VIRTUAL REALITY LEARNING MANAGEMENT SYSTEM

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Abstract. Virtual Reality (VR) is becoming mainstream, and we should meet students in the environment they want to be in. Moreover, virtual reality is uniquely suited for teaching lessons having a 3D visual component. This VR-based learning system is a unique and novel way of teaching STEM topics. It can be used to teach topics in an immersive and engaging way, and aims to increase student engagement and help students visualize difficult concepts. The system combines lecture videos, animated 3D illustrations and web content, in a short lesson format, to gradually teach complex topics.

Keywords: Virtual Reality, Mathematics Education, STEM Education

1 Introduction

Virtual Reality (VR) is becoming mainstream, and we should meet students in the environment they want to be in. Moreover, virtual reality is uniquely suited for teaching lessons having a 3D visual component. This VR-based learning system is a unique and novel way of teaching STEM topics. It is used to teach topics in an immersive and engaging way. It's suitable for teaching any lesson having a 3D illustration. It aims to increase student engagement and help students visualize difficult concepts.

The young generation of digital natives want engaging content in virtual reality, and will be more willing to learn content in that environment. A 2015 study by Touchstone Research [1] reveals that 47% of kids and teens know a fair amount about virtual reality, and after being shown what VR can do, 88% said it was "very cool/off the charts cool".

We believe quality content presented in this platform will not only attract students, but result in better retention and learning outcomes. The platform is uniquely suited to teaching STEM subjects. Sikorsky [12] states, "While the application of VR to core academics remains nascent, early returns are promising: research now suggests students retain more information and can better synthesize and apply what they have learned after participating in virtual reality exercises."

Prior research tells us that using visualizations is essential in teaching STEM topics:

– "Representations are the entities with which all thinking is considered to take place. Hence they are central to the process of learning and consequently to that of teaching. They are therefore important in the conduct and learning of science, given the central commitment of that discipline to providing evidence-based explanations of natural phenomena, in which underlying entities and mechanisms have to be postulated and substantiated on the basis of empirical enquiry" [4].

– "Thinking with images plays a central role in scientific creativity and communication but is neglected in science classrooms" [8].
– "Socializing students into the world of science therefore, requires educators among other goals, to teach students all about models and representations, to expose students to these representations' diversity and characteristics, to use them for promoting the understanding of phenomena and to develop students' ability to think with representations as scientists do." [3].

2 Previous Research

Previous researchers have investigated teaching STEM topics within VR environments. Cecil, Ramanathan and Mwavita [2] developed some STEM lessons in the Second Life platform. Potkonjak et al. [9] explore the use of virtual labs for teaching science subjects. They review several virtual-laboratory initiatives, most of which are specific to one discipline. Mounayri, Rogers, Fernandez and Satterwhite [5] discuss utilizing a VR environment as an educational tool for the operation of a computerized numerical control (CNC) milling machine. Kaufmann, Schmalstieg and Wagner [6] discuss an early VR application for mathematical and geometry education. Roussou [10] created a virtual environment for learning abstract mathematical concepts. Malamos, et al. [7] discuss the implementation of a VR mathematical education tool using X3D.

3 Applications in Mathematics

Mathematics is much more than a degree requirement. It is a beautiful science abundant in both inductive and deductive reasonings along with the right amount of creativity to find new truths. Every student begins a math course with a measure of intuition. If the student's previous was only performing steps someone else told them to do, then their understanding of the material is limited along with their intuition and creativity. On the other hand, if mathematics is treated as a language and students learn to speak that language, then students develop the kind of fluency that allows them to create solutions to problems that are unique to them. That is, students develop the kind of intuition that allows them to find their own voice.

To achieve this for students, the virtual reality learning platform must be flexible in both teaching styles of educators and learning styles of students. To this end, tools will be put in place to allow instructors to create their own lessons that reflects their teaching style and activities that appeal to a student's various learning styles. Here is one possible example from introductory statistics.

The instructor uploads ratio level numerical data sets, and from the lesson features, form corresponding frequency histograms automatically. Each data set will yield frequency histograms with a different distribution, but the same scaling on the axes. The student's task is to use their knowledge of the sample standard deviation formula $s = \sqrt{\frac{(x-\overline{x})^2}{n-1}}$ and determine which histogram has the largest sample standard deviation based upon distribution alone. The instructor will embed their video explaining this activity and giving students ideas on what to look for in making their determination. From this virtual reality lesson, the student may discover visually that the frequency histogram having a normal distribution will have the smallest standard deviation since the highest frequencies are centered at the mean and the outliers having the smallest frequencies. Likewise the "V" distribution has the largest standard deviation because the outliers have the largest frequency while values close to the mean have the smallest frequency.

Suppose we want to introduce to the kind of creativity students will need to manage the rigor of their subsequent math or computer science courses. Doing so requires that we give students a working knowledge of logic used in writing proofs and performing derivations. Using truth tables and formal demonstrations, common in some geometry courses, will be the main components of the following virtual reality lesson.

In addition to the professor's video and uploaded course materials, the student will encounter a virtual guide. The guide will explain the instructions needed to complete each task. Students can interact with the guide through their responses to questions and exercises. Students may select from a battery of questions to ask the guide. The professor may customize this collection of questions to suit their needs. The guide pulls up the specific document with explanations and examples that answer the student's selected question. The guide will present the truth tables of the basic logical connectives, and from there, students fill out truth tables. The professor may also upload packages of custom logical connectives pertinent to course objectives. Students will discover special statements whose final column has entries of only "TRUE". These statements are called tautologies. The guide will also show compound statements and state that the given statement is not a tautology. Students will be tasked with finding a counterexample, or a single row from its truth table where the statement has the truth value of "FALSE". Finally, students will be given a few basic rules for including statements in a formal demonstration along with an exclusive list of tautologies that students must use as reasons for their steps. The guide will provide students with examples and exercises where students merely fill in the details before they are turned loose to write full demonstrations on their own. Professors may also upload packages of additional topics such as quantified statements, sets, relations, functions, writing informal proofs, abstract algebra and mathematical induction.

4 Applications in Physics

Physics is both mathematically and conceptually challenging for students at all levels. Part of the difficulty arises from students having to visualize highly complex three dimensional objects in courses like electrodynamics, classical mechanics, quantum mechanics and relativity. These subjects lend themselves well to a virtual reality environment in which the student can manipulate 3D objects and gain a deeper insight into the concepts that drive the mathematics.

Students in electrodynamics often struggle with Gauss's law and its application to calculating the electric field of insulating and conducting spheres. One application of a VR platform would allow students to take a charged ball and manipulate it by rotation, translation and by introducing a Gaussian surface inside or outside of the sphere. By doing so, students will be subjected to a more "hands-on" approach to doing calculations. Another advantage is that students will naturally view the electric field produced by a charge distribution in three dimensions, instead of a 2D depiction often given in textbooks, which would be especially useful when visualizing the electric field of a line of charge or a cylindrically symmetric charge distribution. Students can potentially also "build" virtual circuits in VR, which could prove to be very useful in online physics classes that rely solely on virtual labs.

In classical mechanics, students often struggle with visualizing a 3D object being rotated using Euler angles. Using VR, students will be able to manipulate 3D objects like spheres, cylinders, and cones and gain a deeper insight into Euler angles. VR could also be used to expose students to virtual demonstrations in online courses. Some possible virtual demonstrations include the double pendulum, free fall, pulley systems, projectile motion, rotational dynamics, etc.

Quantum mechanics and quantum field theory are especially challenging both conceptually and mathematically. Students must have a deep grasp of various coordinate systems including both spherical and cylindrical. Through the use of VR, students can gain a deeper insight into the equations governing the transformations from Cartesian to spherical and cylindrical coordinates since the derivations of the aforementioned equations requires 3D visualization and therefore lend themeselves nicely to a VR approach. Students can also use VR to visualize the orbitals of the Hydrogen atom after solving the Schrödinger Equation in spherical coordinates with a Coulomb potential. Virtual demonstrations of the double-slit, Stern-Gerlach and particle collision experiments are also within reach.

Einstein's theory of gravity, general relativity, lends itself quite nicely to a VR environment. Students can start with a 3D (2 space and 1 time) flat spacetime manifold and then add objects with mass to visualize how mass/energy deforms spacetime. The natural next step would be to have students put a smaller mass in to orbit around a larger one and really drive home the idea that an orbiting object follows the geodesics of the curved spacetime caused by the massive object it is orbiting.

VR will no doubt change the way that students interact with highly abstract concepts in 3D. Students can take a hands-on approach to solving problems in 3D, deriving equations that rely on 3D visualization, and interact with virtual demonstrations and laboratories that complement online class.

5 Current Scope

A prototype has been developed, with a partial feature set. Lessons are typically between 3 and 5 minutes. They each explain a specific subtopic. A lesson consists of the professor's video, a 3D model, and learning content. The video is synchronized with the animated 3D model.

While viewing a lesson, a learner can perform the following activities, among others:

- Move around within the virtual environment, for example, walking around the 3D model that is the subject of the lesson.
- Pause the lesson and manipulate the 3D model by moving it, rotating it, zooming in and out, and so on.

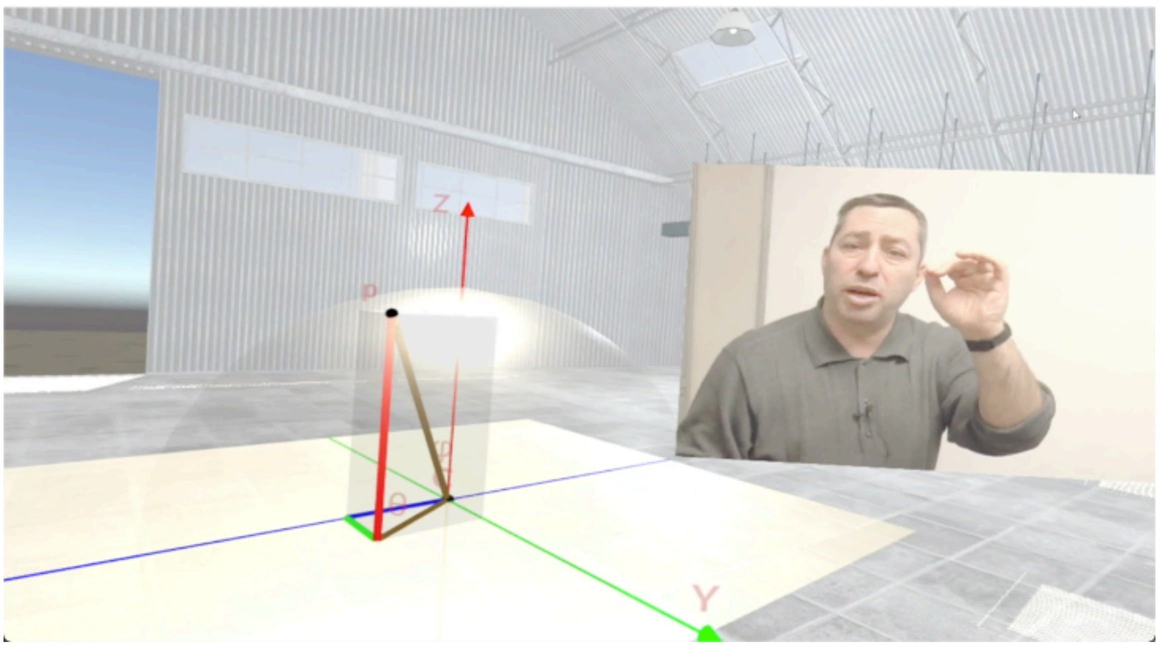

Fig. 1. Spherical Coordinates Lesson

6 Implementation Details

The system currently supports two types of VR headsets,

- Low-end systems require the user's phone to be inserted into the front of the headset, using the smartphone to display a stereoscopic image. These typically offer one controller with limited buttons and no sensors to discern the location of the headset and controller, thus the user can't move around.

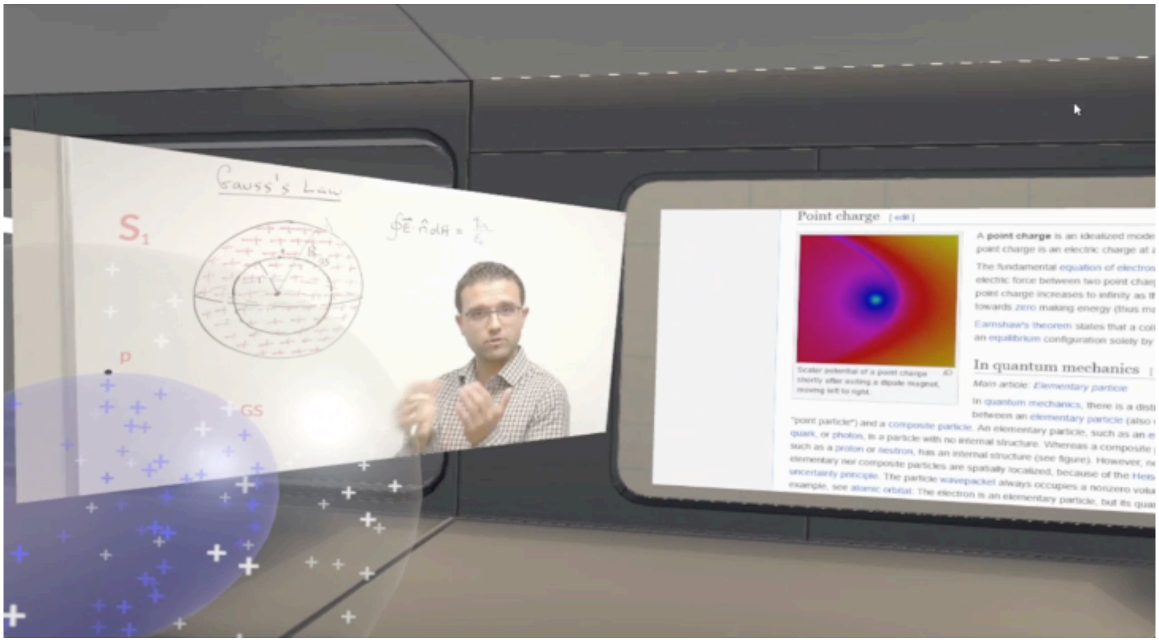

Fig. 2. Gauss's Law Lesson

– High-end systems typically require a VR-ready laptop or desktop, and have two controllers with multiple buttons per controller. These systems also sense the location of the headset and controllers, thus the user can move around, with the display reflecting the user's movements.

Each Lesson contains the following components,

– A short video of the instructor's explanation. This is currently streamed from a cloud server and rendered on a flat surface within the VR environment.

– A 3D model rendering the object of the lesson. This model contains animations that show various aspects of the lesson.

– A script synchronizing the instructor's video and the model's animations. The system kicks off various animations when the video reaches certain points in time.

An example of lesson animation is shown below. This is C# code run by the Unity engine, where the string tag refers to a set of objects in the 3D model (in this case, molecules), and the time is an offset relative to the video's start time, in milliseconds.

```
// Action constructor
public Action(ActionType action, string tag, long time, long rotateAngle,
  bool darkGlow, int percentage = 0);

// Create new list of actions
List<Action> actions = new List<Action>();
actions.Add(new Action(ActionType.Glow, "Carbon", 41500, 0, false));
actions.Add(new Action(ActionType.Glow, "Hydrogen", 42500, 0, true));
actions.Add(new Action(ActionType.Glow, "Oxygen", 44500, 0, false));
actions.Add(new Action(ActionType.Glow, "Nitrogen", 43500, 0, false));
lessonActions = new List<LessonActions>();
```

```
lessonActions.Add(new LessonActions(actions, "Chemistry1", false));
```

7 Future Work

To extend this work, we wish to add several more features to the system,

- Better authoring support, including the ability to upload video lessons and authoring tools that allow nontechnical users to import 3D models from free repositories.
- Cloud deployment, so that the system is accessible by teachers and students anywhere in the world.
- Crowdsourcing. Since professors anywhere would be able to add content (lessons), that additional content will increase the platform's value to all users.
- Interactive lessons. The professor would specify behaviors of the 3D model contained within the lesson, and how the 3D model responds to user inputs.
- Quizzes. The student would complete an interactive quiz before being able to move on to the next lesson.
- Personalized adaptive learning. Lessons would have prerequisites so the student is guided through a sequence of lessons specified by the instructor, and the system would guide the student through the learning paths.

References

1. Burch, A. *Infographic – The New Reality of Virtual Reality (VR) and the Potential with Youth*, 2015 (accessed August 12, 2020).
2. Cecil, J., Ramanathan, P., and Mwavita, M. Virtual Learning Environments in engineering and STEM education. In *2013 IEEE Frontiers in Education Conference (FIE)* (2013), pp. 502–507.
3. Eilam, B., and Gilbert, J. K. *The Significance of Visual Representations in the Teaching of Science*. Springer International Publishing, Cham, 2014, pp. 3–28.
4. Gilbert, J. The role of visual representations in the learning and teaching of science: An introduction. *Asia-Pacific Forum on Science Learning and Teaching 1*, 1 (2010).
5. Hazim A. El-Mounayri, Christian Rogers, E. F., and Satterwhite, J. C. Assessment of STEM e-Learning in an Immersive Virtual Reality (VR) Environment. In *2016 ASEE Annual Conference & Exposition* (New Orleans, Louisiana, June 2016), no. 10.18260/p.26336, ASEE Conferences. https://peer.asee.org/26336.
6. Kaufmann, H., Schmalstieg, D., and Wagner, M. Construct3D: A Virtual Reality Application for Mathematics and Geometry Education. *Education and Information Technologies 5* (2000), 263âĂŞ276.
7. Malamos, A. G., Mamakis, G., Sympa, P., Kotanitsi, E., Crespo, A. J. G., and Lopez, A. Z. Technical Aspects in Using X3D in Virtual Reality Mathematics Education (EViE-m Platform). In *5th WSEAS / IASME International Conference on Engineering Education (EE'08)* (2008).
8. Mathewson, J. H. Visual–spatial thinking: An aspect of science overlooked by educators. *Science Education 83*, 1.
9. Potkonjak, V., Gardner, M., Callaghan, V., Mattila, P., Guetl, C., Petrović, V. M., and Jovanović, K. Virtual Laboratories for Education in Science, Technology, and Engineering: A Review. *Computers & Education 95* (2016), 309 – 327.
10. Roussou, M. A VR Playground for Learning Abstract Mathematics Concepts. *IEEE Computer Graphics and Applications 29*, 1 (2009), 82–85.

11. Salzman, M. C., Dede, C., Loftin, R. B., and Chen, J. A Model for Understanding How Virtual Reality Aids Complex Conceptual Learning. *Presence: Teleoperators and Virtual Environments 8*, 3 (1999), 293–316.
12. Sikorsky, J. *VR Isn't a Novelty: Here's How to Integrate it Into the Curriculum*, 2018 (accessed August 12, 2020).