Towards a 3D Virtual Programming Language to Increase the Number of Women in Computer Science Education

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ABSTRACT

We propose a 3D Virtual Programming Language to provide an interactive tool for beginners and intermediate students. We believe that the direction of our research will help increase the recruitment and retention of women in CS. We developed an initial prototype and surveyed students to determine the figures that work best. Our results show that it is hard for CS students to provide clear 3D representations for programming concepts in some instances yet we were able to derive some common figures.

Index Terms: H.5.1 [Multimedia Information Systems]: Augmented reality—Mixed Reality; K.3.2 [Computer and Information Science Education]: Computer Science Education—

1 Introduction

Building Block Programming (BBP), such as MIT's Scratch have proven to be of value for Computer Science (CS) education in K-12 and College. The value of BBP lies not in reduced complexity but in that it provides a learning environment where concepts can be integrated by students at a faster, more satisfactory rate. It has been shown (see Section 2) that BBP has improved recruitment and retention of women and minorities in CS. Research has shown the importance of diversity in that it promotes greater creativity, better decision-making, and outcomes [27,35]. Nonetheless, the number of women (as well as minorities) in CS remain very low in spite of the fact that women represent more than 50% of the students enrolled in post-secondary institutions since 1980 [1]. Furthermore, CS had a larger representation of women until 1983/1984, when numbers began to decline and they have continued to fall ever since – with a current average of 14.1% in the United States.

In search of a way to include more people into CS, we have started developing a virtual reality solution for K-12 and College level education (with emphasis on the latter population) using BBP. We called our approach a 3D Virtual Programming Language (3D-VPL) as a means to provide an interactive tool for beginners and intermediate students. Our 3D-VPL language objective is to generate Python code that can construct small 3D animated applications in the same environment. One of the biggest challenges we face is interpreting different concepts of a programming language in a 3D environment. This research study provides an early attempt to understand the ideal objects to be used based on how CS students visualize programming concepts, in order to improve our 3D-VPL. Research done in different schools has shown that re-designing introductory courses improves womens recruitment and retention in CS, such as the study performed at Georgia Tech [19]. Our work shows one available option to increase CS understanding by providing a 3D BBP language.

1.1 Contribution

While our contributions target first-year undergraduate CS students, this work also applies to K-12, in particular high-school students as this is the pipeline towards higher education. Our contribution is twofold: (1) provide an early-stage Virtual Reality 3D BBP prototype and (2) evaluate visual representations of 3D concepts based on student feedback.

1.2 Motivation and Challenges

The number of women in CS does not complement the ideal diversity for the 21st century [4]. In the year 1983/1984, 37% of CS degrees were awarded to women, but by 2010/2011 only 17.6% of them were awarded to women. The CS degrees awarded to women have continually decreased at a 20% rate from 2000/2001 to 2005/2006, and an even higher 22.3% rate from 2005/2006 to 2010/2011. In 2013, NSF reported womens graduate rates in CS to be only 18%. The May 2015 Taulbee survey (reporting data from Research 1 (R1) schools for 2013/2014) shows the national graduation rates for women in CS to be at 14.1%, a significant decrease since its peak at 37% in 1984 [20].

Research has demonstrated that Technology Mediated Learning Environments can enhance learning. Virtual Reality (VR) provides a higher-level of immersion, through Head-Mounted Displays (HMD) and Cave Automatic Virtual Environments (CAVE). These environments can be shared by multiple users, in real time, and are key in the development of the next generation learning methods in CS, as well as the improvement in recruitment and retention for women and minorities in the CS major. The drive to increase diversity for women in CS comes with a set of challenges:

Mitigating myths and stereotypes: Misconceptions pose a major barrier for more diverse CS environments. For example, women incorrectly believe that their GPAs are lower than their male counterparts [7, 8]. It is also said that even when women do succeed in CS it is only because they are "exceptional" [8, 21]. Another stereotype is that CS is boring [4] and only about programming (machine-centric) [36]. However, in reality, there are many CS sub-fields which encourage interaction with people (e.g., Human-Computer Interaction). This can be considered a barrier because women have better interpersonal orientation than men [8, 37]. Women also generally think that a career in CS is incompatible with raising families [3]. Media has also played a role in the development of these stereotypes (e.g., War Games, Mr. Robot, The Big Bang Theory) since the early 1980s [15]. Another stereotype is that video games are not be useful, however, research has shown that playing video games can result in improved spatial abilities in both men and women [14]. Based on these findings we can argue that video games should be encouraged for both men and women.

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Recruitment and Retention: Another barrier is the lack of knowledge that CS is an option to women entering college. This includes not knowing that the major is offered, as well as the belief that one is not fit for a career in this field. When choosing to enter a career in the the natural sciences and engineering fields men average 16 years of age in comparison to 20 years of age for women [8]. This challenge creates an opportunity to engage female students in early stages (high school and freshmen college students). Once students are recruited, the next challenge is retention: this requires social awareness in faculty about womens barriers in CS [16, 18].

Improving interest and motivation: A positive attitude, satisfaction with academics, commitment to college, and a sense of belonging and social connectedness all contribute to success in school [25]. Interest in the field being learned is an important factor in determining the completion of a degree, as higher congruence between ones interests and environment "leads to greater satisfaction, performance, and persistence in activities" [6, 31]. Stimulating interest in the academic environment enhances learning and correlates with a multitude of positive academic and occupational outcomes, including course selection, achievement, and persistence in a given field of study or career [6].

Developing interpersonal and self-directional skill for leadership: According to the Council of Graduate Schools Report from 2012, many graduates from four-year colleges do not possess these skills. The type of projects that we include in this proposal will not only increase the number of women in computing, as research has shown [8, 27], but we believe that it will provide more interpersonal and self-directional skills for leadership to all students. There is a clear need for higher education that puts a greater emphasis on the knowledge of human cultures, intellectual and practical skills, and accepting social and personal responsibility (Partnership for 21st century).

Degree completion for Women: There are multiple factors that may affect student departure from the STEM fields; however, many studies show that minority students are more likely to leave college before graduation. Women in CS are not an exception [16]. The number of degrees awarded to women in general continues to decline, while those of African-American and Hispanic women remain unchanged [27]. Research has identified various ways to improve recruitment and retention to lead to a higher number of degrees awarded [15, 19, 27]: (a) create a pre-introductory course (CS-0); (b) redesign introductory courses (CS-1); (c) require students to do pair programming, as it has shown to be effective [39]; (d) encourage female students to do research and attend conferences early in their studies; and (e) create projects that promote greater social awareness, interpersonal and cooperatives skills, among others.

Through our approach, we hope to mitigate the challenges listed above. We hypothesize that the proposed project will help female students (and other groups) become better equipped for computer science (and interdisciplinary) problem solving, be able to apply their knowledge to new situations, improve motivation and interest in their coursework - and therefore increase their chances for retention and degree completion.

2 Background

Aiding computer programming has yielded amazing platforming, such as MIT's Scratch (Scratch Jr.) and Alice. It has become extremely popular to provide BBP options for kids as well as introductory courses in college. There is no silver bullet when it comes to improving CS courses. Techniques have extended to tangible interfaces [22–24, 53], 2D BBPs that generate games [33, 40, 47], AR and VR games [30, 43], and other game-based learning techniques [5, 38], among others [42, 49].

Computer Science education technology designed to promote learning has been previously explored. For instance, Li et al. conducted a study wherein 18 different virtual environments were created to visualize and understand concepts, such as Turing Machines and processor instructions [32]. Parmar et al. devised a VR environment where students were able to learn CS concepts by making a virtual avatar follow dancing movements performed by the students [41]. This study in particular is aligned with our vision, which provides different types of projects (e.g., dancing avatars). In addition, incorporating high-fidelity visuals and engaging experiences are key components in enticing students to further their educational pursuits in CS. Concept abstraction and simplification, when possible, have been suggested by Forte and Guzdial as a key factor to improve retention rates and concept understanding [19]. Abstraction and simplification in CS have been explored as well [13]. In addition to virtual reality, AR provides a different look at traditional virtual environments (VEs) to explore different uses cases. Research shows that new developments in AR, coupled with improved user interface technology, presents numerous opportunities to support of teaching and learning environments [9, 17, 28, 46, 51]. Various efforts have explored and promoted the advantages of AR environments to further CS education. As an illustration, Zha et al. conducted a study wherein it was demonstrated that AR minimizes the gap between high-performing and low-performing students by improving learning effectiveness in the classroom [52]. In addition to aiding students, collaboration is key component for learning. For example, [34] devised an AR solution that allows students to create augmented notes and pin them in their surroundings, these notes could be seen by other students, thus fostering teamwork and innovation. Finally, and relevant to our work and one of our pillars of this proposal, Vitzthum used AR to create visual language [48]. Other studies showing the transition from BBP have also been explored [29], as well as comparison studies between BBP and textual programming [42].

3 Making a case for 3D BBP

As mentioned in Section 2, there has been previous work related to using AR and VR with education, including the area of programming. A recent effort by Radu and MacIntyre developed an AR solution for kids between the ages of 9 and 11 (of existing MIT Scratch users) to exploit spatial cognition in 2D for various reasons including that (a) Scratch does not have a 3rd dimension, (b) to continue using a screen-centric environment, and (c) based on one previous study, children of 6 and 7 years of age had problems when motions of the physical objects did not map the virtual objects [44]. The difference with the work by Radu and MacIntyre [44] with our approach is that we target an older population, which are high-school upper class-men (junior and senior) and first year college students. In addition, Al-Tahat et al. showed that female students in the experimental group, which used Alice (a screen-centric 2D and 3D environment), performed significantly better in assessments in comparison to the control group. [2]. Women are also less likely to play video games; therefore, introducing women to a game-like environment would introduce them to a similar experience. This assumption is based on previous investigation by Carter who found that a significant number of men choose a Computer Science track based on their interest in video games [12]. It is also important to note that our environment provides a collaborative opportunity, which has been shown (by doing pair-programming) to improve retention and confidence [39]. Our approach attempts to tackle the recruitment and retention problem, the latter a problem in the first years of college [11]. Finally, it is important to note that our proposed approach is meant to be adaptive, allowing students to evolve from pure BBP to hybrid (see Figure 1) BBP (with code) and eventually to commonly used programming environments [47].

4 3D-VPL: Virtual Programming Language

Our approach called 3D Virtual Programming Language (3D-VPL), a 3D BBP for VR and AR, is a programming language the leverages new immersive technology to develop programming concepts,

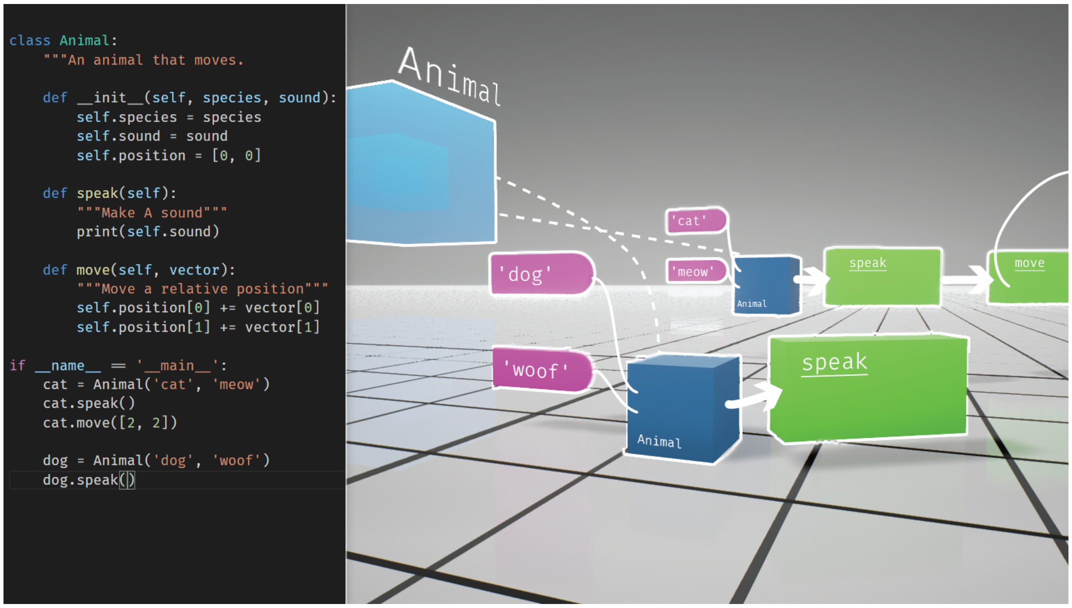

Figure 1: 3D VPL

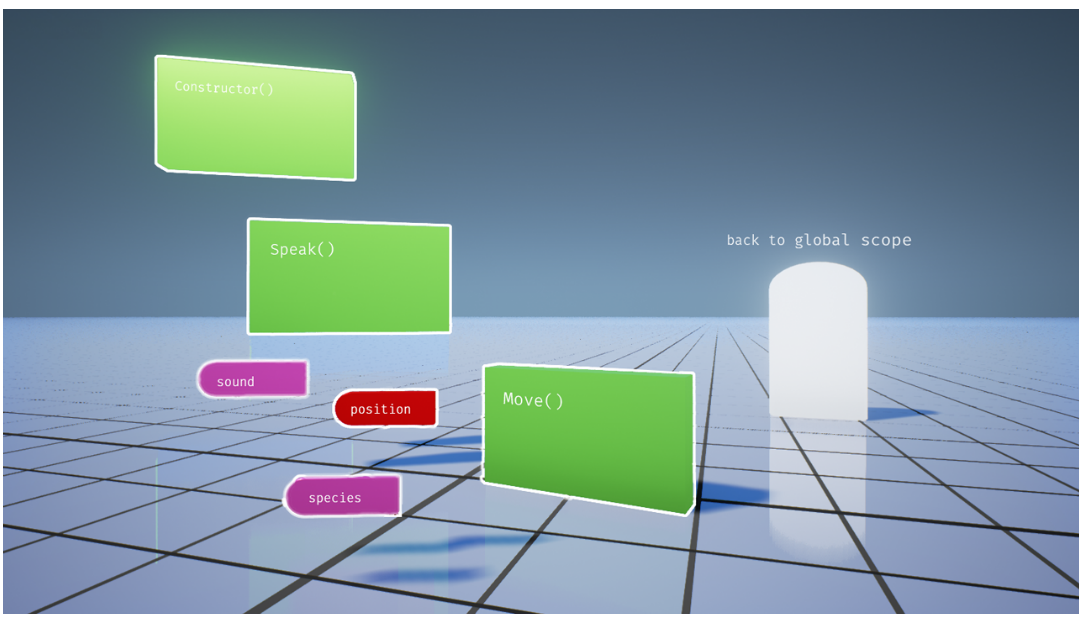

Figure 2: Inside Class

using block-based programming (BBP) to bridge students into traditional programming. In addition, 3D-VPL is designed with pair-programming and team-based problem solving in mind. The fundamental idea is that BBP, together with pair-programming which has shown positive results [45, 50], results in more proficient and confident programmers [39], and may help increase CS representation, in particular women in minority [27, 39]. In addition, the possibility to reach non-traditional CS students makes 3D-VPL a great tool.

3D-VPL's primary objective is to provide a bridge from BBP to traditional programming using our technology. 3D-VPL is meant to create simple and fun programs where students can learn by visualizing concepts and placing them together. The emphasis on our research is based on previous work that has provided paths for increasing the women population in CS [27, 39]. 3D-VPL is the middle ground between BBP option, designed with kids (or young-adults) in mind (e.g., Scratch and Scratch Jr.), and other options, generally designed with game developers in mind (e.g., Unreal Engine Blue Prints). By design, it provides a more realistic path towards CS core concepts [26], while providing the benefits of BBP.

Our approach seeks to utilize 3D environments to represent BBP, allowing students to use a large real-state area to explore and understand programming concepts with different options depending if using a computer desktop, a tablet, or a VR head-mounted display (HMD). For example, Figure 1 provides a view of a small running program using 3D VPL on the right, and the code representation on the left (Python). In this particular case, a class (Animal) is represented by semi-transparent cube, while the objects (cat and dog) are represented with blue cubes. The properties and methods are also shown, in pink and green respectively. The power of this solution is the ability to move around to add and remove objects and add depth to programming. While BBP has shown to improve students education in CS (see §2), it is not clear if the 3D part of VPL will provide the same, or better, results. This is part of our on-going research. However, some evidence seems to point into that direction [2].

3D-VPL provides ways to get inside of class or function to better visualize the inner parts of them. For example, Figure 2 provides a look into the class (Animal), which allows developers to add and remove methods and attributes. A part of our research learning whether this provides a better approach to 2D BBP options, but some research has shown that 3D environments are favorable for women in computing [2]. VPL also provides a 2D BBP not only for comparison, but also because certain projects will favor the more familiar 2D BBP. Another advantage of VPL is that it will run in head-mounted displays (HMDs), VR CAVE, and AR HoloLens, among others.

Another feature of 3D-VPL is the ability to pair-program, which has also shown to improve CS education, particularly in women and minorities [39]. The opportunity offered by VR and AR provides a natural space for collaboration. For example, Microsoft HoloLens provides the interface for multiple of these lenses to work in tandem using the space around (because HoloLens maps its surrounding) and the collaboration between them using special markers already built-in. This makes VPL more than a BBP language but a collaborative platform to enhanced programming. It is important to note that the current version of BPL has not been designed for AR.

5 Eliciting Programming 3D Representations

In our initial research, we found that the shapes used were not ideal for beginners. To address this, we conducted a survey with 50 CS students (40 males, 10 females) in their junior/senior year of their CS undergraduate education. Note that all students have already taken data structures and programming III. We selected students at this level because our questions required a certain degree of CS knowledge. We found that creating a unique set of 3D representations was not easy. In many cases, students were unable to reach a concensus in regards to which shape best represented the given concept. For example, questions would be asked as follow: ”How should a function be represented in 3D?” While at this point we cannot provide a set of figures that have agreement rate, we did collect common 3D representations (in some cases included 2D drawings) in Figure 3. In general, we can see that variables can be identified with blobs (shapeless fluids), empty boxes, or the most interesting representation - a box with question marks printed on each face. Functions could be described as interlocking gears, factory conveyor belts that receive raw materials and produce an input, any kind of hardware tool, or puzzle pieces that can interlock with other pieces. Objects can be identified as any real life object, just like a multi-face cube, person, car, or chair. Classes can be either a completed puzzle, every piece interlocked and on its place, or a cube containing small boxes (variables) and puzzle pieces (functions). Class Inheritance had very broad illustration but most of the drawings show figures sharing a piece from their parent. If-Statements were described as a road that becomes two or more different roads, loops were portrayed as spinning wheels or infinite loops, and the most interesting one was a road with a roundabout that only allows following the road only once the condition is met. Data Structures were illustrated as DNA Helix, Building, binary trees, or the most interesting depiction was a cube with the characteristic of a chemical formula. The closest molecule would be the Cubane molecule without the hydrogen bonds. Last was the List, which involved a page with items as a list, boxes linked together, empty boxes and a train. In a follow-up survey which included 47 participants (31 males and 16 females with average age of 25.5) of different majors (20 Computer Science, 19 Engineering, and 8 from others majors) and levels (17 graduate, 16 senior, 7 junior, 3 sophomore, 2 freshmen, and 2 unreported), were presented with a survey where they could pick the image the best represented the concepts of interest. The top figures selected in this follow-up study are shown with an asterisk in Figure 3. It is important to note that [10] tried to develop common figures for 2D icon-based programming. The question still remains if a user-set will derive better results that an expert-design. This question will be explored as part of our future work.

6 Conclusion

We are motivated not only by the difference that diversity promotes, but also by immersive technologies creating new opportunities for educational interventions. Within this context, VR & AR promise to enhance face-to-face communication by providing spatial cues to support group interaction. We have shown that 3D BBP may provide an option for introductory classes, as well as the demonstration of 3D representation of possible objects. Furthermore, this system would make learning more enjoyable and interactive, qualities valued in learning by women in particular.

Future work will include the development of a set of figures to create simple 3D-VPL applications using a VR HMD. The experiment will be conducted with users testing different shapes and producing a small sample program. Students will be recruited from CS and non-CS majors. We want to learn the difference between students that have some interest in computer science and possibly some background versus those who do not. In addition, we want to continue investigating which shapes certain objects are best represented by in 3D environments (through surveys to non-CS majors). Finally, our main goal is to determine if a subset of students may benefit from spatial learning using 3D-VPL requires further research.

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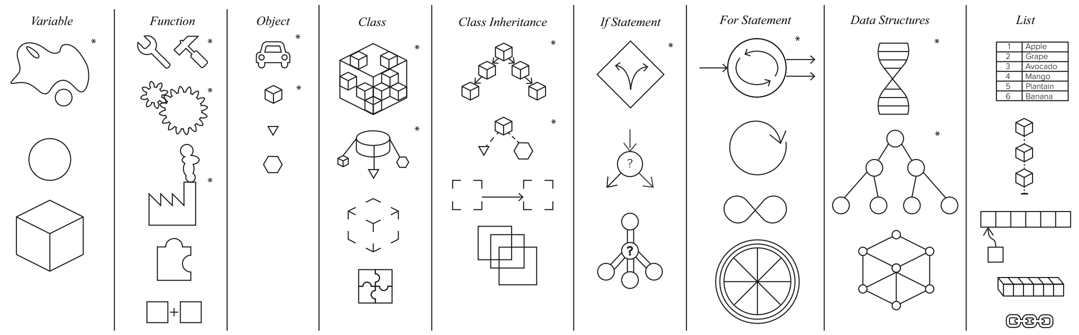

Figure 3: 3D Representations of Programming Concepts Provided by Students

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