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

Francisco R. Ortega∗ Santiago Bolivar† Jonathan Bernal‡ Alain Galvan§ Katherine Tarre¶ Naphtali Rishe‖ Armando Barreto∗∗

Miami, FL.
Florida International University

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 [26,34]. 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.

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 [15,17].

**Improving interest and motivation:** A positive attitude, sat-
sisfaction with academics, commitment to college, and a sense of
belonging and social connectedness all contribute to success in
school [24]. Interest in the field being learned is an important factor
in determining the completion of a degree, as higher congruence be-
tween ones interests and environment “leads to greater satisfaction,
performance, and persistence in activities” [6,30]. Stimulating inter-
est 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 leader-
ship:** 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 [8,26], 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 [15]. The
number of degrees awarded to women in general continues to de-
cline, while those of African-American and Hispanic women remain
unchanged [26]. Research has identified various ways to improve
recruitment and retention to lead to a higher number of degrees
awarded [14, 18, 26]: (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 [38]; (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 intro-
ductory courses in college. There is no silver bullet when it comes to
improving CS courses. Techniques have extended to tangible inter-
faces [21–23, 52], 2D BBPs that generate games [32, 39, 46], AR and
VR games [29,42], and other game-based learning techniques [5,37],
among others [41, 48].

Computer Science education technology designed to promote
learning has been previously explored. For instance, Li et al. con-
ducted a study wherein 18 different virtual environments were cre-
ated to visualize and understand concepts, such as Turing Machines
and processor instructions [31]. Parmar et al. devised a VR envi-
ronment where students were able to learn CS concepts by making

a virtual avatar follow dancing movements performed by the stu-
dents [40]. This study in particular is aligned with our vision, which
provides different types of projects (e.g., dancing avatars). In addi-
tion, 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 pos-
ible, have been suggested by Forte and Guzdial as a key factor to
improve retention rates and concept understanding [18]. 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 for improving learning
and learning environments [9, 16, 27, 45, 50]. Various efforts have
explored and promoted the advantages of AR environments to fur-
ther 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 [51]. In addition to aiding students,
collaboration is key component for learning. For example, [33] de-
vised 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 [47]. Other studies showing
the transition from BBP have also been explored [28], as well as
comparison studies between BBP and textual programming [41].

## 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 [43]. The
difference with the work by Radu and MacIntyre [43] 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 [38]. 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 [46].

### 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 lever-
geages new immersive technology to develop programming concepts,
using block-based programming (BBP) to bridge students into tra-
ditional programming. In addition, 3D-VPL is designed with pair-
programming and team-based problem solving in mind. The funda-
mental idea is that BBP, together with pair-programming which has shown positive results [44, 49], results in more proficient and confident programmers [38], and may help increase CS representation, in particular women in minority [26, 38]. 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 [26, 38]. In addition, the possibility to reach non-traditional CS students makes 3D-VPL a great tool.

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 Blueprints). By design, it provides a more realistic path towards CS core concepts [25], 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 [38]. 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 we were using were not ideal for beginners. To address this, we conducted a survey with more than 50 CS students in their junior/senior year of their CS undergraduate education. We selected students at this level because we needed to ask questions that required CS knowledge. We found that creating a unique set of 3D representations was not easy. In many cases, we were not able to find agreement from the surveys. 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 30 participants of different majors, the top figures selected 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.

REFERENCES


