Implementing a 3D Logo Environment for Learning Mathematics: Potentials and Challenges

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Abstract: *This paper presents an initial implementation of a 3D Logo environment named 'VRMath 2.0' for learning mathematics. As indicated by its name, VRMath 2.0 employs a desktop virtual reality (VR) and the web 2.0 technologies. Educationally, VRMath 2.0 will inherit the power and benefits from the microworld paradigm. Moreover, its educational value will be further extended by its 3D VR interface and web 2.0 style of content creation. The potentials of this learning environment include, but not limited to, the enabling of a wide range of opportunities to investigate and develop human spatial abilities, via an online platform with knowledge building community. The challenges, however, are firstly revolving around the technical issues of implementing a sustainable application, and secondly, our imaginations on how to evolve and utilize this learning environment for learning and research.*

The Context

Computer learning environments have played an important role in mathematics education for some decades. Over the years, powerful computational paradigms rose and shifted as technologies evolved (See detailed review in Hoyles & Noss, 2003). Among these computational paradigms, the Logo Microworld, 3D computer graphics and the Web-based learning environments are of particular interests to this author. Therefore, during 2002 to 2003, this author developed an online virtual reality learning environment (VRLE) named VRMath (Figure 1), in an effort to engender new ways of thinking and doing about mathematics (Pea, 1985; Resnick, 1996).

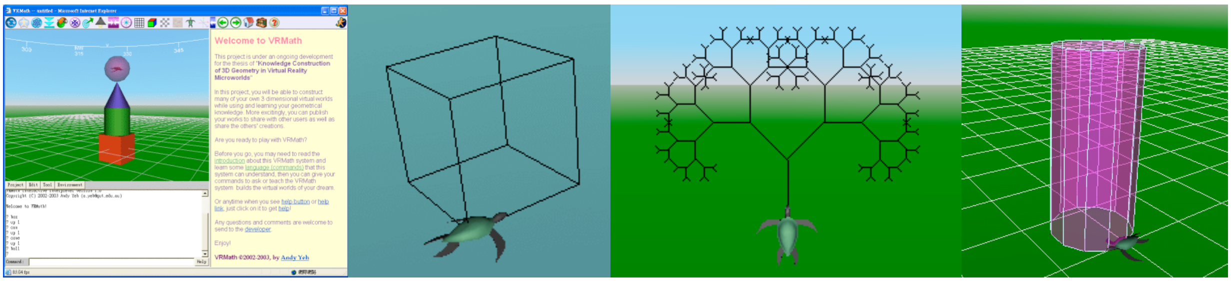

Figure 1. VRMath screenshots

The design of VRMath was largely informed by semiotics (Yeh & Nason, 2004) and constructionism (Kafai & Resnick, 1996), which served as the theoretical foundation and epistemological ground. Technologies were then chosen to implement such a computational learning environment for mathematical meaning making. This paper, however, will not focus on the discussion of theoretical and philosophical background. Instead, the focus of discussion will be on its technological and functional aspects, from which the potential mathematical learning can be manifested. VRMath had a built-in Logo interpreter, which outputs to a 3D virtual space instead of a traditional 2D graphic. The ramifications of this 3D Logo environment were not only the traditional Logo learning activities could be repeated but also the added-on 3D virtual space enabled a new perspective on investigating and developing a wide range of human spatial abilities (Pittalis & Christou, 2010). Unfortunately, in 2007, the 3D technology for virtual space rendering and the native virtual machine for powering the Logo programming language in VRMath have both stopped their support and development. This has resulted in the re-implementation of VRMath by adopting more sustainable technologies and platforms. VRMath 2.0 has, since 2010, started its implementation.

2. The current VRMath 2.0 implementation

To be technologically sustainable, the selection of technologies for implementing VRMath 2.0 has mainly concerned about the use of open standards/sources and not to rely on third party proprietary software (e.g., 3D plugin). In light of this, VRMath 2.0 is being implemented using completely open standards and sources. These include a content management system (CMS) for user management and content creation, HTML5[1] and JavaScript®[2] for the Logo programming interface, and X3D[3] and WebGL[4] for its 3D virtual space. Another important open source technology named X3DOM (Behr, Eschler, Jung, & Z¨ollner, 2009), which integrates HTML5 and X3D, is chosen to bridge the communication between the programming and the 3D interfaces. Because these technologies are all web based open standards, VRMath 2.0 must, and can be freely accessed online, whenever there is Internet connection and a web browser. Figure 2 below shows a snapshot of the current implementation of VRMath 2.0.

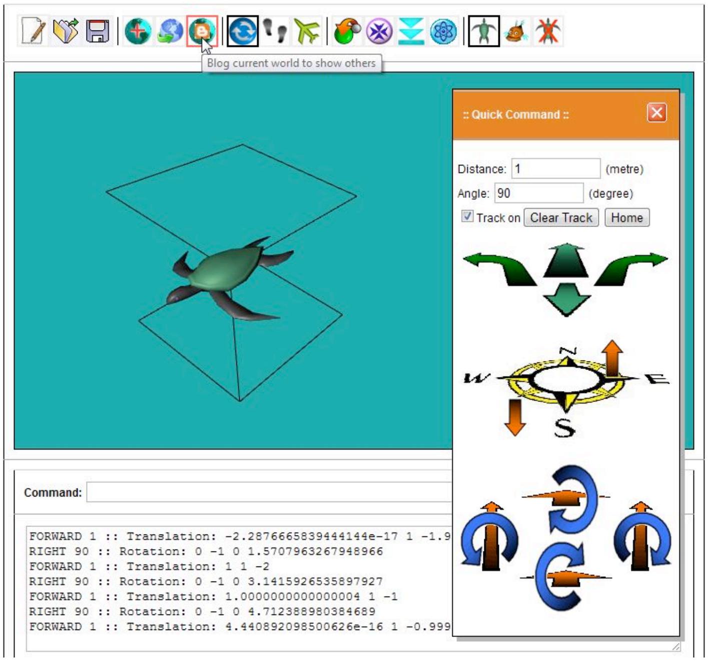

Figure 2. Prototype of VRMath 2.0

[1] HTML5 is the core language of the World Wide Web: the Hypertext Markup Language (HTML). See http://www.w3.org/TR/html5/
[2] JavaScript® is a lightweight, object-oriented language, most known as the scripting language for web pages. See https://developer.mozilla.org/en/JavaScript
[3] X3D is a royalty-free open standards file format and run-time architecture to represent and communicate 3D scenes and objects using XML. See http://www.web3d.org/about/overview/
[4] WebGL is a cross-platform, royalty-free web standard for a low-level 3D graphics API. See http://www.khronos.org/webgl/

The current focus of implementing VRMath 2.0 is, as the title indicates, on the web-based 3D Logo environment. This current prototype has been trialed in a STAR (Spatial Thinking And Reasoning) project (Yeh, 2011) with primary school students. The implementation has presented great challenges but this learning environment also showed great potentials for learning and doing mathematics. At the same time, this author is also aware of other technological developments such as visual programming (e.g., Scratch), computer algebra systems (CAS), and dynamic geometry systems (DGS) etc., and their merits in facilitating the learning of mathematics. It is highly possible that some features of these paradigms, for example the dragging and animating figures of DGS, can be integrated into VRMath 2.0. This paper will now proceed to discuss these potentials and challenges.

3. The potentials and challenges

3.1 Of the VR space

VR has a very unique configuration of 3D space as it imitates the real world. It offers what normal 2D/3D graphics can do, but differs from normal 2D/3D graphics in the following ways:

1. Unlike the normal 2D/3D graphics with Cartesian coordinate system, the VR space including the virtual objects in the virtual space are specified using the units of measurement such as meter. This way, not only the Cartesian coordinate can be applied but also the relative sizes of objects can be made sensible.
2. VR has environmental cues such as panoramic background, sky colors, light and shadow, collision and gravity etc. The environmental cues can usually provide feedback to learners with the awareness of their location and orientation, as well as other virtual objects in space.
3. The interactivity in VR space has a strong sense on first person navigation. This means that quite often in VR space, the learners' spatial orientation abilities are in action. Many 3D applications mainly focus on the rotation of objects, thus only the spatial visualization abilities are called into action.
4. Objects in VR space can have behaviors or animate with certain rules. Objects can also be manipulated via mouse or keyboard. The moving objects combined with navigation in VR space will call the spatial relation abilities into action.

One of the great potentials in VR space is perhaps the full range of human spatial abilities that can be investigated and developed within it. Pittalis and Christou (2010) reviewed literatures and classified spatial abilities into three categories as spatial visualization, spatial orientation, spatial relations. These three spatial abilities can be interpreted in plain words as:

Spatial visualization: The ability to mentally rotate objects while the person's viewpoint stays the same.

Spatial orientation: The ability to mentally change own viewpoint and remain unconfused in a 3D environment while the objects stays the same.

Spatial relations: The ability to comprehend the moving objects in a 3D environment while the person's viewpoint may stay the same or different.

The VR space can afford strong spatial senses, allowing users to be more aware of their position (location), orientation (direction), and movement in space. In VRMath 2.0, virtual worlds can be created as were in the STAR Project, to investigate learners' understanding about location, direction and movement. Figure 3 shows a 3D navigation lesson from STAR project, in which learners are to follow a set of instructions involving location, direction and movement to reach a floating box in the sky. Figure 4 shows a 3D maze wayfinding lesson, in which learners are to use the environmental cues and basic movement (i.e., forward, backward, turn right and turn left) to find an exit.

Figure 3. Geo-Quest navigation lesson

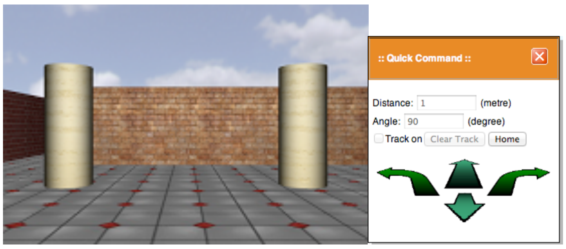

Figure 4. Maze wayfinding lesson

Other potentials about the VR space could include, and not limit to, the immersive hardware integration and perhaps multiuser virtual world. To sum up, the VR space is a superior 3D graphic that allows continuous visual representations of virtual objects, and continuous viewpoints via direct user navigation. It has great potential for developing and investigating human spatial abilities. However, the design of virtual worlds such as those in Figure 3 and 4 still relies on the programmer (this author). How to enable easy creation of virtual worlds in the VR space is one of the big challenges at this moment. The seamless integration and communication between the VR space and the Logo programming component could be the key for the creation of virtual world. The implementation of the programming component, however, is another big challenge.

3.2 Of the programming component

The programming component is the Logo or Logo-like interpreter being implemented in JavaScript. It is Logo-like because the 3D graphic will be changing existing and adding extra commands. The writing of programming codes in Logo is directly related to mathematics as it involves a range of mathematical notations. These mathematical notations include geometry language, mathematical functions, algebraic expressions, logical flow controls, and recursive procedures etc. There has been a big body of research on Logo programming and mathematical learning. Logo programming or microworld has been highly regarded as the central entity that links all mathematical representations. It has also been criticized as text-based only interactions (See detailed review in Hoyles & Noss, 2003).

The focus here is, however, on its new potential when it comes to be 3D microworld. Being a programming language is nothing new, but Logo's unique reference point in 3D space does bring in new ways of constructing shapes. In VRMath 2.0, the set of rotation (turning) and translation (moving) commands has been expanded (see Figure 2). There are now basic six rotation commands and more than twelve translation commands in three frames of references (FOR): egocentric (e.g., forward, left, tiltright), fixed (e.g., up, down, east, north), and coordinate (e.g., setx, sety, setz). It is also easy enough that a new command such as flip can be created using a procedure:

```
TO flip tiltleft 180 END
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With the power of programming and the full range of 3D rotation and translation, VRMath 2.0 is capable of creating any 2D and 3D shapes, or even fractal shapes. However, using the rotation and translation of a reference point to create shapes in 3D space is mostly not studied nor researched. In his STAR project, this author has identified some "quasi-understanding" in young children when they created 2D shapes in 3D space (Yeh & Hallam, 2011). Moving or turning a reference point to create shapes can be easy or difficult. For example, one way to create the five platonic solids in VRMath 2.0, is to know and use their dihedral angles. Using this method, the construction of cube (see Figure 5) is very easy as its dihedral angle is 90 degrees. However, the dihedral angles of tetrahedron, octahedron, dodecahedron and icosahedron are not intuitive to find. The dihedral angle of octahedron, for example, is about 109.47 degrees (i.e., arccos(-1/3)). Secondary students may be able to find and understand this angle, but perhaps not for primary students. However, primary students may utilize the angles of 120 and 45 degrees to successfully construct an octahedron (see Figure 5). How can 3D rotations and movements be utilized to find angles in 3D shapes is one challenge for future study.

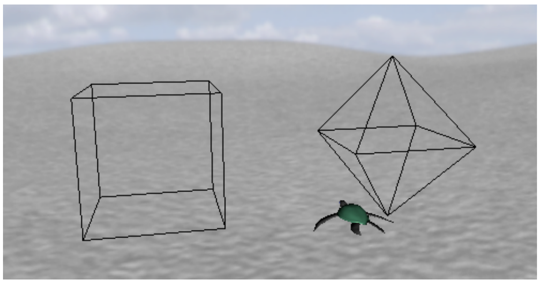

Figure 5. Cube and octahedron

Despite difficulties in constructing some 3D shapes, the recursive and loop abilities of programming can create irregular or non-Euclidian shapes or objects. Due to the nature of the X3D (formally known as virtual reality modeling language), the objects can have their geometric properties such as points set, radius, scale, rotation etc. manipulated via programming. This way, the microworld can be similar to DGS, in which the objects have relationships or conditions tied to each other. Animations can also be done using linear or non-linear (e.g., quadratic) functions to simulate some CAS's calculating and graphing features. The locations and directions of the reference point can be collected by Logo programming to create objects or behaviors of movements. These are, however, not yet implemented features, and remain as the challenges for VRMath 2.0.

3.3 Of the Web 2.0 component

The Web 2.0 component enables the sharing and collaborating of construction. One of the main ideas of integrating Web 2.0 style of content creation is to create and collect a repository of programming codes and procedures, 2D/3D objects, behaviors, models, and worlds. These can then be shared and reused among the members of VRMath 2.0 online community, and thus enable fast creation of 3D contents.

The current design of VRMath 2.0 has the following tools for sharing:

Save current world

Load an existing world into the current world,

Publish current world to share with others, and

Blog current world to show others

In VRMath 2.0, the constructed artifact can be saved in two forms. It can be saved as a Logo program or a X3D world. Logo program/procedure can be opened and re-edited, but not the X3D world. The load function can also load both Logo programs and X3D worlds. The blog function can create a new blog page with the current world in VR space. Learners or creators can then elaborate on how they created the world.

Because it is still the early implementing stage of VRMath 2.0, there haven't been users who have blogged any virtual worlds they created. The implementation of Web 2.0 environment and how to foster a community of practice continue to remain as the big challenges of VRMath 2.0.

4. Conclusion

In this paper, an initial implementation of a 3D Logo environment named VRMath 2.0 for learning mathematics was presented. This initial implementation of VRMath 2.0 was mainly concerned about the sustainability of the implementing technologies. Therefore, technologies with open standards and sources were chosen to avoid dependence on proprietary software.

VRMath 2.0 has three main components: VR space, Logo programming, and Web 2.0 components. Discussions about the potentials for learning and technical challenges for implementation were presented. It was identified that the VR space can offer opportunities for developing and investigating a full range of human spatial abilities. The Logo programming component has its unique ways of constructing shape but the reference point style in 3D environment was mostly not researched or studied. The Web 2.0 component offers a platform for sharing and collaboration. At this early implementation stage, all three components faced certain technical challenges. It was also discussed about the possibility of integrating features from established DGS or CAS. However, due to the nature of VR and Logo, this possibility of integration will open to wider discussion.

Lastly on the final thought, it is felt that although technical challenges exist, our limited imagination is in fact another big challenge. If this presented learning environment has any new ways of using technologies, there will be new ways of learning and new ideas for research that are beyond what were presented in this paper.

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