming. • Learning sequences and performing physical activities to demonstrate sequences. • Introduction to the VEnvI software. • Introduction to the immersive embodied metaphor. • Programming sequences in VEnvI.
3	• Learning loops and performing physical activities to demonstrate loops. • Learning parallelization and performing physical activities to demonstrate parallelization. • Programming loops and parallelization in VEnvI. • Students alternate between programming and viewing their programmed choreography in the immersive VR metaphor with self-embodiment (IEVR condition) or without self-embodiment (IVR condition).
4	• Learning variables and performing physical activities to demonstrate variables. • Learning conditionals and performing physical activities to demonstrate conditionals. • Learning functions and performing physical activities to demonstrate functions. • Programming variables, conditionals, and functions in VEnvI. • Students alternate between programming and viewing their programmed choreography in the immersive VR metaphor with self-embodiment (IEVR condition) or without self-embodiment (IVR condition).
5	• Programming for a dance challenge. • Students alternate between programming and viewing their programmed choreography in the immersive VR metaphor with self-embodiment (IEVR condition) or without self-embodiment (IVR condition).
6	• Viewing dance challenge performances on HMD and classroom projection display. • Post-surveys.

6.3.5 Procedure

The weekly progression of activities for this study is shown in table 6.3. Both study groups (IVR and IEVR) received the same instructions and performed the same activities. Students in the IEVR group visualized their programmed choreography in the immersive embodied virtual environment with a co-located self-avatar which mimicked their movements, whereas the self-avatar was absent in the IVR condition. Students in both conditions were introduced to the Oculus Rift and the Kinect motion sensor, and were informed about the benefits and risks involved when using the VR equipment. In either condition, students were encouraged to dance with their characters.

6.4 Results

6.4.1 Quantitative Results - Cognition

The questions in the cognition questionnaire were analyzed using two principal cognitive taxonomies: the Bloom's revised cognitive taxonomy and the Structure of Observed Learning Outcomes (SOLO) taxonomy. In analyzing the data gathered on the mean scores in each of the categories, a 2x3x2 mixed-model repeated measures ANOVA was employed. The within-subjects factors were the mean pre and post cognition scores in each of the dimensions of a taxonomy, and the between subjects factors were viewing metaphor (DVR vs. IVR vs. IEVR), and age category (younger 11-12 year old vs. older 13-14 year old). Parametric ANOVA analyses were conducted on the data after carefully verifying that the underlying assumptions were met—namely the data in the samples were normally distributed and error variance between samples were equivalent. Thus, it was ensured that Box's test of equality of covariance matrix was not significant, Levene's test was conducted to verify homogeneity of variance, and Mauchly's test of sphericity was conducted to ensure that error variance in groups of samples are equivalent. Pairwise post-hoc tests for levels of the between subjects variables were conducted using Tukey HSD method, and between levels of the within subjects variable was conducted using the Bonferroni adjusted alpha method.

The significant main effects and interaction effects revealed by the ANOVA analysis for the cognitive results are shown in Table 6.4. Table 6.5 shows results from the post-hoc analyses. Figure 6.1 shows mean scores for the pre and post cognitive tests categorized by the various levels of Bloom and SOLO taxonomies.

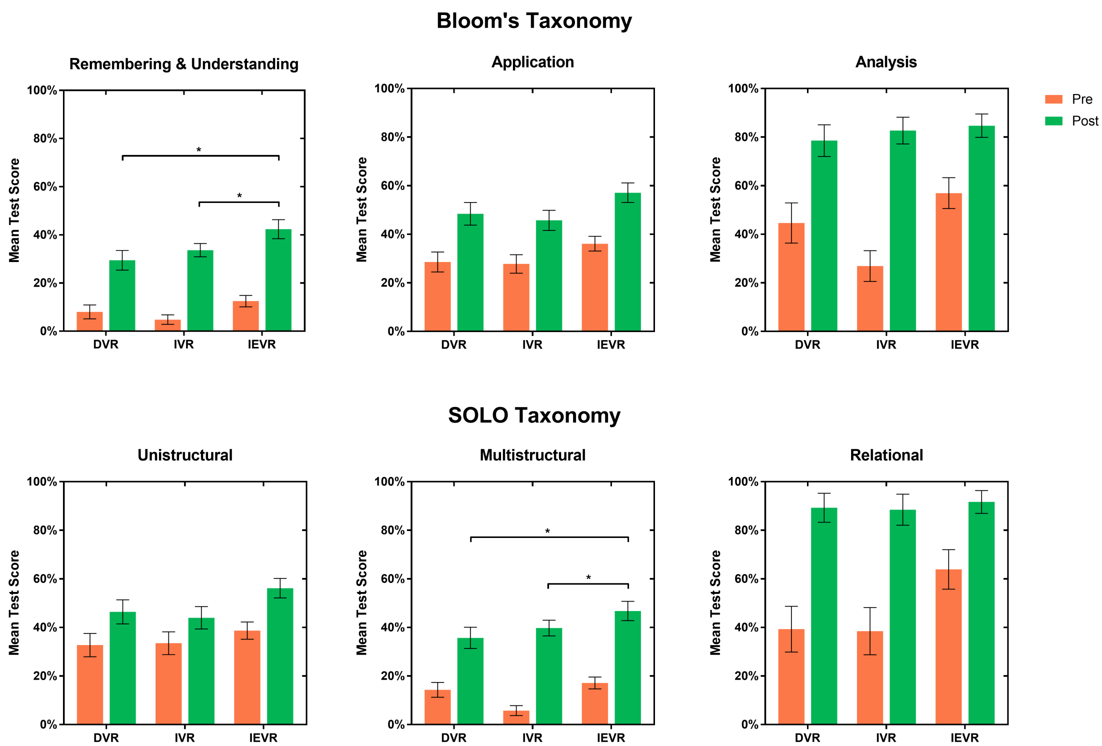


Figure 6.1: Mean cognitive test scores for the remembering and understanding (top-left), application (top-center), and analysis (top-right) categories of the Bloom's taxonomy, and the unistructural (bottom-left), multistructural (bottom-center), and relational (bottom-right) categories of the SOLO taxonomy. * indicates a significant statistical difference with $p < 0.05$. Error bars represent standard error of the mean.

Table 6.4: Significant main and interaction effects from the ANOVA analysis for the cognitive questionnaire. *** indicates a significant statistical difference with $p < 0.001$; ** indicates a significant statistical difference with $p < 0.01$; * indicates a significant statistical difference with $p < 0.05$.

	Bloom's Taxonomy								
Factors	Application			Analysis			Remembering & Understanding		
	F	p	η^2	F	p	η^2	F	p	η^2
Session	66.05	<0.001***	0.45	59.88	<0.001***	0.42	186.92	<0.001***	0.70
Condition							3.43	0.037*	0.08
Age	8.07	0.006**	0.09						
Session x Condition							3.07	0.05*	0.07
	SOLO Taxonomy								
	Unistructural			Multistructural			Relational		
	F	p	η^2	F	p	η^2	F	p	η^2
Session	29.64	<0.001***	0.27	175.58	<0.001***	0.68	48.76	<0.001***	0.37
Condition				3.20	0.046*	0.07			
Age	7.40	0.008**	0.08						

6.4.1.1 Bloom's Taxonomy

- Remembering and Understanding

The ANOVA analysis revealed a significant main effect of session, F(1,82) = 186.92, $p < 0.001$, $\eta^2 = 0.70$, a main effect of condition, F(1,82) = 3.43, $p = 0.037$, $\eta^2 = 0.08$, and a session by condition interaction effect, F(1,82) = 3.07, $p = 0.05$, $\eta^2 = 0.07$.

Post-hoc Bonferroni tests revealed that overall participants scored significantly higher in the post-test session (M=35.83%, SD=21.22) as compared to the pre-test session (M=8.89%, SD=13.67), $p < 0.001$. Post-hoc Tukey HSD pairwise comparisons revealed that students in the IEVR condition (M=42.36%, SD=23.77) scored significantly higher in the post-test session than students in the IVR condition (M=33.65, SD=14.04), $p = 0.05$, and students in the IEVR condition also scored significantly higher than the students in the DVR condition (M=29.46, SD=21.57), $p < 0.05$.

- Application

The ANOVA analysis revealed a significant main effect of session, F(1,82) = 66.05, $p < 0.001$, $\eta^2 = 0.45$, and a main effect of age, F(1,82) = 8.07, $p = 0.006$, $\eta^2 = 0.09$.

Table 6.5: Descriptive statistics and post-hoc results from the quantitative analysis of the cognitive questionnaire. *** indicates a significant statistical difference with $p < 0.001$; ** indicates a significant statistical difference with $p < 0.01$; * indicates a significant statistical difference with $p < 0.05$.

Taxonomy	Level	Session	Condition	Age	N	μ	SD	p
Bloom	Remembering & Understanding	Pre-test			90	8.89	13.67	<0.001***
		Post-test			90	35.83	21.22	
		Post-test	IEVR		36	42.36	23.77	0.04*
			DVR		28	29.46	21.57	
		Post-test	IEVR		36	42.36	23.77	0.05*
			IVR		26	33.65	14.04	
	Application	Pre-test			90	31.36	19.82	<0.001***
		Post-test			90	51.11	23.78	
		Post-test		11-12	64	46.70	23.02	0.005**
				13-14	26	61.97	22.48	
	Analysis	Pre-test			90	44.44	39.98	<0.001***
		Post-test			90	82.22	30.27	
SOLO	Unistructural	Pre-test			90	35.34	23.36	0.001***
		Post-test			90	49.60	24.96	
		Post-test		11-12	64	45.31	24.30	0.01**
				13-14	26	60.17	23.82	
	Multistructural	Pre-test			90	12.96	14.73	<0.001***
		Post-test			90	41.30	21.96	
		Post-test	IEVR		36	46.76	23.85	0.046*
			DVR		28	35.71	23.00	
		Post-test	IEVR		36	46.76	23.85	0.05*
			IVR		26	39.74	16.38	
	Relational	Pre-test			90	48.89	50.27	<0.001***
		Post-test			90	90.00	30.17	

Post-hoc Bonferroni tests revealed that overall participants scored significantly higher in the post-test session (M=51.11%, SD=23.78) as compared to the pre-test session (M=31.36%, SD=19.82), $p < 0.001$. Post-hoc Tukey HSD pairwise comparisons revealed that older students (M=61.97, SD=22.48) scored significantly higher in the post-test session as compared to younger students (M=46.70, SD=23.02), $p < 0.01$.

- Analysis

The ANOVA analysis revealed a significant main effect of session, F(1,82) = 59.88, $p < 0.001$, $\eta^2 = 0.42$. Post-hoc Bonferroni tests revealed that overall participants scored significantly higher in the post-test session (M=82.22%, SD=30.27) as compared to the pre-test session (M=44.44%, SD=39.98), $p < 0.001$.

6.4.1.2 SOLO Taxonomy

- Unistructural

The ANOVA analysis revealed a significant main effect of session, F(1,82) = 29.64, $p < 0.001$, $\eta^2 = 0.27$, and a significant main effect of age, F(1,82) = 7.40, $p = 0.008$, $\eta^2 = 0.08$.

Post-hoc Bonferroni tests revealed that overall participants scored significantly higher in the post-test session (M=49.6%, SD=24.96) as compared to the pre-test session (M=35.34%, SD=23.36), $p = 0.001$. Post-hoc Tukey HSD pairwise comparisons revealed that older students (M=60.17, SD=23.82) scored significantly higher in the post-test session as compared to younger students (M=45.31, SD=24.30), $p < 0.01$.

- Multistructural

The ANOVA analysis revealed a significant main effect of session, F(1,82) = 175.58, $p < 0.001$, $\eta^2 = 0.68$, and a significant main effect of condition, F(1,82) = 3.20, $p = 0.046$, $\eta^2 = 0.07$.

Post-hoc Bonferroni tests revealed that overall participants scored significantly higher in the post-test session (M=41.3%, SD=21.96) as compared to the pre-test session (M=12.96%, SD=14.73), $p < 0.001$. Post-hoc Tukey HSD pairwise comparisons revealed that students in the IEVR condition (M=46.76%, SD=23.85) scored significantly higher in the post-test session than students in the IVR condition (M=39.74, SD=16.38), $p = 0.05$, and students in the IEVR condition also scored significantly higher than the students in the DVR condition (M=35.71, SD=23.00), $p < 0.05$.

- Relational

The ANOVA analysis revealed a significant main effect of session, F(1,82) = 48.76, $p < 0.001$, $\eta^2 = 0.37$.

Post-hoc Bonferroni tests revealed that overall participants scored significantly higher in the post-test session (M=90%, SD=30.17) as compared to the pre-test session (M=48.89%, SD=50.27), $p < 0.001$.

6.4.2 Quantitative Results - Presence

The two independent factors that were considered for analysis were condition (DVR vs. IVR vs. IEVR), and the age of the participants (younger 11-12 year old vs. older 13-14 year old). The presence dependent variables consisted of five questions related to telepresence, three questions related to social-presence, two question related to identity, and one related to embodiment. Each of the questions assessed a sub-dimension of the presence factors they measured, and were rated by the students on a 1 (Not Intense) to 10 (Very Intense) scale. The quantitative results were treated with a univariate 3x2 independent samples ANOVA on factors of condition (IEVR vs IVR vs DVR) and age (younger 11-12 year old vs. older 13-14 year old) on each dependent measure of presence. In each of the tests, Levene's test of equality of error variances was tested to ensure that error variances in the groups of samples were statistically equivalent before the ANOVA analysis was further conducted.

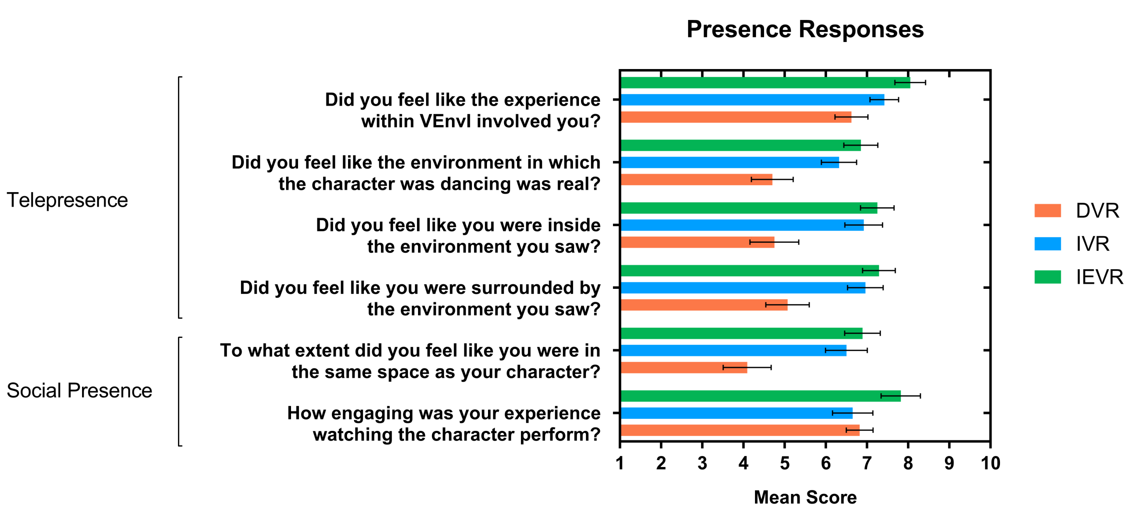


Figure 6.2: Descriptive statistics of the quantitative responses for telepresence and social presence. Error bars represent standard error of the mean.

Figure 6.2 shows the means and standard error of the quantitative presence responses. The significant main effects and interaction effects revealed by the ANOVA analysis for the presence results are shown in Table 6.6. Table 6.7 shows results from the post-hoc analyses.

Table 6.6: Significant main and interaction effects from the ANOVA analysis for the presence questionnaire. *** indicates a significant statistical difference with $p < 0.001$; ** indicates a significant statistical difference with $p < 0.01$; * indicates a significant statistical difference with $p < 0.05$.

Category	Question	Factor	F	p	η^2
Telepresence	Did you feel like the experience within VEnvI involved you?	Condition	3.36	0.039*	0.07
	Did you feel like the environment in which the character was dancing was real?	Condition	5.11	0.008**	0.11
	Did you feel like you were inside the environment you saw?	Condition	7.75	0.001***	0.15
	Did you feel like you were surrounded by the environment you saw?	Condition	7.00	0.002**	0.14
Social-presence	To what extent did you feel like you were in the same space as your character?	Condition	8.97	<0.001***	0.17
	How engaging was your experience watching the character perform?	Condition	4.60	0.036*	0.07

With regards to telepresence question, *"Did you feel like the experience within VEnvI involved you?"* the ANOVA analysis revealed a significant main effect of condition, F(1,89) = 3.36, $p = 0.039$, $\eta^2 = 0.07$. Overall, participants in the IEVR condition rated their experience to be significantly more involving (M=8.05, SD=1.96) as compared to those in the DVR condition (M=6.62, SD=2.04), $p < 0.05$.

With regards to telepresence question, *"Did you feel like the environment in which the character was dancing was real?"* the ANOVA analysis revealed a significant main effect of condition, F(1,89) = 5.11, $p = 0.008$, $\eta^2 = 0.11$. Overall, participants in the IEVR condition rated their environment to be significantly more real (M=6.85, SD=2.11) as compared to those in the DVR condition (M=4.70, SD=2.69), $p < 0.01$. Also, participants in the IVR condition (M=6.32, SD=2.73) rated this feeling to be significantly higher as compared to those in the DVR condition (M=4.70, SD=2.69), $p < 0.05$.

With regards to telepresence question, *"Did you feel like you were inside the environment you*

Table 6.7: Descriptive statistics and post-hoc results from the quantitative analysis of the presence questionnaire. *** indicates a significant statistical difference with $p < 0.001$; ** indicates a significant statistical difference with $p < 0.01$; * indicates a significant statistical difference with $p < 0.05$.

Category	Question	Condition	N	μ	SD	p
Tele-presence	Did you feel like the experience within VEnvI involved you?	IEVR	36	8.05	1.96	0.03*
		DVR	28	6.62	2.04	
	Did you feel like the environment in which the character was dancing was real?	IEVR	36	6.85	2.11	0.006**
		DVR	28	4.70	2.69	
		IVR	26	6.32	2.73	0.044*
		DVR	28	4.22	2.67	
	Did you feel like you were inside the environment you saw?	IEVR	36	7.25	2.45	0.001***
		DVR	28	4.75	3.15	
		IVR	26	6.92	2.33	0.01**
		DVR	28	4.75	3.15	
	Did you feel like you were surrounded by the environment you saw?	IEVR	36	7.29	2.38	0.002**
		DVR	28	5.07	2.80	
		IVR	26	6.96	2.20	0.017*
		DVR	28	5.07	2.80	
Social-presence	To what extent did you feel like you were in the same space as your character?	IEVR	36	6.89	2.60	<0.001***
		DVR	28	4.09	3.09	
		IVR	26	6.50	2.58	0.005**
		DVR	28	4.09	3.09	
	How engaging was your experience watching the character perform?	IEVR	36	7.82	1.95	0.036*
		IVR	26	6.65	2.50	

saw?" the ANOVA analysis revealed a significant main effect of condition, F(1,89) = 7.75, $p < 0.001$, $\eta^2 = 0.15$. Overall, participants in the IEVR condition (M=7.25, SD=2.45) rated their feeling of being inside the environment to be significantly higher as compared to those in the DVR condition (M=4.75, SD=3.15), $p < 0.001$. Also, participants in the IVR condition (M=6.92, SD=2.33) rated this feeling to be significantly higher as compared to those in the DVR condition (M=4.75, SD=3.15), $p < 0.01$.

With regards to telepresence question, *"Did you feel like you were immersed and surrounded by the environment you saw?"* the ANOVA analysis revealed a significant main effect of condition, F(1,89) = 7.00, $p = 0.002$, $\eta^2 = 0.14$. Overall, participants in the IEVR condition (M=7.29, SD=2.38) rated their feeling of being immersed and surrounded by the environment significantly higher as compared to those in the DVR condition (M=5.07, SD=2.80), $p = 0.002$. Also, participants in the IVR condition (M=6.96, SD=2.20) rated this feeling to be significantly higher as compared to those in the DVR condition (M=5.07, SD=2.80), $p < 0.05$.

With regards to social-presence question, *"To what extent did you feel like you were in the same space/room as your character?"* the ANOVA analysis revealed a significant main effect of condition, F(1,89) = 8.97, $p < 0.001$, $\eta^2 = 0.17$. Overall, participants in the IEVR condition (M=6.89, SD=2.60) rated their feeling of being in the same space as their character significantly higher as compared to those in the DVR condition (M=4.09, SD=3.09), $p < 0.001$. Also, participants in the IVR condition (M=6.50, SD=2.58) rated this feeling to be significantly higher as compared to those in the DVR condition (M=4.09, SD=3.09), $p < 0.01$.

With regards to social-presence question, *"How interesting or engaging was your experience watching the character perform?"* the ANOVA analysis revealed a significant main effect of condition, F(1,89) = 4.60, $p = 0.036$, $\eta^2 = 0.07$. Post-hoc Tukey HSD tests revealed that among 6th grade students, participants in the IEVR condition (M=7.82, SD=1.95) rated their experience to be significantly more engaging than participants in the IVR condition (M=6.65, SD=2.50), $p < 0.05$.

The 2-way ANOVA analysis did not reveal any significant effects in the participants' scores on the telepresence dimension of *"How intense was your experience using VEnvI?"*, in the social-presence dimension of *"To what extent did your character seem real?"*, in the identity dimension of *"Did you feel like the character was a partner you were dancing with?"* and *"Did you feel like the character was yourself?"*, or in the embodiment dimension of *"How much did you feel like dancing with the character?"* between any of the levels of the independent factors.

6.4.3 Quantitative Results - Attitude towards Computing and Dance

The participants' responses in a pre and post experience questionnaire were analyzed which consisted of nominal variables of, in some cases, yes or no type responses and in others strongly disagree / disagree / neutral / agree / strongly agree type responses. Based on the type of response gathered in this survey, non-parametric statistical analyses were conducted, the results of which are shown below.

6.4.3.1 Pre vs. post responses across the three conditions

A related-samples Wilcoxon signed-rank test was conducted on responses for questions asked to understand student opinions regarding programming and dance in a pre and post fashion. Student responses were analyzed across each of the three conditions (DVR vs. IVR vs. IEVR) to analyze the effect of viewing metaphor on student opinions. A summary of the results is shown in table 6.8.

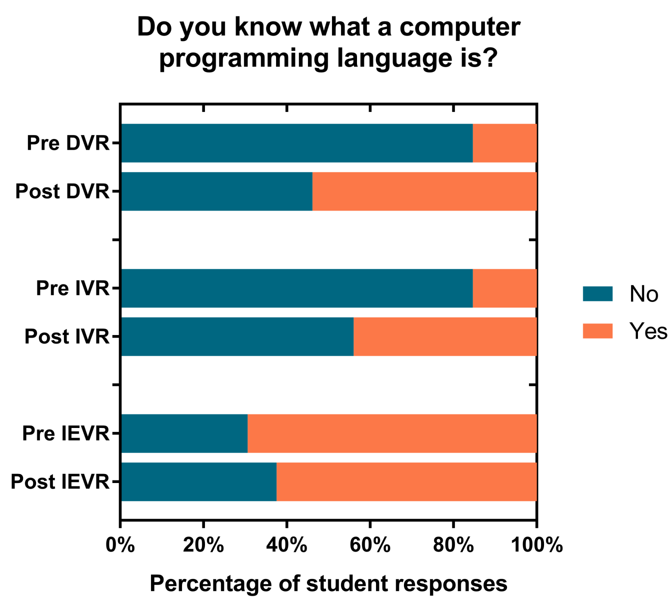


Figure 6.3: Student responses for the question "Do you know what a computer programming language is?"

For the question *"Do you know what a computer programming language is?"* (see fig. 6.3), the Wilcoxon signed-rank test indicated that overall student reports on knowledge of computer programming languages were significantly higher in the post-experiment responses as compared to pre-experiment, Z = -4.802, p < *0.001*. Across the conditions, student responses were significantly

Table 6.8: Results from the related-samples Wilcoxon signed rank test on student opinion responses for questions regarding attitude towards computing and dance.

Question	Condition	Z	p
Do you know what a computer programming language is?	Overall	-4.802	<0.001***
	DVR	-2.887	0.004**
	IVR	-2.646	0.008**
	IEVR	-2.84	0.005**
Do you see yourself as a computer programmer?	Overall	-2.558	0.011*
Do you feel like you are confident at programming?	Overall	-3.24	0.001***
	IVR	-2.747	0.006**
	IEVR	-1.966	0.05*
I want to learn more about programming.	Overall	-3.076	0.002**
	IVR	-2.295	0.022*
	IEVR	-2.137	0.035*
Do you feel like you are confident at dancing?	Overall	-2.128	0.033*
	IVR	-2	0.046*
	IEVR	-1.934	0.046*
I want to learn more about dance.	Overall	-3.235	0.001***
	IVR	-2.762	0.006**
	IEVR	-2.501	0.012*
I want to learn more about choreography.	Overall	-1.971	0.049*

higher post-experiment as compared to pre-experiment for the IVR condition (Z = -2.646, p = *0.008*), IEVR condition (Z = -2.84, p = *0.005*), as well as DVR condition (Z = -2.887, p = *0.004*).

For the question *"Do you see yourself as a computer programmer?"*, the Wilcoxon signed-rank test indicated that overall student reports on seeing themselves as computer programmers were significantly higher in the post-experiment responses as compared to pre-experiment, Z = -2.558, p = *0.011*.

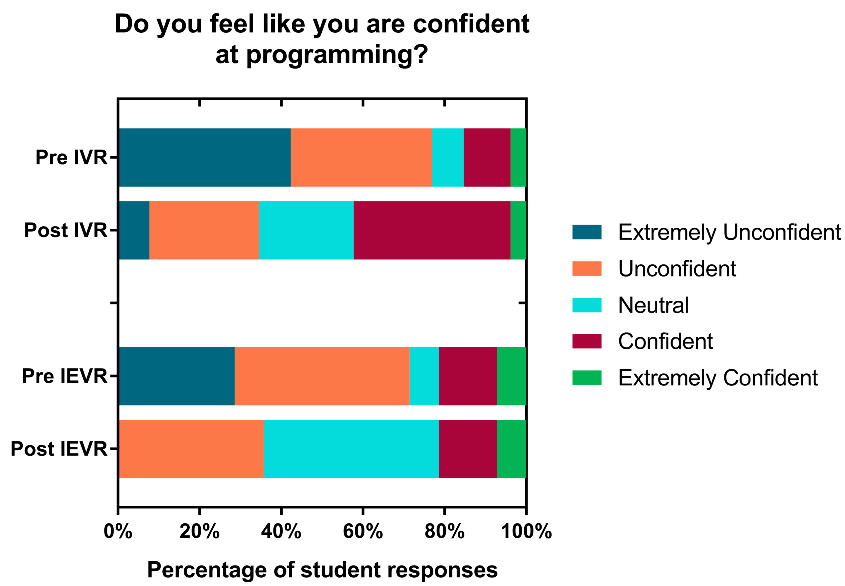


Figure 6.4: Student responses for the question "Do you feel like you are confident at programming?"

For the question *"Do you feel like you are confident at programming?"* (see fig. 6.4), the Wilcoxon signed-rank test indicated that overall student reports on programming confidence were significantly higher in the post-experiment responses as compared to pre-experiment, Z = -3.24, p <*0.001*. Across the conditions, student responses were significantly higher post-experiment as compared to pre-experiment for the IVR condition (Z = -2.747, p = *0.006*) and the IEVR condition (Z = -1.966, p <*0.05*). There were no significant differences found between pre and post in the DVR condition.

For the statement *"I want to learn more about programming"* (see fig. 6.5), the Wilcoxon signed-rank test indicated that overall student reports on wanting to learn more about programming were significantly higher in the post-experiment responses as compared to pre-experiment, Z = -3.076, p = *0.002*. Across the conditions, student responses were significantly higher post-experiment

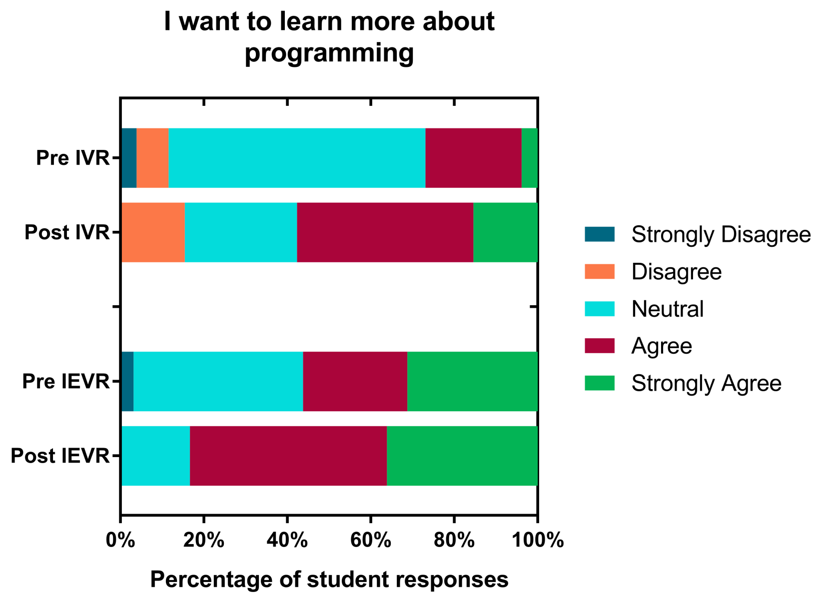


Figure 6.5: Student responses for the question "I want to learn more about programming."

as compared to pre-experiment for the IVR condition (Z = -2.295, p = *0.022*) and the IEVR condition (Z = -2.137, p <*0.035*). There were no significant differences found between pre and post in the DVR condition.

For the question *"Do you feel like you are confident at dancing?"* (see fig. 6.6), the Wilcoxon signed-rank test indicated that overall student reports on dancing confidence were significantly higher in the post-experiment responses as compared to pre-experiment, Z = -2.128, p = *0.033.* Across the conditions, student responses were significantly higher post-experiment as compared to pre-experiment for the IVR condition (Z = -2, p <*0.05*) and the IEVR condition (Z = -1.934, p <*0.05*). There were no significant differences found between pre and post in the DVR condition.

For the statement *"I want to learn more about dance"* (see fig. 6.7), the Wilcoxon signed-rank test indicated that overall student reports on wanting to learn more about dance were significantly higher in the post-experiment responses as compared to pre-experiment, Z = -3.235, p <*0.001.* Across the conditions, student responses were significantly higher post-experiment as compared to pre-experiment for the IVR condition (Z = -2.762, p = *0.006*) and the IEVR condition (Z = -2.501, p <*0.012*). There were no significant differences found between pre and post in the DVR condition.

For the statement *"I want to learn more about choreography"*, the Wilcoxon signed-rank test

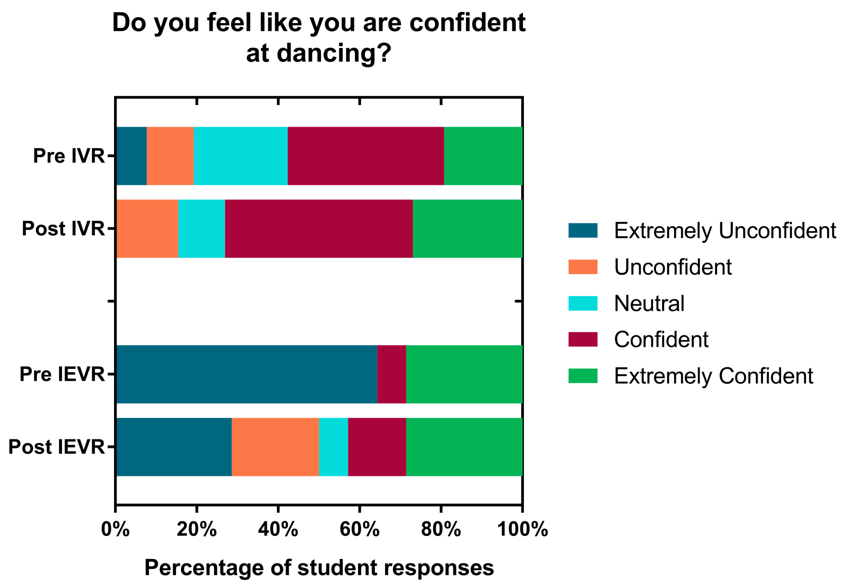


Figure 6.6: Student responses for the question “Do you feel like you are confident at dancing?”

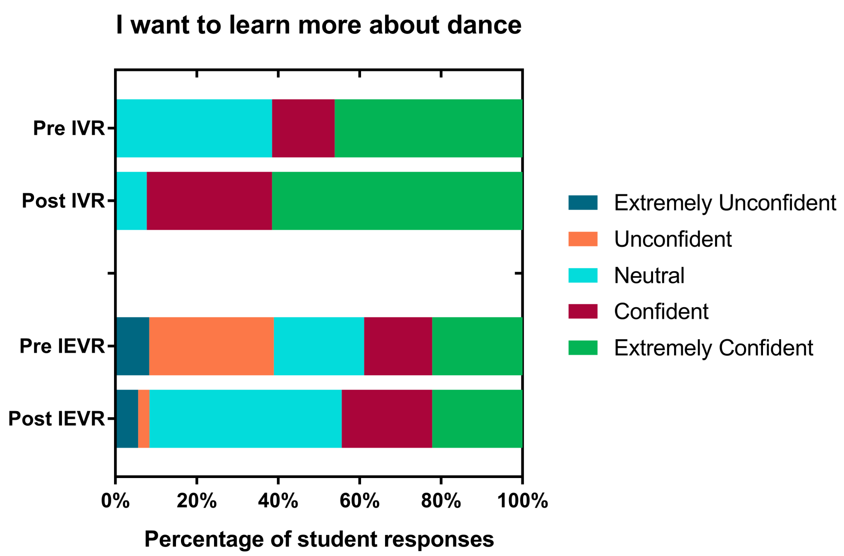


Figure 6.7: Student responses for the question “I want to learn more about dance.”

indicated that overall student reports on wanting to learn more about choreography were significantly higher in the post-experiment responses as compared to pre-experiment, Z = -1.971, $p < 0.05$.

6.4.3.2 Post-experiment responses between the three conditions

A Kruskal-Wallis H test was conducted to analyze the post-experiment responses for the independent factor of condition (DVR vs. IVR vs. IEVR). Post-hoc pairwise analysis was conducted using rank sum test.

For the question *"Do you see yourself as a computer programmer?"*, the H test showed statistically significant differences in the overall post-experiment student reports between the three conditions, H(2) = 11.761, $p = 0.003$. Post-hoc tests showed that mean rank was significantly higher in the DVR condition (mean rank = 50.81) as compared to the IVR condition (mean rank = 31.56), $p = 0.001$.

For the statement *"I want to learn more about programming"*, the H test showed statistically significant differences in the overall post-experiment student reports between the three conditions, H(2) = 14.954, $p = 0.001$. Post-hoc tests showed that mean rank was significantly higher in the IEVR condition (mean rank = 44.83) as compared to the IVR condition (mean rank = 28.46), $p = 0.008$. Also, the mean rank was significantly higher in the DVR condition (mean rank = 52.74) as compared to the IVR condition (mean rank = 28.46), $p < 0.001$.

For the question *"How likely are you to choose computing as a major in college?"*, the H test showed statistically significant differences in the overall post-experiment student reports between the three conditions, H(2) = 11.273, $p = 0.004$. Post-hoc tests showed that mean rank was significantly higher in the IEVR condition (mean rank = 46.06) as compared to the IVR condition (mean rank = 29.48), $p = 0.009$. Also, the mean rank was significantly higher in the DVR condition (mean rank = 50.33) as compared to the IVR condition (mean rank = 29.48), $p = 0.001$.

For the question *"Do you see yourself as a dancer?"*, the H test showed statistically significant differences in the overall post-experiment student reports between the three conditions, H(2) = 6.156, $p = 0.046$. Post-hoc tests showed that mean rank was significantly higher in the IVR condition (mean rank = 50.40) as compared to the IEVR condition (mean rank = 37.55), $p = 0.019$.

For the question *"Do you feel like you are confident at dancing?"*, the H test showed statistically significant differences in the overall post-experiment student reports between the three conditions, H(2) = 6.547, $p = 0.011$. Post-hoc tests showed that mean rank was significantly higher in the IVR condition (mean rank = 24.04) as compared to the IEVR condition (mean rank = 14.60), $p = 0.011$.

For the statement *"I want to learn more about dance."*, the H test showed statistically significant differences in the overall post-experiment student reports between the three conditions, H(2) = 7.754, $p = 0.021$. Post-hoc tests showed that mean rank was significantly higher in the IVR condition (mean rank = 51.46) as compared to the IEVR condition (mean rank = 34.25), $p = 0.006$.

For the question *"I want to learn more about choreography."*, the H test showed statistically significant differences in the overall post-experiment student reports between the three conditions, H(2) = 8.765, $p = 0.012$. Post-hoc tests showed that mean rank was significantly higher in the IVR condition (mean rank = 54.02) as compared to the IEVR condition (mean rank = 37.22), $p = 0.007$. Also, the mean rank was significantly higher in the IVR condition (mean rank = 54.02) as compared to the DVR condition (mean rank = 38.09), $p = 0.014$.

6.4.4 Quantitative Results - Creativity

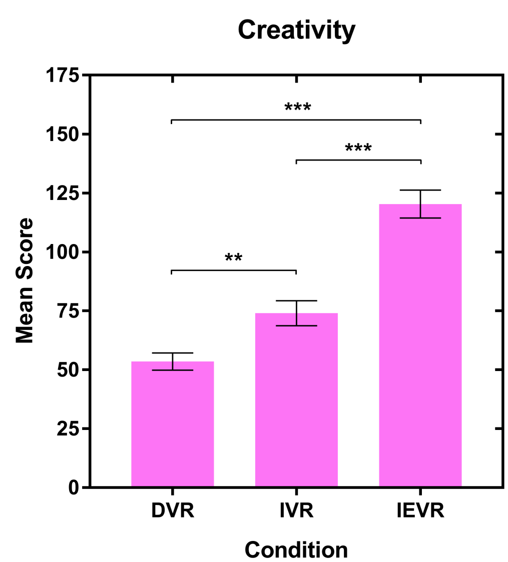


Figure 6.8: Mean creativity scores of the students for each of the DVR, IVR, and IEVR conditions. *** indicates a significant statistical difference with $p < 0.001$; ** indicates a significant statistical difference with $p < 0.01$. Error bars represent standard error of the mean.

The creativity scores obtained from the final programmed performances of the students were analyzed against the factor of condition (DVR vs. IVR vs. IEVR). Levene's test for homogeneity was significant, which meant that the data failed the assumption of homogeneity of variances. Therefore, a Welch one-way ANOVA was used for the analysis. Pairwise post-hoc tests for the three levels of condition were conducted using the Games-Howell method which does not assume equality of variances. The descriptive statistics of these results are shown in figure 6.8.

The Welch ANOVA analysis revealed a significant main effect of condition, F(2, 55.43) = 45.4, $p < 0.001$, $\eta^2 = 0.51$. Overall, participants in the IEVR condition (M=120.33, SD=35.75) scored significantly higher as compared to those in the IVR condition (M=74.02, SD=26.95), $p < 0.001$. Participants in the IEVR condition (M=120.33, SD=35.75) also scored significantly higher than those in the DVR condition (M=53.5, SD=19.21), $p < 0.001$. Further, participants in the IVR condition (M=74.02, SD=26.95) scored significantly higher than the participants in the DVR condition (M=53.5, SD=19.21), $p = 0.007$. Thus, student creativity significantly increased between each condition from DVR to IVR to IEVR.

6.4.5 Qualitative Results

Overall the students really enjoyed the VEnvI experience, and responded positively with quotes such as *"VEnvI was really fun and interesting!"* and *"It was very cool and I learned a lot."* One student was glad that she chose to participate in the study, stating *"I probably wouldn't have even tried or signed up for this but it was worth it."*

Students in the VR condition did not specifically mention the self-avatar in their comments, however they rated the VR experience highly positive overall. *"VR stuff and the program made us feel like it was amazing"* said one student, *"looking into the virtual world was unbelievable"* said another. Students really liked the experience of using the Oculus Rift, stating *"I felt involved when we put on the virtual goggles"* and *"I wish I could have did the goggles more."* Students found the VR experience realistic, and mentioned *"VR is so similar to real life"* and *"I would use VENVI (to) escape from reality."*

Students reported high sense of presence with quotes such as *"I felt like I was actually there"*, *"It felt so real but I know it wasn't"*, and *"It felt like I was there with my character."* Students commented on the realism of the virtual environment with statements such as *"It was very vivid"* and *"It was like I teleported."*

Students also commented on the learning benefits of VEnvI by saying *"This was very educational"*, *"I like that it combines programming and dancing"*, *"It helped me learn computer pro-*

gramming", and *"I felt like I learned a little more about code."* Students found VEnvI user-friendly, stating *"I think it was pretty easy to use VEnvI"* and *"the words and things we learned were easy to understand."* Students believed VEnvI to be useful, one student stated that VEnvI *"will help with my future of being an engineer."*

Students also voiced out concerns with the experience and suggested various improvements. One student stated, *"If you kept walking forward there is a limit of how far you can go, whereas in real life you can go as far as you want."* The cabling of the HMD will limit or obstruct the movement of the users unless a wireless solution is implemented. Many students wanted the ability to customize the environment, stating *"I wish you could change the scene"* and the need for *"more backgrounds like a city or a farm."* Students also desired interactivity with the virtual character, wondering *"if the character was actually able to have a conversation with"* and *"if they could talk to us and (us to) the dancer."* Students desired more moves within VEnvI, one student said *"it needs more dance moves, the ones you have to pick from aren't interesting to watch."* Finally, some students wanted the character to look like themselves, with the desire for *"creating one to resemble me"* and to *"make a character and make them me."* The possibilities for these features are discussed in the future work section in chapter 8.

Chapter 7

Discussion

7.1 Cognition

The primary goal of this study was to determine if active learning within VEnvI via immersive embodied viewing of student's performances in virtual reality facilitated embodied cognition. The results of objective 1 indicated that most students thought the the immersive experience within VEnvI would help them learn better. The interview responses and behavioral analysis showed that the immersive embodied interaction metaphor motivated dancing, movement and learning thereby showing great potential to facilitate embodied cognition.

Results from both objective 2 and objective 3 revealed that immersive embodied VR (IEVR) within VEnvI achieved higher success in enhancing computational learning among the students as compared to the immersive non-embodied condition (IEVR), and the desktop-only condition (DVR) wherein immersion and embodiment was absent. This was denoted by the higher cognitive scores in the IEVR condition under the remembering and understanding category of Bloom's taxonomy, and the multistructural domain of the SOLO taxonomy, as compared to both the IVR and the DVR conditions. Virtual embodiment within VEnvI helped the students in understanding several independent concepts better, and enabled recalling and explaining them more successfully, as elucidated by the SOLO and Bloom's categories.

This shows that for lower levels of cognition involving recall of several independent programming concepts and providing explanations, immersive embodiment by means of a co-located virtual self-avatar facilitates embodied cognition and leads to improved pedagogical benefits.

Results indicated that female students performed significantly better than male students in the remembering and understanding category of Bloom's taxonomy, and the multistructural and relational domains under the SOLO taxonomy. This provided evidence that girls exhibited higher skill in recalling and explaining computational ideas and concepts, were more adept at picking up relevant aspects of computational thinking, and were able to coherently integrate them. Research shows that boys and girls learn differently [49]. The development of the VEnvI program was grounded in enhancing the interests, contributions, and retention of under-represented minorities, especially girls, in the field of computer science. With dance and movement choreography as the medium of learning computational concepts, VEnvI was primarily targeted towards middle school girls. Research has shown that girls learn better than boys in co-operative educational environments as opposed to competitive learning environments [49], and they perform better with a hands-on learning approach [5, 69]. Since all these qualities are inherent in the VEnvI curriculum, this might explain why girls would perform better than boys in the VEnvI cognitive test overall. Further, it is possible that boys were self-conscious about utilizing dance as a medium for learning computer science concepts; such an aversion would result from the stereotype of dance and certain forms of movement practices being considered feminine [97, 43]. One hypothesis might be that girls were able to benefit more from VEnvI by taking learning via dance more seriously. A complementary hypothesis might be that boys were probably more interested in the game-like aspects of VEnvI.

Results from objective 2 showed that older students (age 13/14) performed significantly better than younger students (age 11/12) in the remembering and understanding, and application categories of the Bloom's taxonomy, and the unistructural and multistructural domains of the SOLO taxonomy. Older students were better at picking up computer science concepts and applying them. In the results of objective 3, this significance was again found in the application level of Bloom's taxonomy and the unistructural level of the SOLO taxonomy. Research shows that self-assessment is an important factor for acquiring study skills among older students [47]. Within the VEnvI program, self-assessment was encouraged, especially by visualizing their programmed performances either on the desktop or classroom projection screen, or in the immersive VR display. Older students are also more keen in responding to training [23], and perform better under instructional control [51]. The instructional learning within the VEnvI program combined with self-evaluation of the programmed choreography within the virtual learning environment, therefore, supports the higher performance of older students in the cognitive test as compared to younger students.

Irrespective of the conditions, all students scored significantly higher overall post-experiment as compared to pre-experiment, strongly supporting the VEnvI outreach program's efficacy in imparting computational thinking in middle school students.

7.2 Presence

A secondary goal of this research involved studying the effects of immersive embodiment on presence within VR among middle-school students. Both the IVR and the IEVR metaphors within VEnvI were successful in immersing the students in the learning environment, supported by the high telepresence and social presence scores as compared to the non-immersive DVR condition. As shown in literature, a higher level of presence and immersion has the potential to improve performance and enhance learning [114, 15, 112]. Students experienced a sense of "being there" in the VEnvI environment and were able to socially connect with their virtual characters for whom they authored programmed choreography in both the IVR and IEVR metaphors. Students reported immersive virtual reality within VEnvI to be more engaging, which results show motivated them to actively learn the underlying programming concepts.

The ability to see a co-located virtual self-avatar and its virtual shadow that mimicked the movements of the real self in the IEVR condition, and to be able to look around in the virtual world in both the IEVR and the IVR conditions, just like in the real world, seemed to be the major factors in experiencing high telepresence with the middle school children. 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.

7.3 Attitude towards the field of computing

Overall, the activities within the VEnvI curriculum positively altered students' perceptions of computer science and computer scientists and broadened their perspectives. Students were more confident about computer programming, and identified themselves to be computer programmers post VEnvI experience. Students also expressed a higher desire to learn more about computer programming after interacting with VEnvI. VEnvI was also successful in positively altering student perspectives about dance, with more students reporting confidence in dancing, and wanting to learn more about dance and choreography post VEnvI experience.

Virtual reality proved to be successful in grabbing the attention of middle school students. Both the IEVR and the IVR conditions were significantly more successful in positively altering students' attitudes towards computer programming and dance as compared to the non-immersive DVR condition, as shown by the results of objective 3.

A desire to choose computing as a major in college was not shown to be significant across any of the three conditions. This can be attributed to the short duration of the study, as each group of students interacted with VEnvI for only a six-week experiment period. A long-term intervention and follow-up interactions with the students is required in assessing the effects of VEnvI and the immersive embodied metaphor on altering students' desires to choose computer science as a career.

7.4 Usability

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.

7.5 Creativity

For their final performances, the students programmed choreographies for a song of their choosing. These programmed performances were evaluated as a measure for creativity based on the blocks used by the student, the complexity of the program, and its duration. A gradual increase in creativity was observed between the three conditions, where students in IVR condition scored significantly higher than students in the DVR condition, and students in the IEVR condition scored significantly higher than both IVR and DVR conditions. Overall, virtual reality was able to enhance the creativity among students. Perhaps watching their characters perform the programmed choreographies through an egocentric first-person perspective allowed the students to critically analyze their programs and think more creatively, resulting in increased variety, complexity, and duration. Further, embodiment within the virtual environment by means of a virtual self-avatar resulted in significantly better scores than the conditions without active embodiment. Having a virtual body possibly allowed the students to embody their programmed choreographies and allowed them to utilize embodied cognition to think about their programs, leading to a surge in creativity.

Chapter 8

Conclusions and Future Work

Minority populations, especially women in science, technology, engineering, and mathematics (STEM) fields continue to remain underrepresented, and novel interventions such as virtual environment interactions (VEnvI) has immense potential to aid in alleviating this problem. VEnvI proved to be successful in developing computational thinking in middle school students, and enhancing their interest and engagement in the field of computer science, and was able to produce significantly higher learning benefits among girls.

Immersive embodiment by means of co-located virtual self-avatars within virtual reality enabled VEnvI to facilitate embodied cognition for learning computer programming concepts, and for increasing creativity among the students. Virtual Reality has immense potential to captivate the minds of students, enhance their learning experience, and motivate a willingness to learn. VEnvI was able to achieve this by making learning of computer programming concepts fun by means of immersive virtual reality and marrying it with dance. Immersive virtual reality within VEnvI was able to engage students and boost their interest in computer science education, as corroborated by the significantly higher cognitive scores.

Qualitative responses from the students support the quantitative findings. Students advocated for using the immersive embodied VR metaphor to visualize their programmed choreographies stating reasons such as *"I'm a visual learner"*, *"I can see what looks better"*, *"It helps me see my mistakes"*, and *"It helps [in building] confidence"*. The co-operative learning environment was evident in responses such as *"We used each other's ideas to make better ones"*, *"It was more fun with friends around"*, *"No one bothered me. We talked and had fun"*, and *"No one was hovering over* *my shoulder, stifling my creative spirit"*. Boys reported self-consciousness with comments such as *"Awkward"* and *"Too many people around"*. Finally, VEnvI helped in increasing engagement and interest, shown by quotes like *"I liked how it's easy to learn coding"*, and *"Definitely loved the virtual reality experience"*. A distinctive moment that defined this research was when a student had the following conversation:

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."*

8.1 Contributions

Three key contributions of this research are:

- Providing a continuum for immersive embodied virtual reality, and validating the first three levels of the continuum in the form of educational virtual reality.
- Facilitating embodied cognition via immersive self-embodiment through the means of co-located self-avatars in support of modern cognition theories such as grounded cognition [8].
- Developing a middle-school curriculum which utilizes dance as a medium for experiential learning of abstract programming concepts to increase interest and retention.
- Design and evaluation of a novel approach for hands-on and co-operative learning mapped to widely used levels of learning—Blooms and SOLO taxonomy, as opposed to competitive learning environments, which can be pivotal for getting more females interested in taking up careers in computing.
- Providing significant evidence for higher learning overall in middle school through immersive environment compared to non-immersive desktops.

8.2 Significant Impact

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, and especially in the field of education. One of the broader aims of this research 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 [9] or studies in using VR technologies with children in the autism spectrum [101]. The usability and likability of VR games in education has been studied by Virvou and Katsionis [128] and have suggested that further research on virtual reality educational games is warranted. This research provides evidence of heightened sense of presence via immersive embodied virtual reality among middle-school students, and provides the VR community an insight into the minds of middle-school students regarding their reactions to immersive VR for education.

This research also has a significant impact on the education research community. This work is one of the first that links active body movements in VR to cognition. Widely-cited empirical research in psychology suggests static body postures influencing valence such as grin or smiling while holding a pen between teeth [118] or hearing false rate of heart-beat [126]. These findings can be linked to mental simulations through passive bodily states, as in modern cognition theories [8] suggesting that learning occurs through modal symbols in the real-world. The other arms of such theories have argued for many decades that embodiment can affect cognition [30, 42], but there has not been any empirical studies that have provided evidence in the favor of such theories. This work is pivotal in the way of not only designing an immersive system mapping the key affordances of immersion to abstract concepts of computing (such as sequences, loops, parallel programming, variables, conditionals, and functions), but it goes on to provide evidence of improving learning through its system, and finally tying the benefits to females more than males.

8.3 Limitations

The studies presented in this research have sources of error from several contributors. The number of students participating in each study was limited. Participants were enrolled from the graphics communications and dance aerobics classes at the partnering middle school, which were elective classes and competing in class enrollment against other elective classes such as sports or band. Further, parental consent was required for the study activities as well as video and audio recording, which reduced the participation further. Finally, a number of participants' data had to be discarded due to incomplete or missing data.

Another limitation was the length of the study. The study duration was six weeks, which was relatively short considering the activities involved included filling out a number of questionnaires. A study spanning the entire school year could possibly lead to improved power of the results and a stronger effect on student interest in the field of computing. Further, analyzing the effect of the VEnvI intervention on students choosing computer science as their career path would require long-term follow up studies.

Finally, this research only looks at one form of embodiment within immersive virtual reality by means of co-located virtual self-avatars. However, self-avatars are not the only means of embodying a user within the virtual world. Other ways of enabling active embodiment involve authoring new movements for the virtual characters using body tracking, socially responsive virtual peers, virtual doppelgängers created using a 3D scan of the user as a virtual representation of themselves, and a body-based programming metaphor by implementing the immersive embodied interactive VR (IEIVR) metaphor within VEnvI. These forms of embodiment have considerable prospects for research in facilitating embodied cognition.

8.4 Future Work

The primary goal of this work was to evaluate the ability of immersive embodiment within virtual reality to facilitate embodied cognition. From this point there are several future research directions that could further this initial goal as well as answer new research questions about students' interaction with virtual environments and virtual characters for STEM education.

8.4.1 Immersive embodied interactive virtual reality (IEIVR)

Within the current design of the studies, the students program their choreographies on their laptop computers and then view them within the immersive VR metaphor (IVR or IEVR). An immersive way of creating their programmed choreographies within the virtual environment can be implemented, leading to the fourth and final level of the immersive embodied VR continuum—IEIVR. This will provide a seamless immersive experience. Further, within IEIVR students will directly interact with the visual programming interface by means of bodily gestures, thus embodying the programming activity, possibly facilitating embodied cognition further.

Developing the IEIVR metaphor within VEnvI has great challenges. Design challenges include a complete redesign of the VEnvI programming interface to accommodate a fully immersive interaction metaphor. The 3D user interface will need to be user-friendly and intuitive for the target audience of middle-school students. The students will spend a considerable amount of time programming within the IEIVR metaphor, and such an extended duration of immersive VR experience will increase the risk of fatigue, nausea, cybersickness, eye-strain, and ocular-motor discomfort. Care needs to be taken to minimize these risks in order to ensure that the students benefit from the intervention.

8.4.2 Movement authoring

Students currently use pre-recorded movement blocks within VEnvI to create their programmed choreographies. By implementing movement authoring within VEnvI, students can record their own movements and add to the movement bank within VEnvI. This will not only allow the students to use their bodies in generating new content to use in their programs, thus embodying the process of programming within VEnvI, but also lift their limitation on the available move blocks to program which could hold their interest longer.

The current dance moves within VEnvI are obtained via a motion-capture animation process where the movements of a professional dancer are recorded using an extensive infrared optical motion-capture system, converted to 3D animations, and then processed and added to VEnvI over an extended period of time. Movement authoring will require this process to be real-time or close to real-time to be a usable feature.

8.4.3 Character authoring

VEnvI currently provides students with character customization features. However, the extent of customization available to the students is limited. It would be interesting to research how students react to seeing themselves or their peers as virtual characters within VEnvI and programming choreographies for them. Lucas et al. found that having an avatar that looks like the user, by means of 3D scanning the user's body to generate the virtual avatar, improves their subjective experience [77]. A virtual doppelgänger that looks exactly like the user or their peers can enhance the immersive embodiment within VR and may lead to improved learning via embodied cognition.

8.4.4 Socially responsive virtual agents

Student responses from the studies indicate that they desired social interactivity from the virtual characters they programmed choreographies for. The virtual characters should be able to acknowledge the user's presence in the virtual environment, and socially respond to the users. This notion can be taken further by allowing the virtual character to be a social dance and partner within VEnvI. Users can program dance choreographies with the virtual character as a partner, in a way that the virtual character responds to the movements and positions of the user within the virtual environment. Such a system will embody the social interactions of the user with their virtual dance partners.

Appendices

Appendix A Teaching Plan

RESEARCH OVERVIEW

Evaluation Questions

- Is VENVI successful in teaching the students basic programming concepts?
- Does the software enhance their interest towards the field of computer science and other related STEM fields?
- Does virtual reality add to the novelty and excitement of learning programming through VENVI, and further enhance students' interest in computer science?
- Do students feel a higher sense of presence, or the feeling of being there inside the virtual environment, when experiencing immersive virtual reality as compared to a non-immersive experience?
- Are the students more active and willing to dance with their programmed virtual characters in the immersive VR experience compared to the non-immersive experience?

Research Question

- How does the grounded embodied curriculum and immersive virtual reality support the development of computational thinking?

IN-DEPTH OVERVIEW
Session 1

Location: RCE Classroom
People: Dhaval, Joey, Lorraine, Nikeetha
Time: 50 minute session
Activities: In general, session will be utilized for introductions, purpose of the program, introducing students to the programming environment, and learn basic dance steps.

XX:00 - XX:30 Introduction and Questionnaire

- Introductions from the team
- Pre-survey and demographics
- Pre-cognitive questionnaire
- What is VENVI?
  - VE to introduce computational programming using movement, primarily dance.
  - What is computational programming, why is it important?
  - Are dance and programming related?
  - Program and choreograph virtual character, opportunity to perform with it.
  - How was it created? Motion capture, games, programming.
  - You can make something like this. Programming can be fun.
- What are we doing over the weeks?
  - Learning dance concepts, learning programming concepts, learning VENVI, working on basic choreography concepts to create a virtual-physical (informal) performance, having a competition / dance-off.
- Why are students participating?
  - Collecting data in this process about what you all think.
  - VENVI is under development so we want you to break it, try to find cool, new ways to play with it, SAVE often, be open to the fact that things might not work, and PLEASE give us feedback on making it better. This is research and development, the frontlines of creating a new program.
- What do they hope to do during the program? What expectations do they have?

XX:30 - XX:50 Warm-up activities and introduction to dance

Students will learn some of the choreography available in VENVI. This will be focused on Cha-Cha slide or Denzel's movements.

1. Warm-up: Breathing, body warm-up, feet with basic sequences (step touches, grapevines, variations), walk around the room
2. Leader/Follower (if needed)
3. Learn 2 Denzel-inspired sequences
   a. *Don't stop til you get enough* (MJ)

b. *Move on up* (Curtis Mayfield)

XX:50 *Dismissal*

Session 2

Location: RCE Classroom
People: Dhaval, Joey, Lorraine, RCE teacher
Time: 50 minute session
Activities: Session will be utilized for introducing following three basic computational concepts to the students: sequences, loops, and parallelization.

XX:00 - XX:15 Programming concepts: Introduction

- What are computer scientists? What do they think computer scientists look like? What do computer scientists do?
- What is programming? Why is it important? Examples of applications. (Asking the students first, then researchers answering these questions)

XX:15 - XX:25 Programming concepts: Sequences

- What are sequences?
    - A particular order in which things follow each other.
    - Do sequences occur in real life?
- How do sequences relate to dance?
    - In dance, we call creating the dance as choreographing: piecing together the movements that make up a dance phrase, like in the Cha-cha slide - 2 steps right, 2 steps left… that is a dance phrase together with other phrases, like the hops, right, left, stomps, and the cha-cha phrase to create a dance sequence.
- Physical activity to demonstrate sequences.
    - Divide into groups. Have each person perform one move. Each group member performs their moves in a sequential order.

XX:25 - XX:35 Programming concepts: Loops

- What are loops?
    - Perform something over and over again, a sequence that is repeated a number of times.
    - Do loops occur in real life? Examples.
- How do loops relate to dance?
- Physical activity to demonstrate loops.
    - Put your arms up in a V. Now put your arms in what's called a Low V [demonstrate]. Now that's our sequence: high V, low V. On the count of three, I want everyone to do the sequence. 1, 2, 3… Ok. Now I'm going to say a number, and that's how many times I want you to do that sequence. 2, 3, 4. Now this time I say a number, I want you to do the sequence fast. Ok? 6. [If funny, call it the bird loop].
    - Create sequence among divided groups. Give each group a random number to repeat their sequence. If easy, have them perform loops faster.

XX:35 - XX:45 Programming concepts: Parallelization / Do-Together

- What is parallelization?
    - Doing two or more things at the same time.
    - Do you do things together in real life? Examples.
- Can you think of parallelization in dance?
- Physical activity to demonstrate do-together.
    - Divide into groups. Each group comes up with two moves (one for upper body; 2nd for lower body). Perform each move separately as a group; then both moves together as a group.

XX:45 - XX:50 Programming concepts: Summary and recall

- Can you tell me the three programming concepts we learned today?
- What does sequence mean? Can you give an example?
- What does loop mean? Can you give an example?
- What does do-together mean? Can you give an example?
- Can you have two of these concepts at the same time? Can you have all three concepts at the same time? For example, can you loop a do-together?

XX:50 Dismissal

Session 3

Location: RCE Classroom
People: Dhaval, Joey, Lorraine, RCE teacher
Time: 50 minute session
Activities: Session will be utilized for introducing VENVI and learning how to program in VENVI.

XX:00 - XX:30 Introduction to VENVI

On big screen, demonstrate basic functionality:

- Character creation
- VENVI interface
- Drag and drop
- Locomotor vs. non-locomotor
- Duplicate
- Play
- Sequences
- Loops
- Do-together

Students (in the VR condition) will be introduced to the immersive visualization (IV) metaphor within VENVI.

- A demo will be setup before the students arrive. The visuals seen in the head-mounted display will be mirrored on the large screen display.
- IV will be introduced as a new way to see their character perform. They can do this at any point during programming.
- The demo will be shown on the large screen, performed by one of the researchers.
- Why should you try it out? What to watch out for? Will it be harmful in any way?

XX:30 - XX:50 Programming in VENVI

- Program the Cha-Cha slide moves together with the students.
- Students will make their own programmed choreography in VENVI
- Students can experience IV anytime while programming.

XX:50 Dismissal

Session 4

Location: RCE Classroom
People: Dhaval, Joey, Lorraine, RCE teacher
Time: 50 minute session
Activities: Session will be utilized for learning few more computational concepts: variables, conditionals, and functions. Students will practice these new concepts within VENVI.

XX:00 - XX:10 Programming concepts: Variables

- What are variables?
  - Something that can change, does not stay the same.
  - In programming, used to store information that can change.
  - Do variables occur in real life?
- How do variables relate to dance?
- Physical activity to demonstrate variables.
  - Divide into groups. Have each group come up with a team name (variable name). Each group will come up with a one move sequence. Present team names in various sequences for them to perform. Maybe add numbers next to team names to indicate loop repetitions for performance.

XX:10 - XX:20 Programming concepts: Conditionals

- What are conditionals?
  - Do something if a requirement is met.
  - Do sequences occur in real life? If it's not raining, I'll go outside and play. Else, I'll watch TV.
- How do conditionals relate to dance?
- Physical activity to demonstrate conditionals.
  - Each student has a move to perform. When the instructor raises hand (true), students perform their move. When the instructor's hand is down (false), all movements cease.
  - Elimination Game
    - True = perform move. False = touch floor and still. Last person to perform false gets eliminated from game. Last person is winner.

XX:20 - XX:30 Programming concepts: Functions

- What are functions?
  - Functions are a set of actions, which are grouped together to form a procedure or routine.
  - Do functions occur in real life? Examples. Getting ready for school every day is a routine.
- How do functions relate to dance?

    - When we're listening to music and sometimes when we're choreographing a dance, we might have repeated bars or moves.
    - So what's your favorite song that has a part that is repeated throughout? This is called the refrain or chorus.
- Physical activity to demonstrate functions.
    - Divide into groups. Each person in group comes up with one move. Create a sequence. Name their sequence. Instructor calls on random groups to perform their sequence.

XX:30 - XX:50 Programming in VENVI

- Provide the students with a song
- Students will try out the new concepts in VENVI

At the end of the session, students will be informed of a dance challenge.

- Dance programs will be analyzed and the best performance will be selected, based on creativity and complexity of the code.
- Possibility of receiving prizes / certificates?
- Students can choose their own song which is clean and appropriate.
- There will be a maximum time limit (3 minutes?) for the running time of the programmed choreography.
- Students may or may not choose to dance with their characters.
- Students should start and finish their choreography in one session (session 5).
- Dances will be shown to the class in the next session (session 6).

XX:50 Dismissal

Session 5

Location: RCE Classroom
People: Dhaval, Joey, Lorraine, RCE teacher
Time: 50 minute session
Activities: Session will be utilized to introduce the immersive visualization metaphor. Students will work on the dance challenge, and experience the immersive VR visualization.

XX:10 - XX:50 VENVI programming for the challenge

- Students will spend rest of the session programming for the dance challenge.
- Students can experience IV anytime while programming.

XX:50 Dismissal

Session 6

Location: RCE Classroom
People: Dhaval, Joey, Lorraine, RCE teacher
Time: 50 minute session
Activities: Session will be utilized for viewing final performances and conducting post-tests.

XX:00 - XX:30 Viewing dances created by the students

- All dances will be viewed one after the other. Students may perform.
- Extra points for performance?
- Winners will be announced.

XX:30 - XX:45 Cognitive, Presence and Usability Questionnaire (Post-tests)

XX:45 - XX:50 Closing

- Students will be thanked for taking part in the study.
- Students will be asked if they have any questions or comments.

XX:50 Dismissal

Appendix B Participant Recruitment Script

R. C. Edwards recruitment script

Hello everyone,

My name is Dhaval, and this is Joey. We are from Clemson University, and we are here to talk about a research program which you might find interesting. But before we do that, please raise your hand if you know what computer programming or coding is (raising my hand, waiting for students to raise hands).

If you ask me, it can sometimes be boring to learn computer programming. Wouldn't it be fun to learn programming by playing games and dancing? We have built such a game, called VEnvI, in which you create a dance for a virtual character, and dance with the virtual character, and learn programming while doing it.

Our research program will be held every Friday, starting on the 15th of this month, and you will get to dance and play and learn computer programming in an interesting way. This program will last for 6 weeks, and participation is completely voluntary.

We are handing out two forms today, one for you and one for your parents or guardians. If you wish to participate in this program, please return the signed copies to your teacher. Now I would like to show a teaser of what VEnvI looks like. (We show a video of VEnvI).

Appendix C Parental Consent Form

Parent Permission Form
Clemson University

The Dancing Alice Project

VEnvI (Virtual Environment Interactions)

Description of the Research and Your Child's Part in It

Dr. Alison Leonard, Dr. Sabarish V. Babu, and Dr. Sophie Joerg are inviting your child to take part in a research study. Dr. Leonard, Dr. Babu, and Dr. Joerg are Assistant Professors at Clemson University. Dhaval Parmar, Lorraine Lin, Nikeetha D'Souza, and Elham Ebrahimi are the graduate students from Clemson University working with us in this study. The purpose of this research is to explore how creating animated characters to dance with can help students learn computer programming in a fun way.

Your child's part in this study will be to attend a research program during the school study hall sessions. He/she will work with our team for part of the time learning some basic dance steps and choreography. They will then learn some basic computer programming concepts. After this, they will learn to use and play with a computer game called VEnvI, through which they will create animated characters and program them to dance. Finally, he/she will have the option to view and experience the dance choreography that he/she programmed, as well as perform with the animated character while viewing the character on a virtual reality headset. Before and after the program, your child will be asked to fill out a survey about their knowledge of computing and dance as well as enjoyment of the program. We will also ask him/her questions at the end of the program. Throughout the program, we will take pictures, collect audio, and film the activities in which your child is involved. These pictures, audio files, and film will not be made publicly available, and will be primarily used by our team to analyze the results of the study and the pictures may feature in a research publication arising from the study.

This research study is expected span across 5 to 6 study hall sessions (1 session per week).

Risks and Discomforts

There are certain risks or discomforts that we might expect your child to go through if they take part in this research. For example, there are possible risks involved in physical movement, such as sore muscles, stumbling, etc. These might also include risks from looking at computer screens, such as eyestrain, dizziness, and nausea. In order to minimize this risk or discomfort, we will take time to stretch thoroughly prior to dancing, and have breaks during sessions while using VEnvI. In addition, if students feel tired or experience any eyestrain or discomfort, they can notify the researchers and can stop the study at any time without penalty.

A comfortable virtual reality experience requires an unimpaired sense of motion and balance. Your child will be advised to not use the equipment if he/she is tired, needs sleep, has digestive problems, is under emotional stress or anxiety, or is suffering from cold, flu, headaches, migraines, or earaches, as this can increase his/her susceptibility to adverse symptoms. Some people are susceptible to seizures or loss of consciousness when exposed to certain flashing lights or light patterns present in everyday life. It is advised to not let your child participate in the experiment if he/she has a history of epilepsy or seizures.

Your child will be informed to notify the researcher immediately if he/she experiences any discomforts. If he/she continues to feel bad after the study, the school nurse will be contacted immediately.

Possible Benefits

Your child might benefit from this research by learning some concepts that are important for logical thinking and creating compositions in school. He/she might also benefit from the exercise time during the dance portion of the program. The child also can learn about new technology and innovations in virtual environments, animation and computing.

Protection of Privacy and Confidentiality

We will do everything we can to protect your child's privacy and confidentiality. We will not tell anybody outside of the research team that your child was in this study or what information we collected about your child in particular.

All of your child's information that is collected will be assigned a code so that none of the information is identifiable. After five years, the audio, pictures and video will be destroyed.

Choosing to Be in the Study

Your child does not have to be in this research study. You do not have to let your child be in the study. You may tell us at any time that you do not want your child to be in the study anymore. Your child will not be punished in any way if you decide not to let your child be in the study or if you stop your child from continuing in the study. Your child's grades will not be affected by any decision you make about this study.

We will also ask your child if they want to take part in this study. Your child will be able to refuse to take part or to quit being in the study at any time.

Contact Information

If you have any questions or concerns about this study or if any problems arise, please contact Dr. Alison Leonard at 414-405-5539, or Dr. Sabarish V. Babu at 980-253-8481. If you have any questions or concerns about your child's rights in this research study, please contact the Clemson University Office of Research Compliance (ORC) at 864-656-6460 or irb@clemson.edu. If you are outside of the Upstate South Carolina area, please use the ORC's toll-free number, 866-297-3071.

Consent

I have read this form and have been allowed to ask any questions I might have. I give my permission for my child to be in this study.

______________________________________ ________________________

Signature of Parent Date

Child's Name: ____

A copy of this form will be given to you at your request.

Appendix D Student Assent Form

Child/Minor Agreement to Be in a Research Study
Clemson University

The Dancing Alice Project

VEnvI (Virtual Environment Interactions)

You are being invited to be in a research study. Below you will find answers to some of the questions that you may have.

Who Are We?

- We are Dr. Alison Leonard, Dr. Sabarish V. Babu and Dr. Sophie Joerg. We are researchers at Clemson University in South Carolina. Dhaval Parmar, Lorraine Lin, Nikeetha D'Souza, and Elham Ebrahimi are the graduate students from Clemson University working with us in this study.

What Is It For?

- We are conducting a study to understand how we can have fun dancing creating an animated character on the computer.

Why You?

- You have been selected because you are studying at R. C. Edwards Middle School; however, you can still participate in these activities even if you're not a part of our study.
- During the study, you will be asked to share your opinion. None of the information you share will impact your grades in school.

What Will You Have to Do?

- You will take part in the Dancing Alice Project, learn a few things about computers, and have fun creating an animated character on the computer and dancing with it, using a game called VEnvI.
- If you participate in the study, we will ask you to let us use information about your participation for our study.
- The information we would like to use is:
    - Questions we ask you about the program, before and after the program.
    - Pictures, recordings of your voice, and film of some of the program as you go through it.

What Are the Good Things and Bad Things that May Happen to You If You Are in the Study?

- If you would like to find out about our research study, we will be glad to answer your questions so you can learn about doing research.
- You will learn and experience new things, which will be fun as well as useful. You will also learn about how computer games and 3D programs are created.
- When we tell other researchers about our study, we might show them your pictures or films, or play recordings of your voice. You might not be comfortable having other people seeing your pictures or films, or hearing your voice.

- There are certain discomforts that you might experience if you take part in this research. However, the experiment does not require anything more than watching a typical computer monitor. You will be allowed to take breaks to rest, and you may quit the research at any time without penalty.

- A comfortable virtual reality experience requires an unimpaired sense of motion and balance. Do not use the equipment if you are tired, need sleep, have digestive problems, under emotional stress or anxiety, or suffering from cold, flu, headaches, migraines, or earaches, as this can increase your susceptibility to adverse symptoms.
- Some people are susceptible to seizures or loss of consciousness when exposed to certain flashing lights or light patterns present in everyday life. Do not participate in the experiment if you have a history of epilepsy or seizures.
- If you experience any discomforts, notify the researcher immediately. If you continue to feel badly after the study, please contact the school nurse immediately.

What If You Want to Stop? Will You Get in Trouble?

- Your participation in this study is voluntary. If at any time you wish to stop, please let your teacher or a researcher know.
- You will not be in any trouble for asking not to participate.
- None of the information we collect from you will positively or negatively impact your grades or your participation in other activities.

Do You Have Any Questions?

- You can ask questions at any time. You can ask them now. You can ask later. You can talk to me or you can talk to someone else at any time during the study. Here are the telephone numbers to reach us:
    - 414-405-5539. Dr. Alison Leonard, School of Education.
    - 980-253-8481. Dr. Sabarish V. Babu, School of Computing.

By signing below, I am saying that I have read this form and have asked any questions that I may have. All of my questions have been answered and I understand what I am being asked to do. I am willing and would like to be in this study.

______________________________ ____________________

Signature of Child/Minor Date

A copy of this form will be given to you at your request.

Appendix E Authorization for Media Recording

Clemson University Authorization for Use of Photographic/Image/Video/Voice Recording

Clemson University Research Project: VEnvI (Virtual Environment Interactions)
Department: School of Education and School of Computing
Clemson University Contact: The faculty contact is Sabarish V. Babu & Alison E. Leonard and the graduate student contact is Dhaval Parmar.

Child Participant's Name: ____
Parent's Name: ____

By signing below, you are giving Clemson University permission to make audiovisual recordings and photographs of your child while he/she is participating in the research project described above and to use those recordings and photographs for research and/or educational purposes.

PLEASE READ THIS DOCUMENT CAREFULLY. It affects the rights you may have concerning the use by Clemson University of any photographs, video, images or voice recording taken of your child during the research project identified above.

I, ____ hereby grant permission to Clemson University and its representatives, volunteers, students and employees to take photographs and/or or videos of my child identified above, to make recordings of my child's voice, and to obtain a transcript of my child's spoken or written words during his/her participation in the Clemson University research project described above. I give Clemson University permission to use these images, recordings, and spoken or written comments, as follows:

1. To copy, reproduce, distribute, modify, display and perform.
2. To use in composite or modified forms in any media, now known or later developed, including but not limited to publications, books, journals, newspapers, television, radio, sound track recording, motion picture, filmstrip, still photograph, the Internet, the world wide web, or any transcript.
3. For education, and research purposes including but not limited to research and/or academic papers, books and publications; research presentations at academic conferences/meetings; and classroom presentations throughout the world and in perpetuity.
4. My child's name and contact information will not be disclosed in connection with these uses.

I agree that I will receive no further consideration for these uses and that Clemson University owns all rights to the images and recordings. I waive the right to inspect or approve uses of the images, recordings or written copies.

I hereby release Clemson University, its representatives, agents, employees and assigns from any claims that may arise from these uses, including claims of defamation, invasion of privacy, or rights of publicity or copyright. This release is binding on me, my heirs, assigns and estate and represents the entire agreement between my child and Clemson University regarding the matters herein.

I agree that Clemson University is not obligated to use any of the rights granted under this Agreement.

____ ______________________
Signature of Parent or Guardian Date

Appendix F Demographics Survey

PARTICIPANT ID: ______________________________

VEnvI Pre-Survey

COMPUTERS:

1. Is there a computer at home that you are allowed to use by yourself?
   ☐ Yes ☐ No

2. Do you have your own computer?
   ☐ Yes ☐ No

3. Do you have restrictions on computer use?
   ☐ Yes ☐ No

4. If so, please explain the type of restrictions you have, like, for how long, or what activities on the computer are not allowed, etc.

5. On average, how many hours a week do you think you spend using a computer?
   ☐ 0 ☐ 1-2 ☐ 3-5 ☐ 6-9 ☐ 10+

6. List three things you like to do on the computer.

7. Do you play video games?
   ☐ Yes ☐ No

8. If so, on what system do you play? (Choose more than one if you do use more than one system.)
   ☐ Desktop or laptop (PC, Mac, etc.)
   ☐ Tablet (iPad, Android tablet, etc.)
   ☐ Mobile phones
   ☐ Xbox
   ☐ Xbox 360
   ☐ PlayStation 4 (PS4)
   ☐ PlayStation 3 (PS3)
   ☐ PlayStation Portable (PSP)
   ☐ Other: ____________________

Page **1** of **6**

PARTICIPANT ID: ______________________________

9. Which game do you like to play the most, and why?

10. Have you ever played the following dancing games?
    ☐ Dance Dance Revolution
    ☐ Dance Central
    ☐ Just Dance
    ☐ Other: ____________________

11. Have you ever done computer programming before?
    ☐ Yes ☐ No

12. If so, please tell us what kind of programming you have done, or what types of programs you have worked on.

13. Describe any summer camps or after school activities have you been a part of that involve programming.

14. Have you ever heard of Scratch, ALICE, or Looking Glass (programming languages with animated characters)?
    ☐ Yes, I have heard of them and have used them before
    ☐ Yes, I have heard of them but have not used them before
    ☐ No, I have not heard of them

15. Do you know what a computer programming language is?
    ☐ Yes ☐ No

16. In one or two sentences, tell us what you think a programming language is.

17. Do you see yourself as a computer programmer?
    ☐ Yes ☐ No

PARTICIPANT ID: ______________________________

18. Why do you, or don't you see yourself as a computer programmer?

19. I believe that being able to make a computer program is an important skill.
    - ☐ Strongly Agree
    - ☐ Agree
    - ☐ Neutral
    - ☐ Disagree
    - ☐ Strongly Disagree

20. I want to learn more about programming.
    - ☐ Strongly Agree
    - ☐ Agree
    - ☐ Neutral
    - ☐ Disagree
    - ☐ Strongly Disagree

21. How likely are you to choose computing as a major in college?
    - ☐ Extremely Likely
    - ☐ Likely
    - ☐ Neutral
    - ☐ Unlikely
    - ☐ Extremely Unlikely

22. What do you think computer scientists do?

PARTICIPANT ID: ______________________________

DANCE:

1. Have you ever participated in a formal dance program or dance class?
   ☐ Yes ☐ No

2. Do you enjoy dancing at home alone or with friends?
   ☐ Yes ☐ No

3. Do you watch dance on TV, internet, in movies, or as live performances?
   ☐ Yes ☐ No

4. If so, what type(s) of dance do you watch?

5. How much time do you spend dancing in a week?
   ☐ 0 hours ☐ 1-2 hours ☐ 2-4 hours ☐ 5-7 hours ☐ 8+ hours

6. Do you see yourself as a dancer? Why or why not?

7. Do you see yourself as artistic? Why or why not?

8. I want to learn more about dance.
   ☐ Strongly Agree
   ☐ Agree
   ☐ Neutral
   ☐ Disagree
   ☐ Strongly Disagree

9. I want to learn more about choreography.
   ☐ Strongly Agree
   ☐ Agree
   ☐ Neutral
   ☐ Disagree
   ☐ Strongly Disagree

PARTICIPANT ID: ______________________________

GENERAL INFORMATION

1. When is your birthday?
   ______ /_____ /______
   (month) (date) (year)

2. How much do you like school?
   ☐ A lot
   ☐ It's okay
   ☐ A little
   ☐ Not too much
   ☐ Not at all

3. If you wish, please explain your answer to the previous question.

4. What is your most favorite subject in school?
   ☐ Mathematics
   ☐ Language Arts
   ☐ Science
   ☐ Social Studies
   ☐ Other: ___________________

5. What is it about this subject that makes it your favorite?

6. What is your least favorite subject in school?
   ☐ Mathematics
   ☐ Language Arts
   ☐ Science
   ☐ Social Studies
   ☐ Other: ___________________

7. What is it about this subject that makes you dislike it?

PARTICIPANT ID: ______________________________

8. What do you like to do after school during your free time? Do you have an after school activity, class, etc.?

9. What languages do you speak at home?

10. How do you identify your race or ethnicity?
    ☐ White
    ☐ African American
    ☐ Hispanic
    ☐ Native American
    ☐ Asian
    ☐ Pacific Islander
    ☐ Multiracial
    ☐ Other: ______________

11. How do you identify your gender?
    ☐ Female
    ☐ Male
    ☐ Other: ______________

PARTICIPANT ID: ______________________________

VEnvI Post-Survey

1. Do you see yourself as a dancer? And/or a choreographer? Why or why not?

2. Do you see yourself as artistic? Why or why not?

3. I want to learn more about dance.
   ☐ Strongly Agree
   ☐ Agree
   ☐ Neutral
   ☐ Disagree
   ☐ Strongly Disagree

4. I want to learn more about choreography.
   ☐ Strongly Agree
   ☐ Agree
   ☐ Neutral
   ☐ Disagree
   ☐ Strongly Disagree

5. Do you know what a computer programming language is?
   ☐ Yes ☐ No

6. In one or two sentences, tell us what you think a programming language is.

7. Do you see yourself as a computer programmer?
   ☐ Yes ☐ No

8. Why do you, or don't you see yourself as a computer programmer?

PARTICIPANT ID: ______________________________

9. I believe that being able to make a computer program is an important skill.
   ☐ Strongly Agree
   ☐ Agree
   ☐ Neutral
   ☐ Disagree
   ☐ Strongly Disagree

10. I want to learn more about programming.
   ☐ Strongly Agree
   ☐ Agree
   ☐ Neutral
   ☐ Disagree
   ☐ Strongly Disagree

11. How likely are you to choose computing as a major in college?
   ☐ Extremely Likely
   ☐ Likely
   ☐ Neutral
   ☐ Unlikely
   ☐ Extremely Unlikely

12. If not, what major do you think you will choose?

13. What do you think computer scientists do?

14. How likely would you participate in VEnvI again?
   ☐ Extremely Likely
   ☐ Likely
   ☐ Neutral
   ☐ Unlikely
   ☐ Extremely Unlikely

15. Please explain why or why not you would participate in VEnvI again.

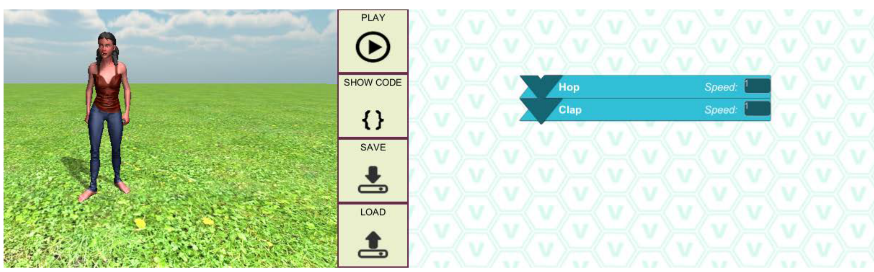
Appendix G Cognitive Questionnaire

PARTICIPANT ID: ______________________________

VEnvI – Cognitive Questionnaire

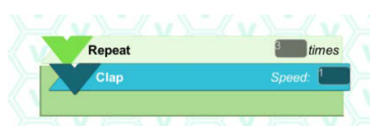
COMPUTATIONAL THINKING

The picture below is from a software called VEnvI. The blocks on the right hand side tell the character how to dance. For example, when "PLAY" is pressed, the character will hop in the air and then clap her hands. The questions below will ask you about different ways the character can perform as well as your general understanding of computational thinking concepts. Please answer to the best of your ability.



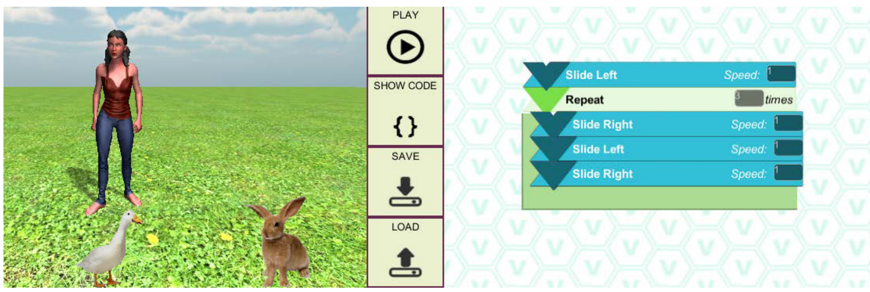
1. The first block below (Picture A) will cause the character to clap twice. How many times will the character clap with the second set of blocks (Picture B)?

Picture A



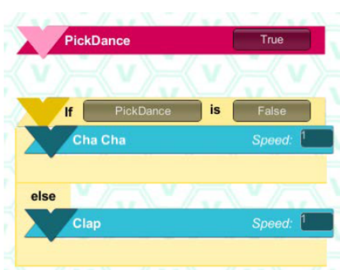
Picture B

2. Based on the blocks below, if the character performs “Slide Left” she will be next to the rabbit. If she performs “Slide Right” she will be next to the duck. Once “PLAY” is clicked, when the character finished the moves in the code below, will she be next to the duck or the rabbit?
   ☐ Duck
   ☐ Rabbit



3. What is a variable? Explain in your own words. Give an example.

4. Based on the blocks below, will the character perform the “Cha Cha” or “Clap”?
   ☐ Cha Cha
   ☐ Clap

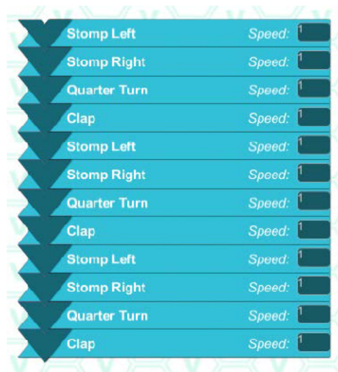


5. (a) Look at the blocks in Picture A and Picture B below. Would a character performing Picture A and another performing Picture B do the same thing?

   ☐ Yes

   ☐ No

Picture A



Picture B

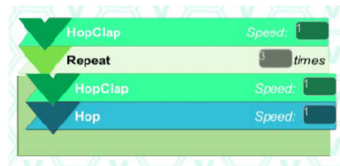
   (b) Look at the blocks in the pictures given in the previous question again. Which blocks (Picture A or Picture B) do you think are better to use? Why?

6. What is the purpose of a loop?

7. What is the purpose of a function?

8. The block in Picture A instructs the character to hop once while clapping. Based on the blocks in Picture B, how many times will the character hop?

Picture A

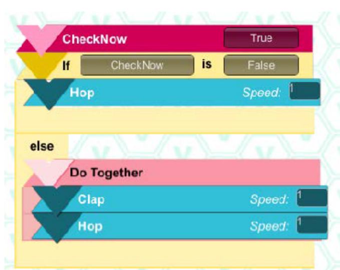


Picture B

9. What is a conditional statement in programming?

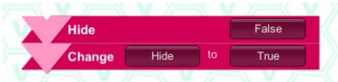
10. Give an example of a conditional in your life.

11. Look at the blocks below. When "PLAY" is clicked, what will the character perform?



PARTICIPANT ID: ______________________________

12. What is the value of "Hide"?
    ☐ False
    ☐ True



13. What order should the blocks below be put into if I want the character to clap first, move to the right side, and then reverse twice?

14. Describe the steps you would use to make and eat a peanut butter and jelly sandwich.

Appendix H Debriefing Questionnaire

PARTICIPANT ID:

VEnvI Debriefing Questionnaire

About your experience:

1. How intense was your experience using VEnvI?

Not Intense									Very Intense
1	2	3	4	5	6	7	8	9	10

Why? :

2. Did you feel like the experience within VEnvI involved you?

Not Involving									Very Involving
1	2	3	4	5	6	7	8	9	10

Why? :

3. Did you feel like the environment in which the character was dancing was real?

Not Real									Very Real
1	2	3	4	5	6	7	8	9	10

Why? :

4. Did you feel like you were inside the environment you saw?

Not Inside									I Was There
1	2	3	4	5	6	7	8	9	10

Why? :

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5. Did you feel like you were immersed and surrounded by the environment you saw?

Not immersed									Completely Immersed
1	2	3	4	5	6	7	8	9	10

Why? :

6. Did the presence of others around you affect your decision to dance or not?

Not at all									Very much
1	2	3	4	5	6	7	8	9	10

Why? :

7. Did the presence of others around you affect your programming in VEnvI?

Not at all									Very much
1	2	3	4	5	6	7	8	9	10

Why? :

8. Did the presence of the virtual character affect your decision to dance or not?

Not at all									Very much
1	2	3	4	5	6	7	8	9	10

Why? :

9. Did the presence of the virtual character affect your programming in VEnvI?

Not at all									Very much
1	2	3	4	5	6	7	8	9	10

Why? :

PARTICIPANT ID:

About your virtual character:

10. To what extent did you feel like you were in the same space/room as your character?

Not In The Same Room									We Were In The Same Room
1	2	3	4	5	6	7	8	9	10

Why? :

11. How interesting or engaging was your experience watching the character perform?

Not Interesting									Very Interesting
1	2	3	4	5	6	7	8	9	10

Why? :

12. Did you feel like the character was a partner you were dancing with?

Not At All									Very Much
1	2	3	4	5	6	7	8	9	10

Why? :

13. Did you feel like the character was yourself?

Not At All									Very Much
1	2	3	4	5	6	7	8	9	10

Why? :

PARTICIPANT ID:

14. How much did you feel like you were dancing as the character?

Not At All									Very Much
1	2	3	4	5	6	7	8	9	10

Why? :

15. Did you give the character a personality? If so, describe it.

16. To what extent did your character seem real?

Not Real									Very Real
1	2	3	4	5	6	7	8	9	10

Why? :

17. How much did you feel like dancing with the character?

Did Not Want To Dance									I Danced A Lot
1	2	3	4	5	6	7	8	9	10

Why? :

PARTICIPANT ID:

About VEnvI:

1. Did you think it was easy to learn and use VEnvI? Explain.

2. Would you use VEnvI a lot? How do you think you will use it? By yourself? With friends?

3. Do you think watching the character perform in this way will help you learn better? Give examples to explain.

4. What would make the virtual character more interesting for you?

5. What did you like/not like about VEnvI? Why?

6. How can you improve VEnvI? What would you like to change?

7. If you had more time to work on your project, what would you do next?

8. If you could make any type of project in VEnvI, what type of project would you make and why?

Thank you so much for taking the time to fill out this survey. Do you have any questions for us, or anything you wish we should have asked?

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