JoLLE@UGA®
Journal of Language & Literacy Education

Embodying and Programming a "Constellation" of Multimodal Literacy Practices: Computational Thinking, Creative Movement, Biology, & Virtual Environment Interactions

Alison E. Leonard
Nikeetha Dsouza
Sabarish V. Babu
Shaundra B. Daily
Sophie Jörg
Cynthia Waddell
Dhaval Parmar
Kara Gundersen
Jordan Gestring
Kevin Boggs

ABSTRACT: Merging computational thinking and an embodiment-centered curriculum, VEnvI (Virtual Environment Interactions) seeks to expand the professional and academic possibilities for K-12 students through opening up pathways that synthesize knowledge across and through digital media, computer science, and the arts. This paper presents findings from a case study research intervention with 5th grade students at an arts magnet school in a small urban municipality in the Southeastern United States. This research iteration is part of a larger, ongoing design-based research project, pioneering the design, development, and testing of a virtual environment and associated curriculum for blending creative movement and computer programming for upper elementary and middle school students. After conducting quantitative and qualitative analysis, researchers found students' computational knowledge improved through their engagements in a "constellation" of multimodal literacy practices (Steinkuehler, 2007, n.p.) during the process of choreographing and programming a complimentary virtual character's movements based on a 5th grade biology standard about cells.

Keywords: computational thinking, creative movement, embodiment, multimodality, literacy

Alison E. Leonard is the Assistant Professor of Arts & Creativity in the Eugene T. Moore School of Education at Clemson University. She holds a PhD in Curriculum and Instruction from the University of Wisconsin-Madison and an MA in Performance Studies from New York University. Her research involves arts education; specifically dance in education and embodied forms of inquiry in schools.

Nikeetha Dsouza is a PhD student in Curriculum and Instruction at Clemson University in the Eugene T. Moore School of Education.

Sabarish V. Babu is an Assistant Professor in the School of Computing at Clemson University. Babu's research interests are in the design, development and evaluation of virtual reality systems, specifically in the creation of interactive scenarios and user studies in immersive virtual environments for education and training. Babu has authors or co-authored over 60 research publications in peer-reviewed venues including ACM and IEEE conferences and journals.

Shaundra B. Daily is an Associate Professor in Department of Computer & Information Science & Engineering at the University of Florida. She received her doctorate from the Massachusetts Institute of Technology. Her research involves designing and implementing technology-infused collaborative learning environments, affective computing, and STEM education.

Sophie Jörg is an Assistant Professor in the School of Computing at Clemson University. She received her Ph.D from Trinity College Dublin, Ireland and conducted research at Fraunhofer IAIS, Carnegie Mellon University, and Disney Research, Pittsburgh. Her research revolves around computer animation, virtual characters, perception, and digital games.

Cynthia Waddell is currently the dance teacher at Stone Academy of Communication Arts in Greenville, SC. She holds a MEd from Converse College and a BA in dance from Columbia College.

Dhaval Parmar is a PhD student in Computer Science at Clemson University.

Kara Gundersen has an MFA in Digital Production Arts from Clemson University, and is a PhD student in Human Centered Computing at the University of Florida.

Jordan Gestring is an MFA Candidate in the Digital Production Arts program at Clemson University.

Kevin Boggs is an MFA Candidate in the Digital Production Arts program at Clemson University.

After eleven weeks of working together, we all gathered cross-legged on the floor to reflect on our experiences: an entire class of fifth-grade students, their teacher, two researchers, and one graduate assistant. Following a discussion of what the students enjoyed, what challenged them, and what they would change for next time, one of the researchers asked the group, "Do you think dancing and programming your dance made you a better computer programmer?" One student replied, "Yeah, because it makes you understand what you're doing on the computer . . . so you know what you're doing on the computer, and when you're dancing, it makes it easier 'cause you know the actions."

Another student then explained, "I think it's good that you chose dance instead of something else because it's something people can relate to. You know how it worked in your own body, so it was easier to transfer that into the computer." Essentially, these students were describing their embodied learning experiences of representing knowledge in multimodal ways. Little did the rest of the group know that both of the researchers at that moment were having their own little silent, undetectable, internal celebration—the kids could not have stated the goals of our research any better.

"I think it's good that you chose dance instead of something else because it's something people can relate to. You know how it worked in your own body, so it was easier to transfer that into the computer."

In this paper, we present recent findings from a case study, which is a part of our larger, iterative design-based research project called VEnvI (Virtual Environment Interactions). This project, which started in 2013, focuses on the design, development, and testing of a virtual environment and associated curriculum that utilize embodied approaches to support the development of computational thinking. As we develop the virtual environment, we are also revising the accompanying curriculum where we guide students through choreography and programming sessions during research iterations in school, afterschool, and summer camp settings. The research iteration discussed in this paper has helped us to continually revise our research, virtual environment, and curricular design. Throughout this project, we hypothesize that the parallel processes of choreographing a dance and programming a character in a virtual environment may be an interactive and engaging context that appeals to students not typically interested in programming by broadening their perspectives on computing applications. Likewise, we also believe that programming can provide movement possibilities for students not typically interested or comfortable in traditional dance settings. In conducting our research, we ask the following questions: In what ways do students creating dance performances for virtual characters use their bodies and embodied ways of thinking to work through the actuation of programming choreography onto virtual characters? How do these interactions support the students' knowledge of computational concepts, utilization of computational practices, and development of computational perspectives?

We found that the process of choreographing a dance and programming a complimentary virtual character's dance based on curricular content afforded the students opportunities to engage in a variety of interrelated literacy practices—a "constellation" of multimodal literacy practices using various forms of text (written, spoken, movement, and computer programming) (Steinkuehler, 2007, n.p.). Steinkuehler (2007) describes multimodal literacy practices involving reading, writing, speaking, and gaming in her study of Massively Multiplayer Online Games (MMOGs) as a constellation of literacy practices. We take inspiration from Steinkuehler's work. Similarly, for our student participants, their programming and embodying of multimodal literacy practices formed an assemblage—a constellation—of their meaning making and knowledge during this case study.

Theoretical Perspectives

We view literacy and being literate in both expansive and nuanced ways that encompass reading, writing, and speaking, using a myriad of combinations of text

that include the written, read, and spoken word, as well as other forms of aesthetics and semiotic texts—sound and music, imagery and visuals, digital forms, and through the body (Leonard, Hall, & Herro, 2015; Foster, 1995; Jones, 2013). We call upon the legacy of the New London Group's (1996) definition of literacy as plural literacies that are inherently multimodal, tied to semiotic systems and contextually situated in "a community of practice that renders that system meaningful" (Steinkuehler, 2010, p. 300). These semiotic systems are comprised of discourse. One of the members of the New London Group, Gee (2008; 2011; 2014) refers to "little 'd' discourse" as communication, expression, and "language-in-use" and the "big 'D' Discourse" as the networks, identities, and communities of practice's language within particular group and context. The discourse utilized within a Discourse (d/Discourse) also relies on distinct yet relational knowledge from the students' lives—their homes, school, peer groups, and commercial media (Gonzalez, Moll, & Amanti, 2005; Moje et al., 2004).

Multimodality

Specifically, we highlight the complex and intertwining scope of multimodality and literacy. Multimodality entails representation and integration across varied aesthetic forms—print, visual, audio, gestural, and spatial—and in their varied forms, these representations remain integral to meaning making and communication (Cope & Kalantzis, 2000; Jewitt, Kress, Ogborn, & Tsatsarelis, 2000; New London Group, 1996; Seglem, Witte, & Beemer, 2012). Engaging in multimodal literacy practices means that one is able to decipher meaning across different modes and can make choices based on the affordances and limitations of available modes in order to communicate and represent knowledge (Steinkuehler, 2010).

The process of reconstructing knowledge and meaning through the transfer of content between communication systems is referred to as either transmediation (Siegel, 1995), transferring across media, or transduction, across modes (Kress, 2003). This process allows for the gaining of new insight into knowledge through its reconstruction through another form (Albers, Holbrook, & Harste, 2010; Leonard et al., 2015; Hoyt 1992). While one might transmediate from writing using the media of pen and paper to writing using digital media, one can transduct from writing to drawing since both are different modes of communication even though they may use the same media (Mavers, 2015). Here, we will most commonly refer to transmediation because we are discussing the reconstruction of knowledge between media, i.e. from spoken text to dance.

Computational Thinking

The Discourses of computer science and programming as disciplinary and professional fields have their own conventions, cultures, and ways of communicating. Literacy and literacy practices are defined in multiple ways within these Discourses. Computer literacy includes the ability to boot up a computer, use a mouse and keyboard, and work with basic computer programs. Computational literacy then is the wide set of practices associated with using computational media in our everyday lives (diSessa, 2000). Of interest in this research is what diSessa refers to as a "cognitive pillar" of literacy—computational thinking—which involves the ability to harness the power of computers to solve problems. According to Wing (2006) who popularized the term, "computational thinking involves solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science. Computational thinking includes a range of mental tools that reflect the breadth of the field of computer science" (p. 33). As a result, although the goal of teaching computational thinking is not necessarily to have all students become programmers, thinking like a programmer involves habits of mind and d/Discourses (Gee, 2008) that are useful to a broad range of fields. In this research, we view computational thinking as a set of concepts (sequences, loops, conditionals, parallelism[1]), practices (iterating and reusing[2]), and perspectives (seeing computing as a tool for self-expression) that draw upon the world of computing and remain applicable across multiple disciplines in the sciences

[1] Sequences denote the order of things; loops are repeated sequences; conditionals are when sequences are performed under a set of parameters or conditions; and parallelism denotes sequences of instructions that are happening in parallel.

[2] Iterating involves repeating steps until a condition is met; reusing involves building on the work of others to create your own code.

and with digital media (Daily, Leonard, Jörg, Babu, Gundersen, & Parmar, 2015; Brennan & Resnick, 2012a; 2012b).

A review of very early work in the field suggested that children who participate in computer programming typically score around sixteen points higher on various cognitive ability assessments as compared to children who did not (Liao & Bright, 1991). A study by Clements et al. (2001) showed comparable results on mathematics, reasoning, and problem-solving tests for students programming with Logo—an early language developed by Seymour Papert. Others have shown that students can apply core computational thinking concepts in other aspects of their lives after engaging with programming environments like Scratch or programming robots (e.g. Bers & Horn 2010; Mioduser et al. 2009; Resnick 2009).

Dance and Embodiment

Within the d/Discourses of the fields of dance, dance education, and other scholarly domains that study embodied practices, such as dance and movement, literacy involves communication of, about, and through the body. Dance consistently utilizes and unites "multiliteracies about visual meaning, auditory meaning, spatial meaning, gestural meaning, linguistic meaning, and multimodal patterns of meaning that are combinations of the semiotic modes" (Curran, Gingrasso, Megill, & Heiland, 2011, p. 36). Embodied literacies are also referred to as those literacies that are performed and embedded within the body with dance being an obvious form. As an embodied literacy, gesture merges meaning and the content being expressed through a nod or movement of the hands while speaking (Frambaugh-Kritzer, Buelow, & Steele, 2015; Jones, 2013). However, dance also has its own semiotic system of signs, symbols, codes, and language related to or of the body. Any discussion of dance as literacy, being literate in the elements of dance (body, space, time, effort/force), techniques, and/or discourse involves embodied ways of thinking and being literate (Curran et al., 2011; Dils, 2007). Therefore, dance and the dancing body itself become a form of text in multimodal literacy, and even more, the dancing body becomes the writer, speaker, and reader and also the written, spoken, and read (Leonard et al., 2015; Foster, 1995).

Although theories of embodiment and embodied ways of thinking have long been welcomed in dance and arts education and research (Block & Kissell, 2001; Bresler, 2004; Dils, 2007; Hanna, 2008; 2014; Leavy, 2015; Warburton, 2011), looking at embodied cognition (Wilson, 2002) as essential in inquiry, learning, and expression in schools has received recent and renewed attention as effective in mathematics (Drodge & Reid, 2000), physics (Lu, Kang, Huang, & Black, 2011), geology (Tolentino et al., 2009), Chinese characters (Lu, Hallman, & Black, 2013), health (Johnson-Glenberg et al. 2013), and computational thinking (Daily et al., 2015; Fadjo, Harris, & Black, 2009). Links among embodied cognition, computer programming, and education also build upon the work of Papert (1993), who found students' learning and understanding of mathematical concepts when programming to be more efficient when their active engagements with this knowledge were associated with their knowledge of self, culture, and the body—that the knowledge was syntonic, related to the learner's understanding.

Project Design and Development

The overarching goal of VEnvI is to develop an original virtual environment and curriculum that blends movement and computer programming with a goal of increasing participation and interest of middle-school students in computer science. Providing a specially designed and engaging way to cultivate computational thinking, this virtual environment will allow users to move from choreographing in the physical world to programming a virtual character to perform their choreography in the virtual world. Finally, our aim is that through an associated and embodied curriculum in the virtual environment that users will be able to engage and perform with their virtual character.

In order to create this desktop virtual environment, we are conducting research with students and teachers through iterative analysis, design, development, and implementation cycles (Daily et al., 2015; Wang & Hannafin, 2005). In order to inform our technological and curricular design of this new

virtual environment, our team has been conducting ongoing, design-based research iterations using existing programs, such as Alice by Carnegie Mellon (Cooper, Dann, & Pausch, 2000) and Looking Glass by Washington University (Gross et al., 2010). Both of these environments allow users to program movements of a character but, in addition to using unrealistic, low quality rendered movements, neither is accompanied by an embodied curriculum or is designed specifically for dance choreography. For example, Looking Glass allows users ages 10 and up to create and share animated stories, games, and virtual characters, not necessarily dance (Gross et al., 2010). Therefore, to create higher quality, realistic dance motions, we are using a 14-camera Vicon optical motion capture system to allow us to record accurately even the small subtleties of a dancer's movements. Based on motion capture data collected from the retro-reflective markers attached to an actual dancer's body, we are computing the associated joint rotations and transferring these results to a virtual character (Leonard & Daily, 2013; Daily et al., 2014). See Figure 1 for a comparison between Looking Glass and a beta version of what our program might look like. A video comparison can be found at this link. The first clip shows a character created in Looking Glass performing the Cha-cha Slide. The second clip is an early version of VEnvI. While neither clip perfects the dance, the second is working at coming closer to realistic movement. Any technical issues are currently being worked out within our design.

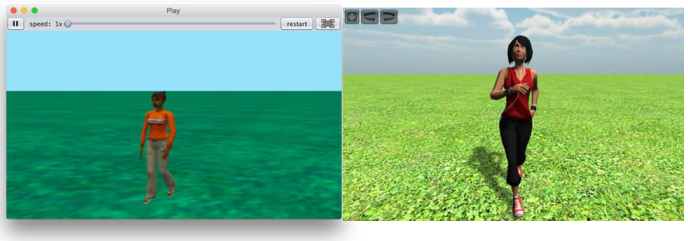


Figure 1. A comparison between an existing program, Looking Glass, and a beta version of our virtual environment, VEnvI (Virtual Environment Interactions). On the left, a character from Looking Glass is performing the Cha-cha Slide. On the right, a beta version of our environment shows a character performing the same step from the Cha-Cha Slide; the VEnvI movements have been created through motion capture.

Methodology

As we are designing VEnvI, we are conducting pilot research iterations using existing programs and small samples of students in various settings: after school programs, science and technology-focused summer camps, and most recently an in-school scenario—the dance class at the arts magnet school. For this ongoing research, we are utilizing a design-based research (DBR) approach, a paradigm for studying learning in a context through the systematic design and study of instructional strategies. Relying on extensive descriptions, systematic analysis of data, consensus-building within the field around interpretations of data, DBR utilizes reliable and validated techniques used in other research paradigms to refine both theory and practice (Brown, 1992; Design-Based Research Collective, 2003).

Additionally, we are utilizing the data collection methodology of participation observation (Tedlock, 2008) since our DBR approach requires the introduction of teaching computer programming, often not part of the formal school curriculum for elementary or middle- school students, and merging it with dance and the choreographic process. Therefore, we as the researchers led the facilitation of the activities in both computer programming and choreography, as well as collected the research data with the dance instructor supporting us. For example, she provided consistency for her students through leading one of her regular warm-ups with the students each day before we began. Our pilot research iterations also stand as research and curricular interventions, augmenting the students' typical school experiences (Lancy, 1993). Each iteration stands as what Stake (2008) calls an instrumental case study, one that provides insight into other similar or future programs and experiences, providing generalizability of experience (Lancy, 1993). These generalizations and case findings can then be used to inform our virtual environment design, as well as the research and curricular design for future data collection.

Research Site

Since the inception of this project, our team has participated in a local arts fair occurring over three days each spring. During one of these outreach

sessions, a parent who was excited about bringing STEAM (Science, Technology, Engineering, Arts + Design, & Mathematics) into her school suggested that we work with a K-5 public arts magnet school in a small urban municipality in the Southeastern United States. After conversations with the principal, arts teacher, and magnet coordinator, a relationship ensued. The city's school district serves over 70,000 students according to 2013-2014 school records accessed via their district website. The arts magnet school serves over 600 K-5 students (69% from a downtown neighborhood assigned to the school and 31% from across the district who apply for attendance). Of the school's population, 70% are White, 20% are African American, 5% are Hispanic, <1% are Asian, and the remainder reported as other. Of the students in grades 3-5, 40% are served in a Gifted and Talented Program, and 26% receive Free/Reduced Lunch. The school boasts a robust general education curriculum strengthened by art, music, dance, drama, technology, writing, and physical education. Every week students attend "related arts" classes in art, music, drama, and dance.

During this study, we worked with two sections of Grade 5. There were 44 students total in the classes, but only 41 participated in the research, 27 females and 14 males. The students self-identified their race on a biographical survey. These consisted of 32 White, 7 African American, 1 Asian, and 4 identified as "other race/ethnicity" but did not specify.

Procedures. For eleven weeks, our team facilitated programming and choreography sessions with the two classes of fifth-grade students during their 45-minute weekly dance class. We worked with one class of 22 students on Monday and 20 students on Friday. During these sessions, we began with a physical warm-up, followed by concentrated whole and small group work related to creative movement and choreographing a dance inspired by the parts of a cell, including its cell membrane, nucleus, cytoplasm, and vacuoles[3]. Cells were chosen per the request of the grade-level teachers who were interested in cross-curricular connections that could be made while programming a dance. They chose this curriculum standard since, although they touch upon the subject matter, they do not have time to cover it in depth.

We then moved to programming complementary choreography onto one or two characters using the introductory programming platform, Looking Glass (Gross, Herstand, Hodges, & Kelleher, 2010) (Video 2). Looking Glass (Figure 2) is designed to enable users to create 3D animated stories using drag and drop graphical blocks that represent programming constructs. In Looking Glass, students can utilize the computational concepts and practices mentioned previously to create interactive stories.

Figure 2. Screenshot of Looking Glass. On the left is an example of a virtual character, and on the right is the "My Story" workspace where students drag and drop actions and action orders.

When we first met with the students, they had not yet explored this material in their general education classrooms. To introduce the students to the structure and function of cells, we first re-created and embodied a cell and its basic structures of the cell membrane, nucleus, cytoplasm, and vacuoles using our bodies. Standing in a circle, we enacted the cell membrane's semi-permeable function of allowing nutrients into the cell and blocking harmful elements from entering by having students physically acting out these scenarios. We continued to explore this content physically for the nucleus, cytoplasm, and vacuoles. Additionally, one of the researchers with an extensive background in dance education choreographed a dance that accompanied an originally composed poem explaining the cell, its structure, and function. The students learned this poem and its movements (Figure 3), and these initial movements served as the inspiration for their own cell dances. Working in dyads, the students choreographed their own cell dances to represent the

[3] The function of cells and their structures, including cell membrance, nucleuas, cytoplasm, and vacuoles are part of the state science standards for 5th grade in this school.

concept of a cell and its four structures as outlined in the standards. They were invited to utilize the same movements from the poem or to create their own inspired by the function of each cell part. As part of the school's dance curriculum, the students were well versed in creative movement, choreographing, rehearsing, and performing short dance sequences on their own, using basic choreographic elements of theme and variation (creating a basic movement theme and creating variations on that theme), repetition (the use of repeated actions), unison (performing together with others), and cannon (performing in delayed succession with others), along with creating purposeful movement transitions to flow from one movement to the next. The original cell poem is as follows:

I am a cell. I am the basic unit of life
I am a cell. I am the basic unit of life
I make up all living things
I make up all living things
I am a cell. I am the smallest unit of life
I am a cell. I am the smallest unit of life

I have a cell membrane that separates my outside from my "in"
I have a cell membrane that separates my outside from my "in"
My cell membrane is semi-permeable
My cell membrane is semi-permeable
It is the fence to keep what I need in; it is the boundary to keep what I don't need out
It is the fence to keep what I need in; it is the boundary to keep what I don't need out

I am filled with cytoplasm, my jelly-like insides
I am filled with cytoplasm, my jelly-like insides
Cytoplasm flows inside, and moves with me wherever I go
Cytoplasm flows inside, and moves with me wherever I go

Inside is my nucleus, the power center, controlling the whole operation
Inside is my nucleus, the power center, controlling the whole operation
My nucleus is like my brain; it stores all I need to survive and regenerate
My nucleus is like my brain; it stores all I need to survive and regenerate

Some cells have vacuoles to store all their stuff and even their waste
Some cells have vacuoles to store all their stuff and even their waste
Vacuoles are like the their closet, cubby, and waste bin
Vacuoles are like the their closet, cubby, and waste bin

I am a cell. I am the basic unit of life
I am a cell. I am the basic unit of life
I make up all living things
I make up all living things
I am a cell. I am the smallest unit of life
I am a cell. I am the smallest unit of life

Figure 3. Students performing cell poem. Here the students are performing the cell movements for the nucleus, "the power center" to accompany the spoken poem.

In this video link, the students, along with one of the researchers, is performing the cell poem together. Notice the movements assigned to each cell part. These movements are referenced in the examples in the paper and in the video.

Along with exploring the structure and function of a cell in embodied ways in the dance session, we also facilitated an introduction to computer programming and basic computational concepts and practices. We began by dancing a popular hip hop line dance known as the Cha-cha Slide that centers

around sequence of steps, jumps, stomping the foot, and the cha-cha basic step, repeating the theme sequence and variations in a counterclockwise pattern. Led by the other researcher who has an extensive background in computer science, the students were introduced to computational thinking concepts of sequence and loop, as well as the computational practice of remixing in reference to the Cha-cha Slide. In later sessions, the researcher introduced concepts of conditionals (e.g., if a constraint is met, then carry out a sequence of actions) and variables (i.e., a storage location that can hold any value). In our program, conditionals were demonstrated by saying "If I clap my hands, then perform your sequence." The instructor would then snap, stomp, and then clap. Variables were demonstrated alongside loops; where students were asked to perform their sequence "x" amount of times. The instructor, in this case, would call out the value of x which indicated how many times the students would perform and loop the sequence. Other computational practices of iterating, debugging, and remixing were used implicitly throughout. In many ways, the practice of computer programming is very much like the compositional process of choreographing a dance, where small pieces are integrated into a larger whole (modularization), and body positions are incorporated and changed slightly to create something new (remixing and reusing).

According to the dance instructor, initially, the differences in terminology were a steep learning curve for the students. However, through discussion, they realized that many terms in technology and dance are similar, e.g. writing code is similar to choreographing a dance; the creative process is similar, as well. Once the classes discovered these similarities, working simultaneously in both processes became more seamless. The dance instructor also noted after the project that she can now make connections between the two processes in her everyday teaching. In always looking for ways to connect with the students in ways that are not only familiar to them but that are also relevant in their lives, she explained that she was excited about incorporating computational thinking and embodied literacies in her class. She expressed, "My students live in a time that races at the speed of light. My job is to present opportunities that allow for multiple levels of learning. Integrating technological strategies with dance strategies creates a learning environment with the potential for a multitude of solutions to problems. This way of teaching meets the needs of my diverse student population and prepares them for their future" (personal communication, October 2015).

Measures and Data Collection

We collected both quantitative and qualitative data throughout the sessions. The following describes each form of data collected.

Pre- and post-computational thinking test. A study-specific test was used to gauge students' understanding of computational concepts: sequence, variables, conditionals, and loops prior to the sessions in a pre-test and to measure any changes after the sessions in a post-test. Neither test had a bearing on students' grades within their class. The tests were used solely as a research measure. The ten questions on both the pre- and post-computational thinking tests were identical and presented blocks of code, such as the one shown in Figure 4, and asked students to determine the behavior of the character being controlled by the blocks. The images and code were captured from Looking Glass, the program that the students used. For example, in Figure 4, students were asked, "How many times will the character clap her hands?" Open-ended questions (e.g., "Describe a loop" and "What is a variable?") were also included. The full test is included as an appendix.

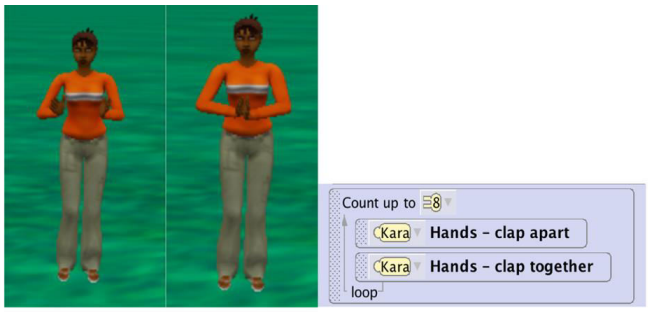


Figure 4. Problem from computational thinking test given to participants. Students are asked to determine the behavior of the character given the instructions presented by the code.

Biographic data. The biographical survey contained 36 questions to assess the students' personal information relevant for our study. It

contained demographic questions to assess their age, grade, race, and language spoken at home. The questions also assessed their preference for school or subjects in a multiple choice format using a scale ranging from "a lot" to "none at all." The questions were organized in 3 major sections—computer usage, dance, and video games. The questions in these categories collected information about the number of hours spent on the computer or dancing, and their preferences for these activities, and open-ended questions related to why they do or do not see themselves as a dancer and how they define computer programming.

Video and photographic data. Each session with the students was video recorded and photo documented from at least one angle. On days when students formally performed their choreography with the group, there were two video cameras capturing the performance, as well as the group reactions and feedback following the performance. Additionally, small video clips of specific student-student and student-researcher interactions were captured at various times.

Figure 5. Photo documentation example. Image of students programming and one student rehearsing his choreography as his partner controls the computer.

Student choreography notes. As the students choreographed and rehearsed their cell-inspired dances in the physical realm with partners, they made their own choreographic notes on paper. These notes served two note-taking purposes while the students were rehearsing: 1) to help them remember their sequences and movements from one week to the next and 2) to assist them in transferring their choreography onto their virtual characters and modifying it. We collected 22 choreography notes, one from each pair (12 from Monday's class and 10 from Friday's class). Each pair organized their notes differently, some with bulleted lists with written text, others with numbered drawings of stick figures performing individual moves (see later Figures 8 & 9).

Group discussions. At the end of many of the sessions, we came together as a group to reflect on what we had done or to assess student understanding, particularly of computational thinking. Upon the completion of the project, we had a group discussion about the entire process that was quoted in the opening vignette of this paper. These discussions, led by a member of the research team were videotaped, and student responses were coded in the qualitative analysis. Semi-structured discussion questions included asking students what they enjoyed, what challenged them, what they wanted to spend more time on, as well as thoughts on the relationship between dance and computer programming. Rather than a formal, group interview, a discussion occurred with students raising their hands and sharing their thoughts based on our prompts as in the opening vignette.

Data Analysis

As described in more detail below, statistical software was used to analyze the quantitative data. The qualitative data was analyzed using several rounds of strategic qualitative coding. Both quantitative and qualitative strategies remained essential to our data analysis due our research questions asking about the ways in which students use embodied ways of thinking and how they support student knowledge of computational thinking concepts, practices, and perspectives. Both these questions require examination of qualitative data, and the latter necessitates the measure of computational thinking, as well.

Quantitative survey analysis. Scores were obtained from the pre-test and post-test for computational thinking. They were marked out of a total of 10, where 1 point is for a right answer and 0 points for a wrong answer. The biographical survey also was analyzed quantitatively with respect to their school subject preference, computer usage, and orientation towards dance. The data then was

analyzed using IBM© SPSS Statistics software to run various forms of analysis, like the paired sample t-test, the independent sample t-test, Pearson's correlation, and Spearman's correlation. The respective graphs (see later Figures 6 & 7) were also generated using the software mentioned. Only significant results from these tests are presented in this article.

Qualitative discourse analysis. Qualitative analysis of the video and photographic data and accompanying observation notes, parts of the biographic survey, and student choreographic notes consisted of three rounds of strategic coding for themes. During the first round of coding, qualitative data was organized via descriptive—words or phrases about topics—and in vivo—quoted words or phrases—coding (Saldaña, 2013). For example, researchers introduced students to the concept of a conditional in programming by prompting them to "fill in the blank": "If I clean my room, ____." Students responded, "I get a treat," or "I make my mom happy." Moments like this were coded descriptively as "introduction to programming concepts." When students were explaining the characteristic of a cell membrane as "semi-permeable," allowing nutrients in and keeping toxins out, the students' in vivo quotes were coded, such as "like a water filter," "like the security at the airport," or "like a linebacker."

A second round of coding was conducted to determine and develop thematic categories and patterns that emerged from the initial codes. Using a combination of pattern coding—identifying emergent themes (Miles & Huberman, 1994; Saldaña, 2013) and focused coding—searching for the most frequent or significant themes (Charmaz, 2006; Saldaña, 2013)—the descriptive and in vivo codes were organized into four large and at times overlapping thematic codes that also directly corresponded to the Discourses involved: (a) computational thinking—a set of concepts, practices, and perspectives that draw upon the world of computing and remain applicable across multiple disciplines; (b) dance & embodiment—related to dance elements, vocabulary, and practices; (c) cell biology—related to defining and representing cell structure and function; (d) multimodal representations—related to when students transferred knowledge from one mode to another, such as dance to programming or programming to verbal discourse.

Based on the patterns that emerged from these four thematic codes, a third round of theoretical coding focused on the nuances within these categories, particularly the fourth category of multimodal representations. Based on a grounded theoretical analysis, theoretical coding condenses themes into the central phenomenon, core experience, or common explanations of the participants that seem to explain, "what this research is all about" (Strauss & Corbin, 1998, p. 146 as cited in Saldaña, 2013, p. 224). Analyzing these instances in the qualitative data, relationships between the multimodal representations and student meaning making emerged, highlighting the complexity of the students' literacy practices and illuminating the quantitative findings. When the students represented their knowledge of cells, their dancing, and programming, they expressed their ideas across multiple modes of representation and discourse, demonstrating what they knew and how that related to their prior knowledge, experiences, and interactions with peers.

Discussion

After conducting both quantitative analysis of the survey and questionnaire data and qualitative analysis of the students' notes, video, photographic, and interview data, we found that the students: 1) improved their computational knowledge, and 2) engaged in complex and meaningful, embodied practices while computer programming. We also found that the process of choreographing a dance and programming a complimentary virtual character's dance based on curricular content afforded the students opportunities to engage in a "constellation of [multimodal] literacy practices" (Steinkuehler, 2007, n.p.).

Analysis of Pre- and Post-computational Thinking Test

Only significant results are presented in the findings. There were significant learning gains when the

difference in scores of the pretest (M = 4.66, SD = 2.12) and posttest (M = 5.82, SD = 1.67) were analyzed using paired samples T-test, t (43) = 3.447, p = 0.001 (Figure 6). The pre-test and post-test scores were also found to be significantly correlated, r = 0.329, p = 0.029.

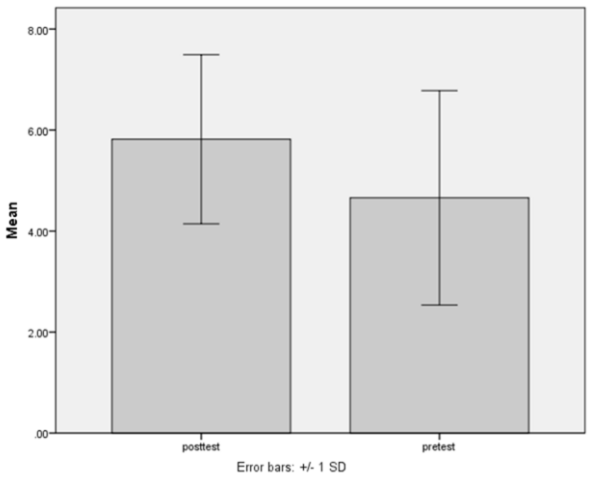


Figure 6. Pretest and posttest comparison. This bar graph depicts the means and standard deviations of the posttest and pretest scores of the computational concept test.

Quantitative Analysis of the Biographical Survey

Another significant finding was that those students who identified themselves as having received formal dance training scored higher on the post-test (M = 5.82, SD = 1.67), t (42) = 2.54, p = 0.015 (Figure 7). While we cannot determine causation, we hypothesize that this finding might be related to the overall project's effectiveness with students more inclined or versed in dance as a form of inquiry and expression. Therefore, they may have benefited from engaging in computational thinking through embodied practices. While we conducted further statistical analysis of the computational thinking test and biographical data, no conclusions could be drawn due to the small sample size. Also, there were minimal data gaps for those students who were absent during the administration of the pre- or post-computational tests or survey.

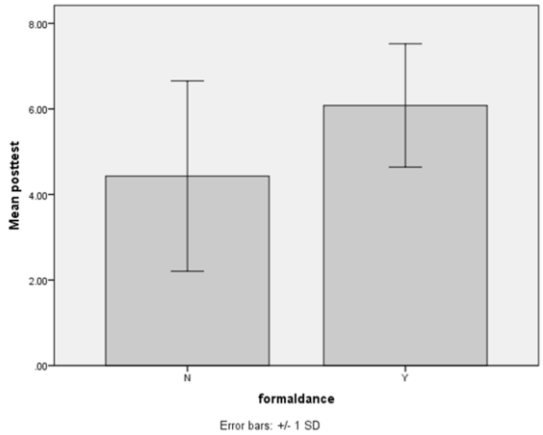


Figure 7. Comparison between groups with and without formal training. Means and standard deviations of the scores attained by Y (group received formal training) and N (group did not receive formal training).

Qualitative Findings

Based on the quantitative data analysis, we note that the students' computational thinking and knowledge significantly increased. The processes that enabled this change were captured qualitatively, and through our analysis with a focus on emergent themes, we have two significant findings in the students' experiences. First, in response to our research question, we noted that the students engaged in a variety of embodied ways (through choreography, physical demonstrations, gestures, and drawings) in order to program and perform with their characters. Secondly, these embodied engagements were varied and diverse, yet still centering on their choreography and programming, serving to paint a complex picture of the students' overall experiences and meaning making during this project.

Moreover, the students engaged in numerous forms of multimodal literacy practices throughout. We believe the accumulated and related literacy practices through these varied d/Discourses formed a "constellation" of multimodal literacy practices (Steinkuehler, 2007, n.p.), improving their increased performance on the computational test. In addition, engaging in this constellation of multimodal literacy practices supported the application and synthesis of their knowledge through the choreographic and programming experiences, connecting the discursive, disciplinary knowledge and relating computer programming, dance, and school curriculum.

A constellation is an imagined shape that stars form when viewed as a group. When looking at literacy practices as a constellation, each practice is linked to a star. When viewed together, as in a constellation, these practices illuminate a more complex picture of how these individual practices form student knowledge and meaning making. More discussion on Steinkuehler's (2007; 2010) use of this term will follow this discussion.

The following are coded scenarios elucidating the range of multimodal literacy practices that students engaged in where they also utilized various forms of d/Discourse, calling upon specific various funds of knowledge (Gee, 2008; 2011; 2014; Gonzalez et al., 2005; Moje, et al., 2004). First varied embodied literacy practices are exemplified, demonstrating the complexity of these practices and how they are inherently multimodal with verbal, written, and pictorial forms embedded within them. They are organized into four coded categories: directed, autonomous, verbalizing, and documenting. Following embodied literacy practices are examples of computational thinking (concepts, practices, perspectives) as literacy practices, exhibiting the multimodal examples of students choreographing, programming, verbalizing, and documenting with the computer. Within this discussion, there is a subset of examples showcasing how students utilized the literacy practice of problem solving.

Embodied literacy practices. Consistently throughout the project, the students embodied their inquiry and knowledge in numerous ways. The students engaged in directed creative movement activities where the researchers invited the students as a group to embody a cell, to perform and loop a sequence of steps, or to remember a sequence by dancing it. In embodying the content, they were expressing their knowledge using movements and movement phrases similar to how one might express knowledge with written text. Also, they were given the opportunity to engage in more autonomous creative and original embodied interpretations of the curricular content through their dances and the problem solving strategies of choreographing while programming.

Directed embodied literacy practices. When reading and comprehending any form of text, one has to interpret meaning. To introduce the students to computational concepts of sequence, loops, and conditionals, one of the researchers invited volunteers to perform a simple movement, such as moving their arms up and down then taking small steps in a pattern on the floor. She then asked the students to loop this sequence three times for the class. At times, a volunteer would leave a step out or perform something in a similar pattern but not the same, exact pattern. After completing their loop, the researcher would question the students, "Is this a loop?" A discussion would then commence since to be an actual loop, the repeated sequence has to be exact. Reading each other's movements allowed the students to think and respond critically. Here verbal questioning, group discussion, and movement modes supported each other. Picture each mode as a star, connect them to reveal part of the constellation—a representation of the students' knowledge and literacy practices.

Autonomous embodied literacy practices. To be literate denotes skills that deal will autonomy, being able to communicate and interpret meaning independently. When the students were asked to create their cell dance sequences, the students were given inspiration from our explorations embodying the cell and also from the cell poem that had both very literal and abstract corresponding movements. They then had to interpret these inspirations and create their own movements and sequences. For example, when performing the stanzas about the nucleus, one of the movements was marching with fisted hands. In one pair's written notes, they wrote, "control her" next to two stick figure dancers. Since they were unable to program the virtual characters to execute these moves due to the program's constraints, they modified the movement to have the characters marching, referring to one of the moves from the movement poem and as a symbolic action of power. While many of the students also added marching to their physical and virtual choreography, others expanded upon the idea of the nucleus being the control center. To depict the nucleus, the cell's central organelle, one dyad enacted a sense of power in their dance by miming a puppeteer controlling a

puppet (Figure 8). In another dance, the students shook their fingers as if telling someone what to do.

During another instance when one student volunteered to embody the nucleus in an activity, another student is captured on video saluting the nucleus volunteer, alluding to the role of the nucleus as a commander of the cell.

Figure 8. Image of student choreography. Dyad on the right of the image rehearsing their choreography for the nucleus. Student on right is "controlling" the other student with her hand above her partner's head. Note the choreographic notes on the floor

.Additionally, one of the poem's stanzas noted that the vacuoles "are like the closet, cubby, and waste bin." Likewise, one pair of students described their vacuole movement in their dance as "[he] grabs me and pushes me down" because the vacuole "stores things." In that same dance, based on the cell membrane and its semi-permeable qualities as "the fence to keep what I need in and the boundary to keep what I don't need out," the students described their cell membrane movements as "[he] grabs me and pulls me in then pushes me out." This instance demonstrates how the students took what they knew about the cell structures and related them to concepts that they were familiar with, abstracting the movements in ways that made sense to them. In these autonomous embodied literacy practices, the students transmediated knowledge across speech, writing/drawing, and movement. Part of the creative process of choreography allows for this artistic license, and the students made these choices independently, writing and speaking with their bodies and on paper in autonomous ways that were syntonic, relatable to them, based on their own funds of knowledge (Leonard et al., 2015; Gonzalez et al., 2005; Moje et al., 2004; Papert, 1993).

Verbalizing embodied literacy practices. Part of the students' sharing of their dances involved performing their dances alongside their virtual characters whose performance was projected, using an interactive whiteboard. They performed the dance once in silence and a second time, talking through their choreography to note the cell inspirations and their computer programming (Figure 9; Video below). At times, it was quite obvious what cell structure the students were representing physically and virtually, and at others, when explained, there was often an "ooh" or "ahh" from the larger group when the students explained. For example, two students explained in their second performance, talking through their choreography that the kicking motion meant to "kick things out" of the cell that the semi-permeable cell membrane would if they were bad for the cell. The collective audible audience response revealed a collective understanding and reading of that movement in relationship to what they knew about the cell.

Figure 9. Students performing with virtual characters. The students are dancing in front of a projection of their virtual characters dancing.

In this video, two students perform their cell dance in front of a screen projecting some of their programmed choreography. If you look closely, you can see the character on the left moving on the screen. After performing the dance once, the students perform it again and talk through their choreography.

After each performance, the audience of students, teacher, and researchers were invited to provide feedback using the prompt of TAG: Tell something that you noticed; Ask a question about what you saw; and Give some positive feedback. Therefore, these descriptive and peer feedback verbalizations of the work added another layer of text to the already complex text of the physical and virtual dance and the programming and choreographic work that went into it. Instances like these strengthen the overall constellation of literacy practices since each practice adds to the larger picture. During one performance, the students dancing dramatically dropped to the ground as their virtual characters disappeared on screen for a couple of seconds. Once they reappeared, the students stood up and continued to dance. During the TAG session, one student remarked that the disappearing part was "cool" and wished he had figured that out on the computer. The performers explained, "We disappeared because you cannot see the cells because they are so small." From the group, audible responses were heard since part of the poem noted that the cell "is the smallest unit of life." When the cells were introduced, it was discussed that one needs a microscope to see cells, but after that, only the line from the poem reminded the students of this. Interestingly, this resonated with the students, and they communicated by abstracting the concept physically in their movement of dropping low to the floor "to hide" and by programming the characters to disappear briefly—a feature on the program that was not presented formally to the group but one that they found on their own from their own exploration.

Additionally, the students verbally expressed their aesthetic choreographic choices, showcasing their dance literacy and the notion that being literate allows for aesthetic expression and representations. During a TAG session, one student asked, "Why did you chose to make [your dance] graceful instead of sharp?" alluding to the fact that the constraints of Looking Glass did not allow for the characters' motions to be fluid; as a result, they were often clunky, rigid, and sharp, and therefore, many students' dances mirrored this quality, as many tried to perform their dance to match their characters'. The students, along with feedback from their dance teacher, discussed how people have different "style preferences." Also, these performers, with extracurricular dance funds of knowledge, wanted the dance to look polished and graceful. Part of the reason it was graceful was that they executed the movements in unison. They explained that since they were not using music, they choreographed the dance to be very specific so that they could "stay together." Here the verbal and physical explanations relied on each other, exhibiting how different modes of communication are embedded within embodied literacy practices.

Documenting embodied literacy practices. The students' choreography notes provided insight into how they transducted their corporeal knowledge using the pen and paper media in both written and pictorial forms. It is also interesting to note that when the students explained their dances during the performance, at times they misspoke or seemed to be confused about what a particular structure was called. They seemed to know their function but mixed up the cytoplasm and the cell membrane. However, from examining their choreography notes, it is clear what movements, via drawings or descriptions, matched which structure, and they were all correct on paper.

In addition, the students documented their choreography in a variety of forms: using written text; stick-figure drawings; symbols depicting a direction or quality of movement, such as an arrow or squiggle; and with numbers, bullets, or boxes to depict order of sequence. On several of these choreography documentations, the students expressed knowledge of computational concepts. For example, in Figure 10, the students drew separate boxes for each movement and each dancer's movements. Whether or not this was influenced by the box format used in Looking Glass to separate an individual character's distinct motion in an action ordering box to denote a specific order of the sequence is unclear, but a parallel between the pictorial representation and computer representation was noted. Also, this pair of students noted how many loops to perform using the computer programming language.

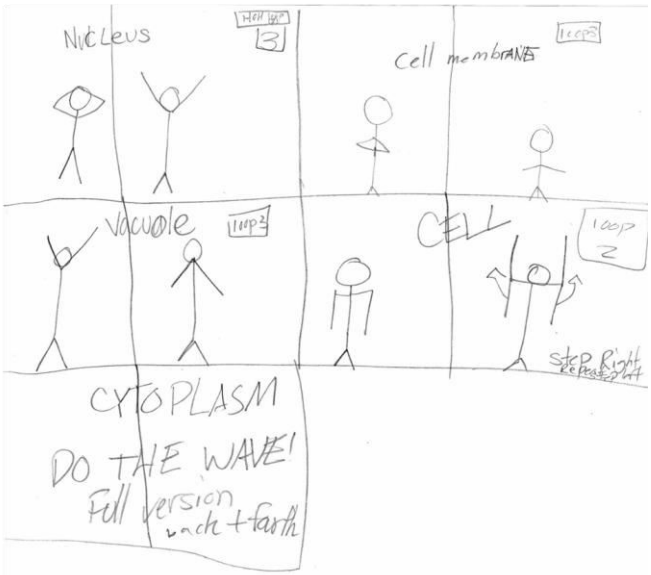


Figure 10. Example of student choreography notes. In this choreography note, the students place each movement and dance in a separate box. Note the instructions for loops.

In another choreography note, the students noted their choreography in a list of key movements and then wrote out the dance in a sentence-like form with annotations about sequence, who performs and in what order, and when in unison (Figure 11). They noted the unison as "do together," the same language used in the computer program. They annotated their unique sentence form with a bracket around the movements referenced. This structure also is reminiscent of the action ordering boxes in Looking Glass (Figure 2). Since the written and drawn texts represented physical movements and programming structures that students manipulated in the programs, these documenting instances also make another form of embodied literacy practices, illustrating how embodied literacy occurs in multimodal forms.

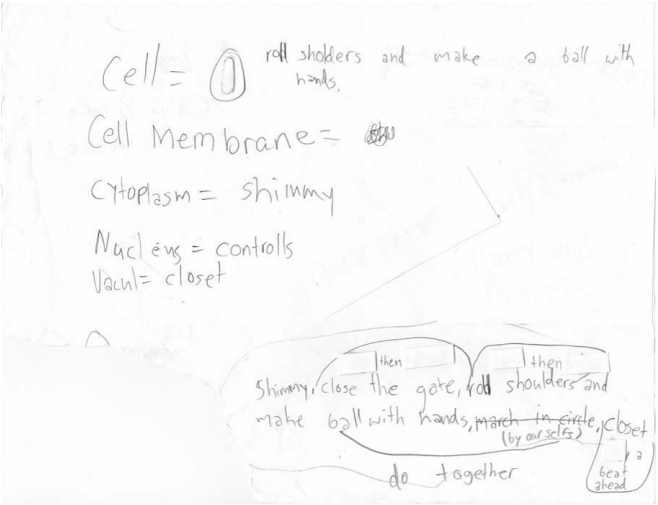


Figure 11. Example of student choreography notes. In this choreography note, the students made a key of their movements and then wrote them in a sequence below that is reminiscent of a sentence. It also includes parts to "do together" and who performs first and then who follows: "___ then ___." Please note that the students' names have been covered.

Computational thinking as embodied literacy practice. Throughout the project, the students were developing their computer literacy and computational thinking skills. For the project, we brought in MacBook Pro laptops, one per dyad. While some students have Mac computers at home, the students used PCs in school; therefore, navigating on a different operating system with its unique format, key sequences, and a touchpad mouse was a skill many needed to develop. In many ways, the students have to learn new ways of moving their hands on the computer to direct the activities on the screen. Even their dance teacher was more familiar with a PC. Since there were only three researchers to assist with technical questions and between 20 and 22 students, often the students had to play on their own to problem solve or, at times, assist each other. Thus, they became collectively proficient on using the Mac technology quickly.

Like a constellation, each literacy practice that the students engaged in from adapting and interpreting concepts into movements and programmed coding language to verbal, written, and pictorial explanations was part of a larger picture. Pieced together, these practices formed an individualized picture of the students' knowledge and meaning making.

One of our main research questions seeks to learn about the students' experiences and development of computational thinking skills with computational concepts, practices, and perspectives. Concepts are like the computing tools (sequences, loops, conditionals, parallelism[1]). Practices are the processes of using those tools (iterating, reusing, and remixing[2]), and perspectives are ways of seeing computing as a tool for self-expression (Daily et al., 2015; Brennan & Resnick 2012a; 2012b). While it became clear through the increase in scores from the pre- to the post-computational thinking test, as well as in the group discussions and activities, that the students were developing a greater understanding of computational concepts and their applications, it also became clear by observing their interactions while on the computer (using the computer, directing their partners to use the computer--pointing and using the mouse pad) and discussing in the group interviews that they were also developing computational practices and perspectives through embodied means.

For example, during one session, a student asked for some assistance in creating a loop. To create a loop, one can drag numerous boxes of the same movement over to the Looking Glass workspace. Another student overheard this and chimed in to explain that there was another, possibly more efficient way to create a loop that he remembered seeing demonstrated on another day. Pointing and gesturing to the computer, he explained that one could use an action-ordering box and choose to enter in the number of times to loop a particular action. Here the students were learning an important computational perspective—thinking like a programmer: that there is often more than one way to execute a task.

Another student remarked that one of her favorite parts of the project was that one could "try out different things to make it go good [sic] and figure out the right moves at the right time and do it again and again to make [the character's] arms go up at the same time using a 'do together' box." What she was explaining was the computational practice of iterations. Computer programmers often must try multiple iterations to perfect a sequence, working on it over and over again. Students were commonly seen playing a preview of their character dancing, then examining the coded sequence to check to make sure it was correct, and then playing the preview again and again until they figured out what needed to be fixed. This process aligns well with the computational practices of iteration (continuously refining code) and debugging (a structured process for finding errors in code). Moreover, through programming the choreography and the watching and critiquing of the previews of the character dancing, they were once again using embodied literacy practices, ones directly related to the body and their understandings of how bodies move.

Students also noted a sense of empowerment in knowing how to make the computer "do what [we] want." Another remarked, "I just like programming in general, controlling the computer and telling it what to do." Here this control and ability to manipulate by programming and moving blocks of code, again relates to the body's role in how we compute, controlling actions on the screen with motions of our hands, clicks of buttons, and reading digital texts and physically responding to them on screen. Relating to the broader context of computing, another student responded, "If we want to do this [computer program in the future], we know how to do it." One student explained that you don't have to be a "techie" or good with technology to computer program. Since during this project it was clear to him that "we all can program; we are all programmers!" Yet, one of his peers disagreed and responded that he was not sure that they actually were "programmers" because his "dad is a computer programmer and he knows a lot of things. It takes a lot of smarts [sic] at the highest level. You have to put in your time." Referring to this broader computer science context, it was interesting to note that the students who had the most intensive and extensive knowledge of programming and had spent significant time using other programming platforms felt that Looking Glass and this introductory level of programming to "not be programming." It seemed that the majority of the students with minimal programming experience, who did not use computer programs in their spare time, felt more empowered and optimistic about their programming abilities during our group interview session.

Problem solving. Even in the most traditional sense of literacy, problem solving remains essential (National Institute for Literacy, n.d.; Steinkuehler, 2007). Since the students were given the task to choreograph and program their own dance sequences in dyads, problem solving and doing so collaboratively became a huge part of their experience during the project. Consistently, the students encountered the challenge of programming a complementary dance for their characters when the capabilities of the virtual character did not parallel their own. As one student explained, the characters "couldn't do exact things like people," and so different dyads solved this problem in various ways. In fact, one student remarked that since the physical and virtual dance did not have to be exact, that that made the process easier for her and her partner.

In one dance, the students wrapped their arms around each other to depict the cell membrane, but in the virtual dance, the characters made a 360-degree turn instead. Both movements had a "rounded" element to them but were not the same. Other students had more intricate motions in the physical dance for the nucleus that were reminiscent to a puppeteer controlling a puppet, while another group used their arms as the "hands of a clock" to signify that the nucleus "controls the whole operation," but then these groups programmed their characters to simply march in place. Yet, the marching move was one that directly corresponded to the movement poem, noting again the transfers across discourse.

Another dyad chose to focus more upfront on the programmed dance. Once their character's movements were completed, they re-choreographed their physical sequence to match the virtual one. The only move that was different was when they motioned with their hands to create a round shape, like a cell, from the poem, while their characters clapped instead. Here both movements dealt with the hands. Their physical aesthetic performance style even matched the rigid, sharp movements of the character. Rather than be concerned about the virtual character not being "like a human," they danced like the character.

Other students shared their choreography and programming strategies. In one dyad, one student felt more comfortable dancing and the other programming so they split up the work and then taught each other what they had done. In order to match the timing of the character with the physical dance, others noted that they would take turns pressing play on the laptop while one would dance, and then would switch. Another pair of students was trying to figure out how to program two characters to perform in unison. They asked a student from another group to explain how he figured it out. He then instructed his peers to locate the specific command action, "Do Together" to group movements together and to populate a "Do Together" box of code with the same movements for each character.

Constellations of Multimodal Literacy Practice

When conducting research on MMOGs, Steinkuehler (2008) found that they allowed for a "constellation of literacy practices," (p. 302), rather than degraded or replaced traditional forms of literacy. Contrary to public criticism of online gaming, her research findings broaden definitions of literacy, critically and empirically defending multimodal forms of literacy. Calling upon the New London Group's (1996) contextual and in-practice notion that "literacies (plural) crucially entail sense making within a rich, multimodal semiotic system" (Steinkuehler, 2007, p. 300), her research demonstrates how MMOGs engage players in varied but related literacy practices. From in-game literacy practices of communicating with other players to fan sites and blogs, "MMOGs entail not only (inter)action in the game's virtual environment but also the production and consumption of online fandom content in the form of discussion boards, website contributions, creative endeavors such as writing stories, and the like. At the **micro level** of a given moment in an individual's gameplay, participation means movement among multiple" spaces of reading and writing. Thus, the literacy practices that comprise MMOGs are "not isolated and autonomous but, rather, interrelated in complex and mutually defining ways" (Steinkuehler, 2007, p. 303).

Moreover, Steinkuehler (2010) explains that unlike other media forms, "video games are about a back and forth between reading the game's meanings and writing back into them" (p. 61). Therefore, players can inscribe their intentions within the game's narrative space, exemplifying digital literary practice.

Our project merging movement and computer programming, while not a MMOG, allowed for meaning making and literacy practices within a complex multimodal semiotic system. Like in the MMOGs, the students were engaging in a particular activity that required multiple forms of literacy that were interconnected and inherently multimodal. To program, one had to interpret the dance and communicate its meaning with the biology, inscribing one's own understanding and prior knowledge. Working in dyads and groups, giving each other feedback and assistance, the experiences were innately multimodal and always about representation and the transmediation of knowledge. Steinkuehler (2010) notes, "All interaction is multimodal. Our communication is more than what is said and heard but by what we perceive through expressions, gazes, gestures and movements" (p 61).

Like a constellation, each literacy practice that the students engaged in from adapting and interpreting concepts into movements and programmed coding language to verbal, written, and pictorial explanations was part of a larger picture. Pieced together, these practices formed an individualized picture of the students' knowledge and meaning making. Like a constellation that is made from the connections of individual stars to create an image, these practices connect to demonstrate knowledge by depicting student knowledge. Just as stars can be a part of multiple constellations, here these practices can make connections in different ways for different students, forming individualized constellations of practice.

In the beginning of the paper, students were quoted as discussing the process of transferring knowledge in one form, dance, to another, programming. They noted the ease of this process since it was something that they could relate to. Even though the students did not note explicitly all the other transmediation processes that they went through during this project at this time, they too were powerful and effective due to that knowledge being of a syntonic relationship to the students (Papert, 1993). Even more, students enhanced their experiences and connections across curriculum and knowledge calling upon their own funds of knowledge from their extracurricular experiences and home life (Gonzalez et al., 2004). Relating knowledge to something that made sense to them allowed them to engage across discursive contexts.

Discourse is never just about language. Gee explains, "Discourses are ways of speaking/listening, writing/reading, acting, interacting, valuing, thinking, and using objects, tools, technologies, places and times, to recognise and get recognised as having specific (often contested and negotiated) socially situated identities" (St. Clair & Phipps, 2008, p. 93). While computer science, dance, and biology might not be realms that one thinks of as related, the students were able to make connections, relate knowledge, and reshape them through varied yet connected multimodal literacy practices. Thus, the d/Discourses were utilized in transdisciplinary ways. Moreover, in translating biology to dance to computer programming, the students were engaging and making connections across these socially and professionally situated networks. And the accumulation of their experiences seemed to make a constellation of multimodal literacy practices for each student.

Literacy is continually shaped by social and cultural contexts. And these constellations of multimodal literacy practices are indeed culturally and socially situated in this particular school and research context but also in our broader global and digital context. Computer science, in a rapidly and continually growing technological world, stands as foundational for educational advances and impact. This project hopes to open up pathways, allowing more students to engage in d/Discourses of professional fields, like computer science and dance, merging this knowledge with one's own syntonic knowledge (Papert, 1993). Gringrasso (Curran et al., 2011) writes, "Becoming literate resembles a journey one engages in as a lifelong process more than a state one achieves that 'gradually builds reading fluency and thinking abilities' " (p. 28; Gordon & Gordon,

2003, xv). Embodying and programming a constellation of multimodal literacy practices visually and physically maps part of that journey of becoming literate for these students.

Conclusion

Over a period of eleven weeks, VEnvI (Virtual Environment Interactions) researchers facilitated workshops in creative movement, programing, and science. The goal was to have students choreograph and perform original dances along with projections of their virtual characters, which had been programmed by the students to perform complementary choreography representing functions of cells. Seeking to make connections between the artistic process of choreographing a dance and the compositional process of programming a character, we investigated the ways in which the students made meaning through their experiences in embodied ways.

Working in dyads to choreograph and program, the students merged curricular science content with embodied, social, and computational knowledge. Ultimately, this case study intervention has inspired design revisions to our ongoing development of our virtual environment platform, VEnvI. Following this case study, we began using our platform during research scenarios and continue to develop its design and functionality. Our hope is that it will be available in the near future for download by students, teachers, and families.

Most significant from this case study interaction, we found that students improved in their overall computational thinking knowledge and skills. Employing multimodal literacy practices, the students also engaged in and negotiated multimodal and multimedia texts and discourse: programming, computing, dance, conversing, writing, and drawing (Kalantzis, Cope, & Cloonan, 2010; Kress, 2003; New London Group, 1996). Thus, through these embodied literacy experiences that were inherently multimodal, the students were interweaving literacy practices, utilizing and representing across multiple modes of discourse to communicate and represent knowledge while also negotiating multiple Discourses related to computer programming, dance, and school (Gee, 2008). Examining how the students made connections across d/Discourse in this multimodal process—navigating computer programming, dance, and traditional forms of literacy and language in school—becomes reminiscent of a constellation, therefore creating a constellation of multimodal literacy practices (Steinkuehler, 2007).

Informed by scholarship and theories of embodiment and cognition, constructivist learning, and literacy perspectives (Dils, 2007; Hanna, 2014; New London Group, 1996; Papert, 1993), this research demonstrates the complex, multimodal processes of reconstructing and recreating curricular knowledge in schools through embodied means, related to multiple forms of media: movement, speech, writing, drawing, and computers. We acknowledge that the positive effects on student knowledge and meaning-making through our research interventions have been possible largely in part to the multimodal, embodied literacy practices that students engaged in during their virtual environment interactions, blending and navigating computer programming and dance within a school context. According to the dance instructor, integrating technology and dance was a positive, new experience for her and the students and opened the door to new possibilities. The students have been asking for more experiences like this one, and she is inspired to make it happen. Ultimately, in conducting and sharing this research, we seek to expand the professional and academic possibilities for K-12 students through opening up pathways that synthesize knowledge across and through digital media, computer science, and arts disciplines.

References

Albers, P., Holbrook, T. and Harste, J.C. (2010). Talking trade: Literacy researchers as practicing artists. *Journal of Adolescent & Adult Literacy*, *54*(3), 164-171.

Alice (2x) [Software]. (2008-2013). Pittsburgh, PA: Carnegie Mellon University. Retrieved from http://www.alice.org/

Bers, M., & Horn, M. (2010). Tangible programming in early childhood: Revisiting developmental assumptions through new technologies. In I. Berson & M. Berson (Eds.), *High-tech tots: Childhood in a digital world* (pp. 49–70). Charlotte, NC: Information Age Publishing.

Block, B. & Kissell, J. L. (2011). The dance: Essence of embodiment. *Theoretical Medicine, 22*(1), 5–15.

Brennan, K., & Resnick, M. (2012a). *Using artifact-based interviews to study the development of computational thinking in interactive media design*. Paper presented at annual American Educational Research Association Meeting, Vancouver, BC, Canada.

Brennan, K., & Resnick, M. (2012b). *New frameworks for studying and assessing the development of computational thinking*. In 2012 annual meeting of the American Educational Research Association. Vancouver, Canada.

Bresler, L. (Ed.). (2004). *Knowing bodies, moving minds: Towards embodied teaching and learning.* Dordrecht, The Netherlands: Kluwer Academic Publishers.

Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *Journal of the Learning Sciences, 2*(2), 141–178.

Charmaz, K. (2006). *Constructing grounded theory: A practical guide through qualitative analysis*. Thousand Oaks, CA: Sage.

Clements, D. H., Battista, M. T., & Sarama, J. (2001). Logo and geometry. *Journal for Research in Mathematics Education Monograph Series,10.*

Cooper, S., Dann, W., & Pausch, R. (2000). *Alice: A 3-D tool for introductory programming concepts*. In Proceedings of the fifth annual CCSC northeastern conference on the journal of computing in small colleges. USA: Consortium for Computing Sciences in Colleges. Retrieved from http://dl.acm.org/citation.cfm?id=364132.364161

Cope, B., & Kalantzis, M. (Eds.). (2000). *Multiliteracies: Literacy learning and the design of social futures.* London: Routledge.

Curran, T., Gingrasso, S., Megill, B., & Heiland, T. (2011). *Forging mutual paths: Defining dance literacy in the 21st Century*. Conference proceedings, National Dance Education Organization. Minneapolis, MN. Retrieved from http://www.academia.edu/1859913/Forging_Mutual_Paths_Defining_Dance_Literacy_in_the_21st_Century--Dance-based_Dance_Literacies

Daily, S. B., Leonard, A. E., Jörg, S., Babu, S. V., Gundersen, K., & Parmar, D. (2015). Embodying computational thinking: Initial design of an emerging technological learning tool. *Technology, Knowledge and Learning, 20*(1), 79-84.

Design-Based Research Collective. (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher*, *32*(1), 5–8.

Dils, A. (2007). Why dance literacy? *Journal of the Canadian Association for Curriculum Studies*, *5*(2), 95-113.

diSessa, A. (2001). *Changing minds: Computers, learning, and literacy*. Cambridge, MA: The MIT Press.

Drodge, E.N., & Reid, D.A. (2000). Embodied cognition and the mathematical emotional orientation. *Mathematical Thinking and Learning*, *2*(4), 249-267.

Fadjo, C. L., Jr., G. H., Harris, R., & Black, J. B. (2009). Surrogate embodiment, mathematics instruction and video game programming. *World Conference on Educational Multimedia, Hypermedia and Telecommunications* (pp. 4041-4046). Chesapeake, VA: AACE.

Foster, S. L. (1995). *Choreographing histories: Manifesto for dead and moving bodies*. Bloomington, IN: Indiana University Press.

Frambaugh-Kritzer, C., Buelow, S., & Steele, J. S. (2015). What are the disciplinary literacies in dance and drama in the elementary grades? *Journal of Language and Literacy Education 11*(1), 65-87.

Gee, J. P. (2008). *Social linguistics and literacies – Ideology in discourses* (3rd ed.). New York:Routledge.

Gee, J. P. (2011). *How to do discourse analysis: A toolkit*. New York: Routledge.

Gee, J. P. (2014). *An introduction to discourse analysis: Theory and method*. New York: Routledge—Taylor and Francis Group.

Gonzalez, N., Moll, L.C., & Amanti, C. (2005). *Funds of knowledge – Theorizing practices in households, communities and classrooms*. New York: Routledge—Taylor and Francis Group.

Gordon, E. E., & E. H. Gordon. (2003). *Literacy in America: Historic journey and contemporary solutions*. Westport, CT: Praeger Publishers.

Gross, P. A., Herstand, M. S., Hodges, J. W., & Kelleher, C. L. (2010). *A code reuse interface for non-programmer middle school students.* In Proceedings of the 15th international conference on intelligent user interfaces. ACM.

Hanna, J. L. (2008). A nonverbal language for imagining and learning: Dance education in K—12 curriculum. *Educational Researcher*, *37*(8), 491-506.

Hanna, J.L. (2014). *Dancing to learn: The brain's cognition, emotion, and movement*. Lanham, MD: Rowman & Littlefield Publishing Group, Inc.

Hoyt, L. (1992). Many ways of knowing: Using drama, oral interactions, and the visual arts to enhance reading comprehension. *The Reading Teacher*, *45*(8), 580-584.

Jewitt C., Kress, G., Ogborn, J., & Tsatsarelis, C. (2000). Teaching and learning: Beyond language. *Teaching Education*, *11*(3), 327-341.

Johnson-Glenberg, M.C., & Hekler, E.B. (2013). "Alien health game": An embodied exergame to instruct in nutrition and *MyPlate*. *Games for Health Journal: Research, Development and Clinical Application*, *2*(6), 122-131.

Jones, S. (2013). Literacies in the body. Journal of Adolescent & Adult Literacy, 56(7), 525-529.

Kalantzis, M., Cope, B., & Cloonan, A. (2010). *A multiliteracies perspective on the new literacies*. New York: Guilford Press.

Kress, G. (2003). *Literacy in the new media Age*. New York: Routledge.

Lancy, D. F. (1993). *Qualitative research in education: An introduction to the major traditions*. White Plains. NY: Longman Publishing Group.

Leavy, P. (2015). *Method meets art: Arts-based research practice*. New York & London: The Guilford Press.

Leonard, A. E., & Daily, S.B. (2013). Dancing in virtual environments (DIVE): Computational and embodied arts research in middle school education. *Voke, 1*(1), 1-26.

Leonard, A. E., Hall, A. H., & Herro, D. (2015). Dancing literacy: Expanding children's and teachers' literacy repertoires through embodied knowing. *Journal of Early Childhood Literacy,* 0(0) 1–23. DOI: 10.1177/1468798415588985

Liao, Y. K., & Bright, G. (1991). Effects of computer-assisted instruction and computer programming on cognitive outcomes: A meta-analysis. *Journal of Educational Computing Research, 7*(3), 251–268.

Looking Glass [Software]. (2014). St. Louis, MO: Washington University. Retrieved from http://lookingglass.wustl.edu/

Lu, C. M, Kang, S., Huang, S. C., & Black, J. B. (2011). *Building student understanding and interest in science through embodied experiences with LEGO robotics.* In Proceedings of World Conference on Educational Multimedia, Hypermedia and Telecommunications. Chesapeake, VA: AACE.

Lu, M. T. P., Hallman, G. L. & Black, J. B. (2013) Chinese character learning: Using embodied animation in initial stages. *Journal of Technology and Chinese Language Teaching, 4,* 1-24.

Mavers, D. (2015). Remaking meaning across modes in literacy studies. In J. Roswell & K. Pahl (Eds.). The Routlege Handbook of Literacy Studies (pp. 282-294). London & New York: Routledge—Taylor and Francis Group.

Miles, M. B., & Huberman, A.M. (1994). *Qualitative data analysis*. Thousand Oaks, CA: Sage.

Mioduser, D., Levy, S., & Talis, V. (2009). Episodes to scripts to rules: Concrete-abstractions in kindergarten children's explanations of a robot's behaviors. *International Journal of Technology and Design Education, 19*(1), 15–36.

Moje, E.B., Ciechanowski, K.M., Kramer, K., Ellis, L., Carrillo, R. & Collazo, T. (2004). Working towards third space in content area literacy: An examination of everyday funds of knowledge and Discourse. *Reading Research Quarterly, 39*(1), 38-70.

National Institute for Literacy (n.d.). *What is literacy?* In Frequently Asked Questions. Retrieved from http://www.nifl.gov/nifl/faqs.html

New London Group (1996). A pedagogy of multiliteracies: Designing social futures. *Harvard Educational Review, 66*(1), 60-92.

Papert, S. (1993). *Mindstorms: Children, computers, and powerful ideas.* New York: Basic Books, A Division of HarperCollins Publishers, Inc.

Resnick, M., Maloney, J., Monroy-Hernandez, A., Rusk, N., Eastmond, E., Brennan, K., et al. (2009). Scratch: Programming for all. *Communications of the ACM, 52*(11), 60–67.

Saldaña, J. (2013). *The coding manual for qualitative researchers*. Thousand Oaks, CA: Sage.

Seglem, R., Witte. S., & Beemer, J. (2012). 21st century literacies in the classroom: Creating windows of interest and webs of learning. *Journal of Language & Literacy Education, 8*(2), 47-65.

Siegel, M. (1995). More than words: The generative potential of transmediation for learning. *Canadian Journal of Education, 20*(4), 455–475.

Stake, R. E. (2008). Qualitative case studies. In N. K. Denzin & Y. S. Lincoln (Eds.), *Strategies of qualitative inquiry* (3rd ed., pp. 119–150). Thousand Oaks, CA: Sage.

St. Clair, R., & Phipps, A. (2008). Ludic literacies at the intersections of cultures: An interview with James Paul Gee. *Language and Intercultural Communication, 8*(2), 91-100.

Steinkuehler, C. (2007). Massively multiplayer online gaming as a constellation of literacy practices. *E-Learning and Digital Media, 4*(3), 297-318.

Steinkuehler, C. (2010). Video games and digital literacies. *Journal of Adolescent and Adult Literacy, 54*(1), 61.

Strauss, A., & Corbin, J. (1998). *Basics of qualitative research: Techniques and procedures for developing grounded theory*. Thousand Oaks, CA: Sage.

Tedlock, B. (2008). The observation of participation and the emergence of public ethnography. In N. Denzin & Y. Lincoln (Eds.), *Strategies of qualitative inquiry*. Thousands Oaks, CA: Sage Publications, Inc.

Tolentino, L., Birchfield, D., Megowan-Romanowicz, C., Johnson-Glenberg, M., Kelliher, A., & Martinez, C. (2009). Teaching and learning in the mixed-reality science classroom. *Journal of Science Education and Technology*, doi: 10.1007/s10956-009-9166-2.

Wang, F., & Hannafin, M. J. (2005). Design-based research and technology-enhanced learning environments. *Educational Technology Research and Development*, *53*(4), 5–23.

Warburton, E. C. (2011). Of meanings and movements: Re-Languaging embodiment in dance phenomenology and cognition. *Dance Research Journal*, *43*(2), 65-83.

Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review, 9*(4), 625-636.

Wing, J. M. (2006). A vision for the 21st Century: Computational thinking. *Communications of the ACM, 49*(3), 33-35.

Appendix

Included here is the 10-question computational pre- and post-test.

ID_____

The following questions aims to gather information on how you think. Please answer the questions to the best of your ability. Please relax and have fun with the following questions.

Put an X next to the best answer for each of the following questions.

1. **The blocks below will cause the character to clap as shown in the figures. How many times will she touch her hands together?**

a. Two times _____
b. Four times _____
c. Six times _____
d. None of the above _____

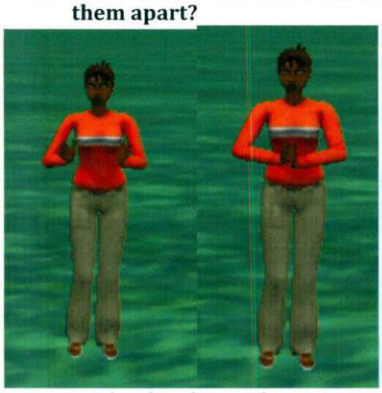
2. **Based on the blocks below, when the character finishes clapping, will her hands be together or apart?**

a. Her hands will be apart ____
b. Her hands will be together _____

--------->

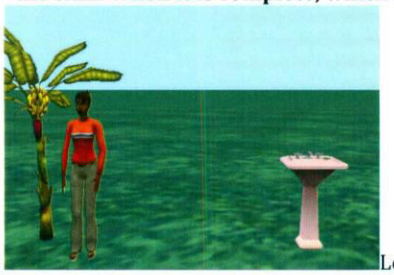
ID_____

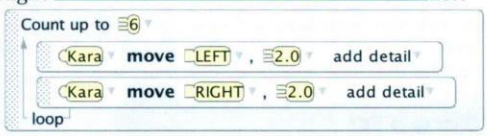
3. Based on the blocks below, will the character put her hands together or hold them apart?



a. put her hands together _____
b. hold her hands apart _____

4. The code below will make the character move in between the banana tree and the sink. When it is complete, which item will she be standing next to?

Right  Left



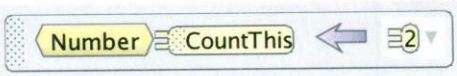
a. She will be next to the Banana tree _____
b. She will be next to the sink ____

5. What is a variable?

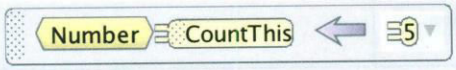
--------->

ID_____

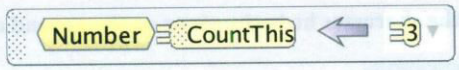
6. Which block will set CountThis equal to 5?

a. 

_____

b. 

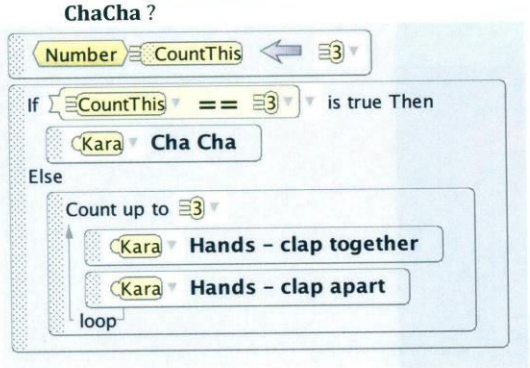
_____

c. 

_____

d. None of the Above _____

7. Based on the blocks below, will the character clap her hands or perform the ChaCha ?



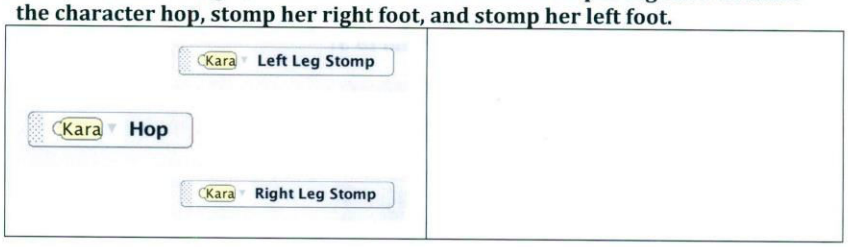
a. Cha Cha
b. Clap hands

8. Describe a loop.

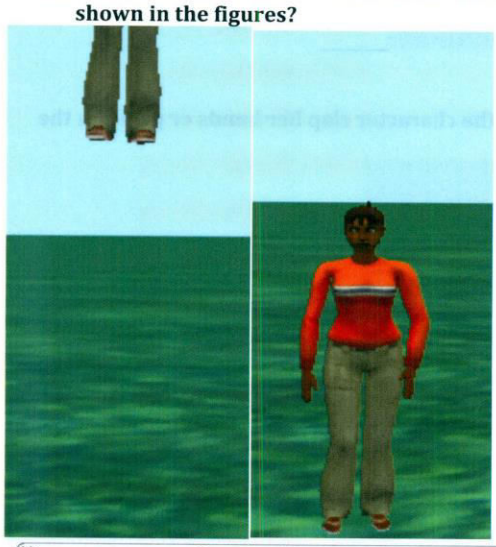
--------->

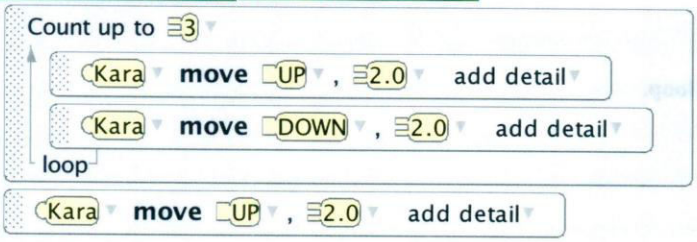
ID_____

9. **In the box on the right, draw how the blocks should be put together to make the character hop, stomp her right foot, and stomp her left foot.**



10. **When the code is finished will the character be in the air or on the ground as shown in the figures?**





a. **In the air ____**
b. **On the ground _____**

---------->