Can Virtual Reality Enhance Learning: A Case Study in Materials Science

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***Abstract*— This Innovative Practice Work in Progress tests whether virtual reality (VR) can enhance students' understanding in scientific fields, specifically Materials Science and Engineering (MSE), when compared to more traditional approaches. Of interest is how VR-based learning activities impact the performance of individuals with experience ranging from none to expert level in MSE compared to paper-based learning activities. To test this, an activity related to crystal structures, similar to what students would see in an introductory level MSE course, was administered to a group of students with varying knowledge levels in MSE. Each participant completed the same worksheet in either VR or on paper. The testing group was composed of seven students, which was too small of a sample size to draw definitive conclusions, yet significant observations could be made. On questions that required recall of prior knowledge, participants using paper-based activities generally performed better, whereas on questions requiring more spatial reasoning and critical thinking, VR participants generally performed better. Most of the participants reported enjoying the VR activities and platform, indicating high usability. These results suggest that VR may be beneficial in teaching complex spatial concepts.**

Keywords—Virtual Reality, Engineering, Education, Materials, Science

I. Introduction

This paper presents a pilot study examining the effectiveness of virtual reality (VR) learning modules in Science, Technology, Engineering, and Math (STEM) education, particularly regarding Materials Science and Engineering topics. The goal of the project is to determine whether VR learning tools can promote higher levels of learning and advance novice and beginner-learners towards expertise in a subject.

It is well known that high spatial reasoning skills are directly correlated to good grades in engineering [1]. Concepts in Materials Science and Engineering particularly rely heavily on spatial reasoning skills. The guiding philosophy in this discipline is that the structure of a materials determines its properties, and most fundamental concepts require a solid understanding of three dimensional (3D) structures from the macro to atomic scale. One of the most fundamental concepts of the discipline is the crystal structure of solids, or the arrangements of atoms in 3D space (see Fig 1).

Traditionally, students learn these concepts by manipulating physical models or by looking at 2D renderings of 3D objects in books or on computer screens. Manipulating real objects is superior to merely looking at 2D representations of 3D objects, however, these physical models are bulky and expensive. Meanwhile, 2D representations of the 3D structures, such as those found in textbooks or on computer screens, often require simplifications or judicious omissions in the structures to be fully understood. VR offers a unique opportunity for students to study and manipulate these crystal structures in an economical and pedagogically sound fashion. Meanwhile, VR has proven to become more affordable and accessible as the technology has advanced, with high-end headsets like the Oculus Rift (~$500), and low-end headsets like Google Cardboard (~$15) available and easy to find.

Several studies have shown that VR can improve the learning of several concepts in STEM fields, especially in medicine, chemistry, physics, and math [2,3,4]. Students with various learning styles benefit from their use especially when learning introductory concepts and developing new skills [5,6]. In the case of the latter, VR-based training simulations of medical skills development such as intravenous cannulation and laparoscopic surgery have been shown to bring novice learners to the skill level of experts more quickly than

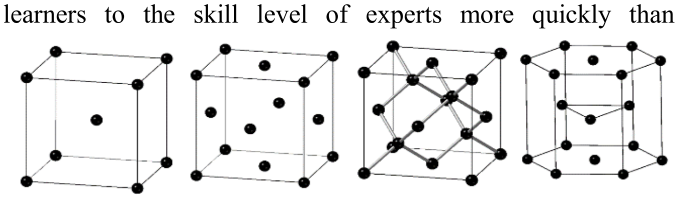

Fig. 1. Basic crystal structures of solids typically used in introductory Materials Science courses, from left to right Body Centered Cubic (BCC), Face Centered Cubic (FCC), Diamond Cubic (DC), Hexagonal Close Packed (HCP)

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traditional methods [7,8,9]. More recently, there have been studies developing virtual training and education environments for engineering education, including civil, electrical, and mechanical engineering [10, 11].

The purpose of this project is to understand whether VR learning tools could be useful in allowing students to overcome difficulties, including spatial reasoning and visualization, with a specific set of concepts in Materials Science (e.g.: crystal structures) as well as determining if adopting VR for teaching and learning purposes is worthwhile. This latter point is particularly important to understand prior to investing money to purchase the requisite hardware, and the time to develop and implement the optimized activities. While the use case of this project centers on highly specialized domain knowledge in Materials Science and Engineering, the results of this study can inform the question whether VR learning tools support higher levels of learning, and move novice learners towards expertise regardless of the field of study.

II. Experimental Design

In this pilot study, one educational activity that examines student understanding of Materials Science concepts related to crystal structures was developed and tested for usability and effectiveness. This activity presented students with four crystal structures (see Fig. 1) and asked questions related to structure identification, comparison, and atomic packing characteristics. The questions, listed in Table I, are typical of what a student could expect in an introductory-level Materials Science course. Of these four questions, only question one required prior knowledge or coursework in Materials Science, while the remaining three questions could be deduced strictly from the presented illustrations. Nevertheless, general knowledge of Materials Science terms would be helpful in answering the latter three questions.

Because there is some question regarding the efficacy of VR-based activities on learning compared to more traditional approaches, an important aspect of the research is to compare different visualization modes. Therefore, two different versions of each activity were created: one where the structures were printed on paper, and one where the structures were presented in VR. CrystalMaker (http://crystalmaker.com/) was used to render the structures in both cases, and Arthea (https://gwydion.co/arthea) running on Oculus Rift headsets (https://www.oculus.com) was used to visualize the structures in VR. Arthea allows users to view, manipulate, and draw on 3D renderings. An example is shown in Fig. 2. For the paper version of the activities, screenshots of same structures used in VR were provided with views down three orthogonal axes and a perspective view.

The seven participants in this study were STEM undergraduates, along with one graduate student at The University of Michigan. The majority of the students came from the Materials Science and Engineering department. After giving informed consent, all participants were given a device to audio record their thought processes and responses to the questions. Whether the participant would do the activity on paper or in VR was determined by the flip of a coin. The participants were each given $10 of a cash equivalent campus currency that can be used at all campus venues and some neighborhood restaurants.

III. Results and Analysis

Table II shows the scores for the activities for each individual student. While the number of participants is too low to draw statistically significant conclusions, several differences in student performance between the activities on paper and the activities in VR were observed. It appears that the students who completed the paper version where better able to identify and name the crystal structures (Q1). This could be due to the

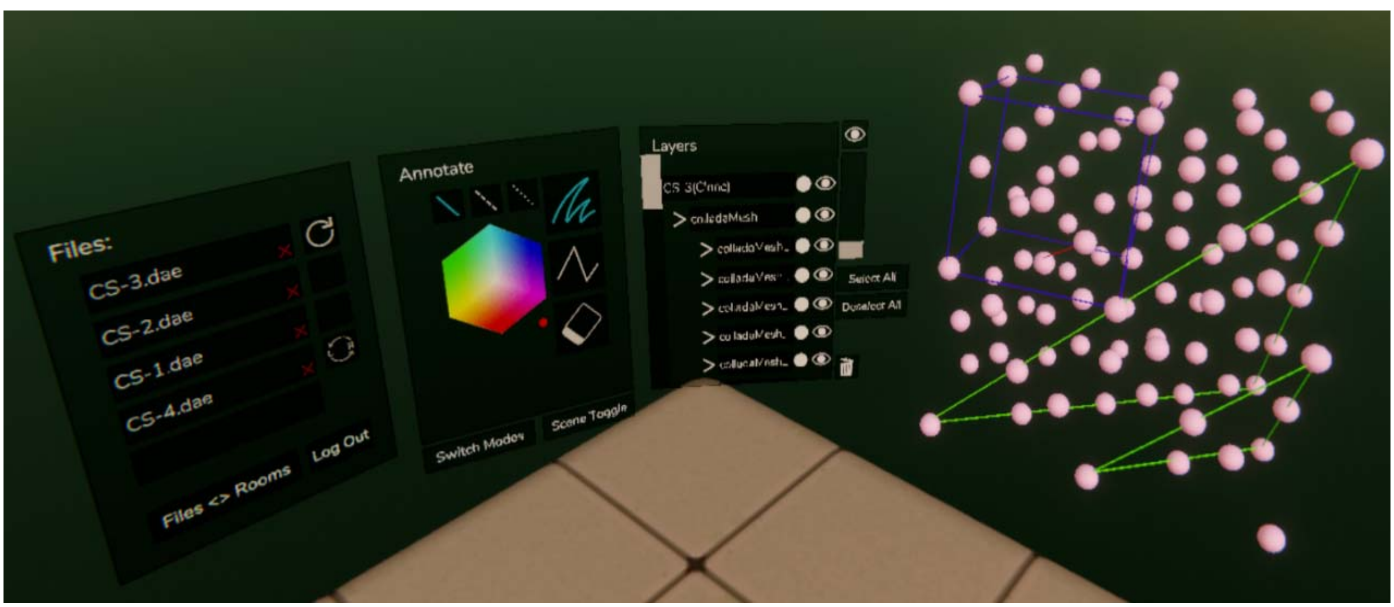

Fig. 2. A screenshot of Arthea being used to answer Question 2: “For each structure identify and shade in the densest packed plane of atoms.”

TABLE I. QUESTIONS ASKED IN THE ACTIVITY

#	Question
1	Given in figures 1-4 are four crystal structures, please identify them.
2	For each structure identify and shade in the densest packed plane of atoms
3	Explain why FCC (2) and HCP (4) have the same packing factor, i.e. density of atoms
4	Compare and contrast FCC (2) and DC (3).

fact that these students originally learned the material from 2D renderings of 3D structures (in books or overhead slides). The VR-based participants may have been hampered by learning how to navigate the VR environment while answering this question. In the following question (Q2) the VR-based participants seemed to perform better at identifying the densest packed plane, possibly because these students were able to rotate the crystal to optimize the viewing of this plane. This was apparent in the case of student 1, who had no prior experience with the topic, nor could name the structures in Q1. Nevertheless, the ability to rotate and manipulate the structure allowed this individual to perform quite well on Q2.

There were two basic ways in which students answered Q3 and Q4. The students who did the activity on paper tended to rely on recalling the information, whereas the students who did the activity in VR tried using the visualizations to deduce the answers. One student working on paper commented:

> *I don't think I remember enough of this to answer these questions adequately.*

Another student working on paper recalled a formula for packing density when answering Q3. In contrast, the students who did the activity in VR tended to visually compare the structures in answering the questions. One student said about the different crystal planes:

> *I can layer them on one another*

Another student said:

> *The planes with closest packing are the same, ..., it's just FCC rotated.*

These observations suggest that these students make use of the visualizations using the VR environment and notice the relationships of the atoms better than those using the paper-based activity.

IV. Future Work

Given that this was a pilot study, the learning activities themselves will need to be somewhat modified to make them clearer. For instance, the worksheets had some questions that were open ended, which lead to hesitation and confusion among some of the participants. This may be due to the fact that such questions in classwork are uncommon, and thus unexpected by the participants in the study. In future iterations, open ended questions will be placed after asking technical "warm up" questions to get students thinking on the right track.

Overall, students reported that they enjoyed the VR activity, noting that it was intuitive and fun to use. For instance, one student said:

> *I think it would have been helpful for me as a student to have something like that.*

Those students who were randomly chosen to do the paper-based activity were shown the VR-based activity after they completed the test. Most of the students commented that they preferred this format to the paper version, in particular one student commented saying

> *Using virtual reality was definitely helpful because I could pull up both models and lay them over each other.*

Not all students were equally enamored with VR. One student questioned whether the VR environment was really better than simply observing the structures on a computer screen. This is an excellent point, and will be examined in a future study.

TABLE II. THE TYPE, FAMILIARITY, AND NORMALIZED SCORES FOR EACH INIDIVIDUAL IN THE STUDY

#	Type	Familiarity	Q1	Q2	Q3	Q4
1	Virtual Reality	None	0.00	0.88	0.33	0.33
2	Virtual Reality	Beginner	0.50	0.38	0.67	0.33
3	Virtual Reality	Beginner	0.75	0.62	0.33	0.67
4	Virtual Reality	Intermediate	0.33	1.00	0.33	1.00
5	Paper	Beginner	0.67	0.75	0.33	0.33
6	Paper	Beginner	0.92	0.75	0.00	0.67
7	Paper	Intermediate	0.58	0.12	0.33	1.00

V. CONCLUSIONS

This pilot study examines the usability and effectiveness of VR-based learning activities to in crystal structures compared to paper-based activities. Despite the small sample size, several observations could be made. The VR environment itself was reported to be fun and easy to use, but participants should have an opportunity to practice using the platform. VR encourages students to observe the structure and deduce answers to the posed questions, as opposed to relying on recall. Based upon this pilot study, we will develop and employ additional learning modules for use in Materials Science courses that cover topics including: crystal symmetry, slip systems, defects, and phase diagrams. Furthermore, we will attempt to examine whether VR-based learning activities can be used across many types of learning and levels of expertise regardless of the field.

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