How can instructors strengthen students' motivation to learn complex 3D concepts in an engineering classroom?

Jaskirat Singh Batra
Materials Science and Engineering
Texas A&M University
College Station, TX, USA
jbatra@tamu.edu

Ra'sheedah Richardson
Center for Teaching Excellence
Texas A&M University
College Station, TX, USA
sheedah@tamu.edu

Robert Webb
Physics and Astronomy
Texas A&M University
College Station, TX, USA
webb@physics.tamu.edu

***Abstract*— The effect of Virtual Reality (VR)-based lectures on student motivation to learn complex 3D materials science concepts is discussed in this Research Full Paper. With the growing classroom size and less personalized attention to students, STEM instructors are challenged with finding ways to strengthen student motivation and sustainably transform the educational experience of current and future learners. Students' ability to visualize and imagine complex 3D concepts in multiple engineering disciplines can be a barrier to learning for diverse learners. This research uses VR technology to study the impact on student motivation to learn materials science concepts based on John Keller's ARCS model of motivation. As a benchmark, student participants (n=26) were given a slides-based lecture, and the initial motivation level was assessed using the Instructional Materials Motivation Survey (IMMS) and reflection questions. Next, the VR intervention was given using low-cost and scalable Cardboard Viewers fitted with personal smartphones, followed by IMMS survey and reflection questions. A mixed-methods approach including the use of a t-test to analyze quantitative data, and Chi's (1997) verbal data analysis to identify emergent themes among qualitative data was applied in this study. Overall student participants' motivation was found to increase due to VR intervention. Among the four components of the ARCS motivation model of instruction, attention and satisfaction components showed a significant increase after the VR intervention, while relevance and confidence components remained unchanged. This finding suggests the use of scalable VR technology as a suitable option for capturing students' attention in order to facilitate learning about complex 3D concepts in engineering classrooms.**

Keywords—student motivation, materials science, engineering education, virtual reality, 3D concepts, scalable classroom

I. Introduction

As science, technology, engineering, and mathematics (STEM) classroom sizes get larger, instructors are faced with a unique challenge of trying to create a learning environment that motivates each individual student to focus on the content in order to facilitate learning. This is also a difficult task when the content to be taught to a large classroom is a complex 3D concept. Some of the 3D concepts are especially challenging for students because they are expected to rely on their imagination and ability to visualize. For example, the concept of 'crystal structures' in materials science requires a good visual ability to draw or imagine a static 3D structure and analyze its components. Similarly, learning about 'dislocation movement' in materials science necessitates the visualization of a moving and changing 3D structure over time.

Among the different methods to simulate a 3D concept in both physical and digital worlds, Virtual Reality (VR) technology is known for its capability to immerse users in a simulated 3D environment while allowing them to interact with 3D objects [1]. Previous VR studies have shown that the VR has a positive impact on the motivation of students at different grade levels as compared to other methods [2]-[11]. In a social studies classroom, VR has been found to increase student motivation among middle-school students when it is used to supplement the existing curriculum [2]. College students who learned environmental science using head-mounted VR displays have shown a higher interest in continuing to use the learning platform compared to those learning with a virtual desktop environment [4]. A study of 39 elementary-school students has shown that VR may contribute towards a small improvement in academic performance while providing a large improvement in student engagement or motivation [5], [6]. In a separate study of 48 engineering college students, it was demonstrated that the students exhibited a higher interest in learning using VR [12].

To facilitate the learning of 3D materials science concepts in a large STEM classroom, the instructors must first motivate student learners. This paper presents a research study that was conducted to investigate whether VR technology can enhance students' motivation to learn complex 3D concepts in materials science. In this study, John Keller's ARCS model of instructional design has been used as a theoretical framework to understand the factors affecting motivation when VR is used in a materials science and engineering classroom. According to this model, motivation has four components that support learning – attention, relevance, confidence, and satisfaction (ARCS) [13]-[15]. The attention component includes strategies for arousing interest. The relevance component highlights the importance of connecting learning to students' needs. The confidence component emphasizes linking learning success to students' own effort and ability. The satisfaction component encourages the use of both intrinsic and extrinsic reinforcement for the learner. These components of ARCS model are described in detail in [13]-[15].

John Keller's ARCS model has already been used to understand learner motivation for other educational technologies such as Augmented Reality [16], and massive open online courses [17]. According to Keller and Suzuki, capturing attention, creating relevance, and boosting confidence are the necessary conditions to build motivation for learning, while providing satisfaction is a necessary condition for a positive learning experience. Once these four conditions are met, the students are likely to have a high motivation level for immediate and long-term continuous learning [18]. To measure motivation and its four components, the Instructional Materials Motivation Survey (IMMS) has been used in many studies [16], [17], [19].

This paper uses a mixed-methods approach to discuss the impact of VR on undergraduate student's motivation to learn an advanced materials science concept when compared to a traditional slides-based lecture. Prior research on the effects of VR on student motivation has relied mostly on quantitative methods. This paper expands the scope of VR motivation research to include qualitative findings that provide new insights into how the student motivation can be further increased.

II. Design and Methods

A. Course type

The Institutional Review Board-approved study was conducted in an introductory materials science course (for non-majors) with 26 student participants from chemistry and multiple engineering majors. This course was taught in spring 2019 semester at Texas A&M University. An advanced materials science concept of 'excitons' was taught in a 50-minute class session. Fig. 1 shows a summary of the study design including the slides-based lecture and initial survey, followed by the VR-based lecture and final survey.

B. Slides-based lecture

First, students were given a 15-minute slides-based lecture on excitons by the instructor using Microsoft® Office PowerPoint® and were able to ask questions during the presentation.

C. Initial survey

Students filled out a paper-based written survey which included the IMMS and the reflection questions. The IMMS instrument is a 36-question survey which provides the ability to measure attention, relevance, confidence, and satisfaction as well as overall motivation. Each question of IMMS is scored on a 5-point Likert scale from 'not true' (1) to 'very true' (5). The reflection questions asked students about aspects of the slides-based lecture that they liked, and aspects of the slides-based lecture that could be improved. The data collection process was not anonymous, however, no identifying data was collected and the surveys were kept confidential.

D. Virtual Reality-based lecture

Each student was provided with a cardboard viewer for the VR-based lecture. Cardboard viewers (Classic V2) were obtained from "I Am Cardboard" [20]. Cardboard viewers are easy to set up and use and they have a low-cost, therefore making them a viable option in larger classrooms. A cardboard viewer was assembled by each student, and their personal smartphone was inserted in the viewing area of the cardboard viewer. The YouTube™ app was used to access the VR content on smartphones. A 360° video of 'Exciton in Lithium Fluoride' was accessed in the VR mode of the app [21]. Students used their personal earphones for listening to audio narration after the video was started using a single button on the cardboard viewer. The length of this video was 3 minutes, and the students were allowed to watch this video more than once during the 10-minute VR intervention.

E. Final survey

After the VR-based lecture, students were asked to again fill out the paper-based IMMS instrument and reflection questions. The reflection questions asked students about aspects of the VR-based lecture that they liked, and aspects of the VR-based lecture that could be improved. Additional reflection questions asked students how they felt about the concept that they were being taught during the VR-based lecture compared to the slides-based lecture, and if the VR-lecture helped them learn better or not.

F. Situational factors

For student safety during the VR lecture in the classroom, the students were required to stay seated in their chairs while viewing the VR module in the cardboard viewer. They were not allowed to stand or walk. This did not restrict the students from being able to rotate 360° within their chair, and from looking up or down in VR. It is important to consider that VR-based learning could also support wheelchair-bound students having limited physical mobility.

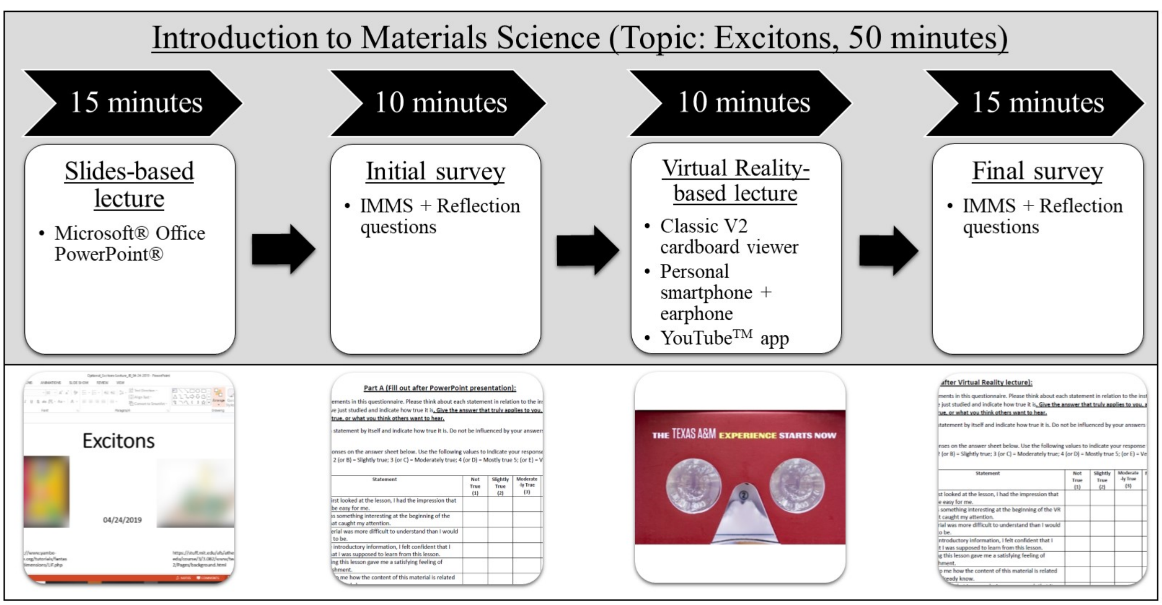


Fig. 1. Diagram of the study design and a description of instructional and survey activities with the time spent on each.

G. Data analysis

A mixed-methods approach towards data collection and analysis was taken. Motivation level and its four components obtained from IMMS data were compared after the slides-based lecture (before VR) and after the VR-based lecture (after VR). The quantitative analysis also included a paired t-test applied to the slides-based and the VR-based data, where the histogram graphs showed approximately normal distribution. In the future, this data will be statistically tested for normal distribution and further analyzed. Based on Chi's qualitative analysis method, the student responses to each reflection question were independently coded by two researchers at the "grain size" of an idea. The emergent coding scheme was used to find common categories and themes in student responses [22].

III. Results and Discussion

A. Overall motivation and its components

The motivation level calculated using the IMMS survey showed that student motivation (on average) was higher after the VR-based lecture compared to the slides-based lecture (Fig. 2). This was confirmed by a highly significant statistical difference obtained in the t-test when comparing the mean motivation from the slides-based and the VR-based lectures (Table I).

Four components of motivation calculated from the same IMMS survey also showed that the attention and satisfaction factors were the ones showing an increase after the VR intervention, compared to the relevance and confidence factors which stayed the same. The t-tests confirmed that there was a highly significant statistical difference in the mean values of attention as well as satisfaction when comparing their values before and after the VR-based lecture. On the other hand, there was no significant difference in the mean values of relevance and confidence when comparing their values before and after the VR-based lecture.

TABLE I. P-VALUES OF MOTIVATION AND ARCS COMPONENTS OBTAINED FROM THE PAIRED TWO-SAMPLE T-TEST APPLIED TO SLIDES-BASED AND VR-BASED DATA

Motivation and ARCS components	P-value (two-tail)	Significance	Null hypothesis
Motivation	6.72×10^{-5}	$P < 0.001$ (Highly significant)	Reject
Attention (A)	2.28×10^{-7}	$P < 0.001$ (Highly significant)	Reject
Relevance (R)	7.75×10^{-1}	$P > 0.05$ (No significance)	Accept
Confidence (C)	3.77×10^{-1}	$P > 0.05$ (No significance)	Accept
Satisfaction (S)	2.43×10^{-5}	$P < 0.001$ (Highly significant)	Reject

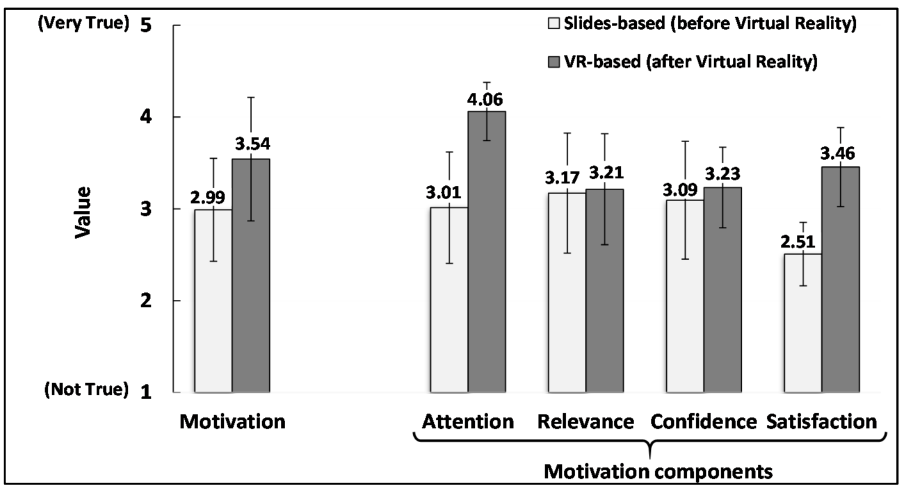


Fig. 2. Motivation level and the attention, relevance, confidence, and satisfaction components before and after the Virtual Reality lecture (n=26).

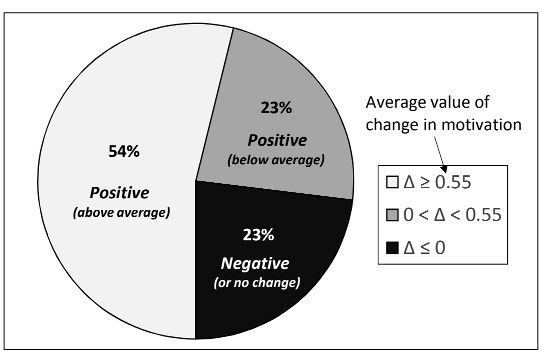


Fig. 3. Fraction of study participants (n=26) showing a *positive (above average)*, *positive (below average)* or *negative (and zero)* change in motivation (Δ) after and before the Virtual Reality intervention. Average increase in motivation level for this group was 0.55.

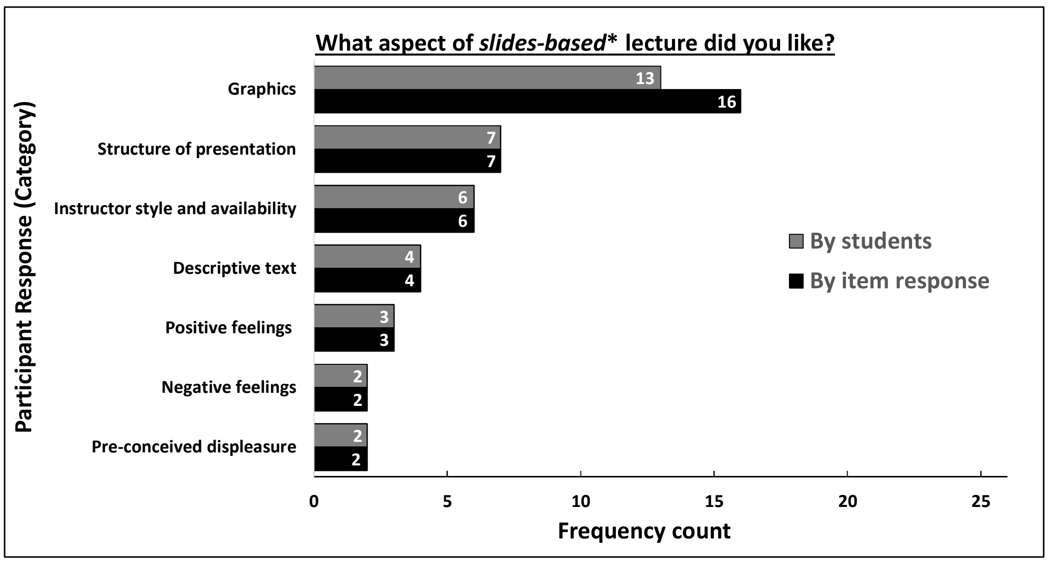
The increase in the average motivation level before and after the Virtual Reality intervention was 0.55 for this group. Out of 26 study participants, 20 students (77%) showed a positive change in motivation after the VR intervention (Fig. 3). Specifically, 54% of the participants showed an *above-average* positive change in motivation level after the VR intervention for this group, while 23% of them showed a *below-average* positive change in motivation level. The remaining 6 students (23% of participants) showed either a negative or zero change in motivation level after the VR intervention. This means that the VR intervention had an overall positive impact on the motivation level of 77% of the participants, while it had negative or no impact on the remaining 23% of the participants.

B. Student reflection of Slides-based lecture

When students were asked about the aspect of the slides-based lecture that they liked, their responses belonged to the following categories: 'graphics', 'structure of presentation', 'instructor style and availability', 'descriptive text', 'positive feelings' about the slides-based lecture, 'negative feelings' about the slides-based lecture, and 'pre-conceived displeasure' about slides-based lecture style (Fig. 4).

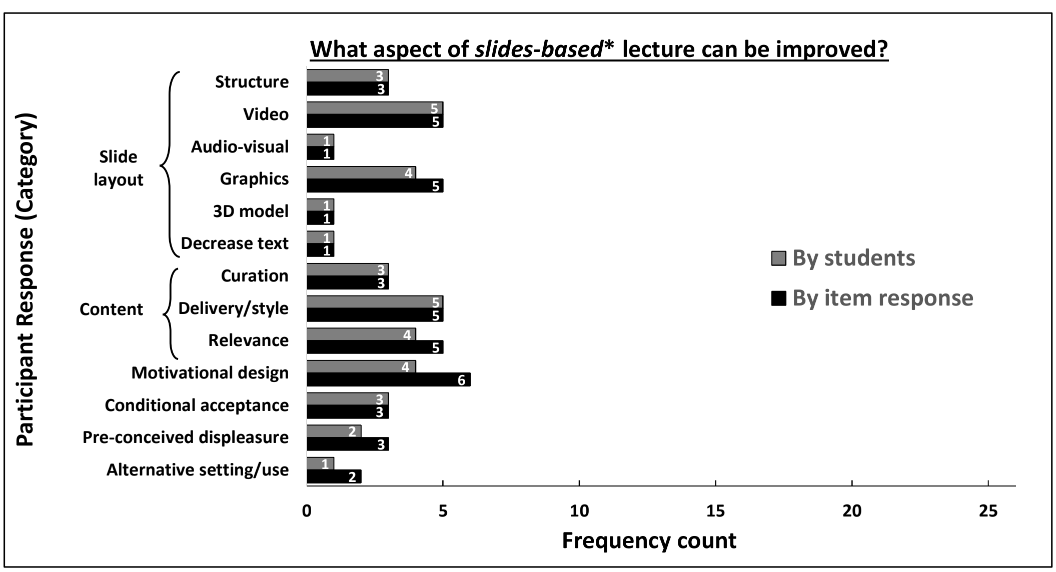
Most students liked the graphics that were used in the presentation slides. The graphics-related items were mentioned 16 times in the responses of 13 students. The second-most liked aspect of the slides-based lecture was the structure of the presentation, closely followed by the clear instructor style and availability of the instructor. Some students also liked the slides-based lecture due to the appropriate use of descriptive text explaining the information. The remaining responses to this question were related to either positive or negative feelings that students had about the slides-based lecture, and any pre-conceived displeasure that they had about this lecture style due to existing negative bias or prior experience. The positive feelings included curiosity about the content and familiarity with the slides-based format. The negative feelings included those of boredom and confusion.

When asked about the aspect of the slides-based lecture that can be improved, student responses belonged to many different categories, the two largest ones being 'slide layout' and 'content' (Fig. 5). For improvements to the slide layout, many students suggested the use of more videos and graphics to explain the concept. A few other suggestions centered on improvements to the structure of the slides, the use of audio-visuals, the incorporation of 3D models, and a decrease in the amount of text per slide.



**In the survey question, the name of the slides-based presentation program was used*

Fig. 4. Category and frequency of participant responses to the question "What aspect of *slides-based** lecture did you like?"



**In the survey question, the name of the slides-based presentation program was used*

Fig. 5. Category and frequency of participant responses to the question "What aspect of *slides-based** lecture can be improved?"

Within the content category of improvement to the slides-based lecture, students placed the most emphasis on the clear delivery of content, while also expressing that the content should be made relevant to them in the form of real-life examples, analogies, connections to prior knowledge, etc. The final sub-category of content curation included the selection of the right amount and type of content to be taught within a time period.

Further, some students indicated that the slides-based lecture should be more engaging, increase student confidence, and capture their attention quickly, all of which are noticeable aspects of the ARCS model of 'motivational design'. The next category included 'conditional acceptance' of the slides-based lecture given that the slides are well-designed, information is accessible on slides, and instructor delivery is pleasant. In Fig. 5, there were a few students who had 'pre-conceived displeasure' about slides-based lecture, which is similar to the student responses to the previous question in Fig. 4. In the final category of 'alternative setting/use,' the responses suggested that the slides could be used in a flipped-classroom lecture style to prepare students for active learning in class such as in-class problem solving, getting feedback from the instructor, and discussing applications.

C. *Student reflection of Virtual Reality-based lecture*

When students were asked about the aspect of the Virtual Reality lecture that they liked, their responses belonged to five distinct categories shown in Fig. 6: 'Visualization' (14 students), 'Attention' (8 students), 'Interaction' (4 students), 'Immersion' (3 students), and 'Innovation' (2 students).

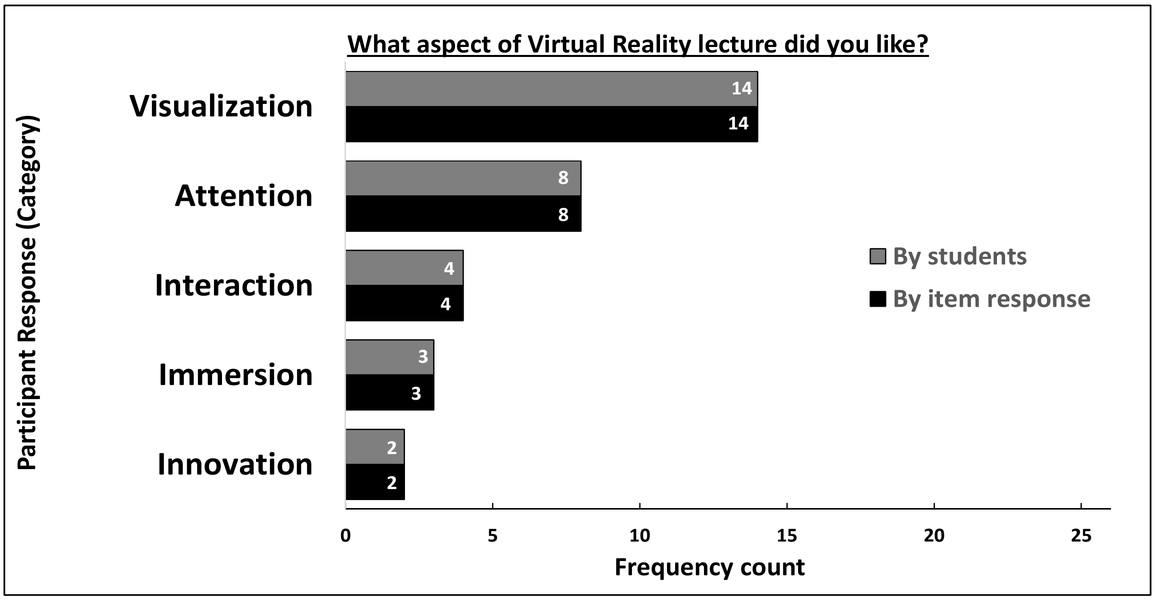


Fig. 6. Category and frequency of participant responses to the question "What aspect of Virtual Reality lecture did you like?"

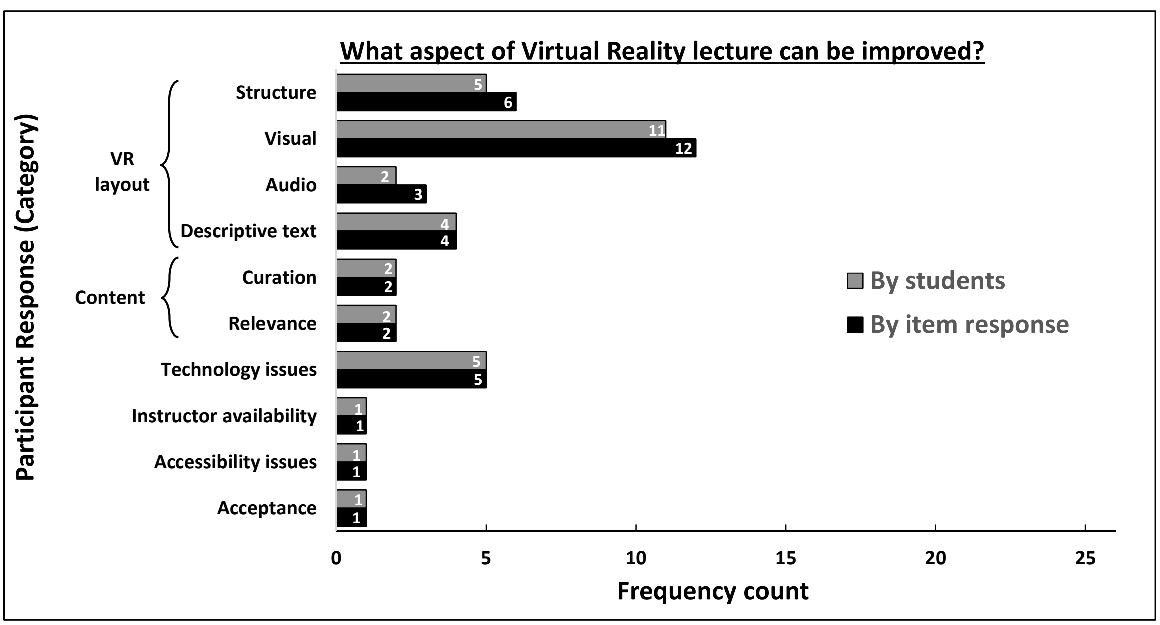


Fig. 7. Category and frequency of participant responses to the question "What aspect of Virtual Reality lecture can be improved?"

The visual capability of VR, and its ability to hold students' attention for a longer period of time became evident from their responses. This is similar to the increase in attention calculated from the IMMS survey after the VR intervention, as shown in Fig. 2. The interaction and immersion potential of VR observed from student responses can also be useful for experiential learning.

For the VR-based lecture, it was noticed that there were very few student responses related to the category of innovation. The lower student responses related to innovation are favorable in a learning environment. As the students become more familiar with this technology, the novelty and innovative elements of VR could eventually get lost. With less focus on innovation, the VR could be an effective instructional technique.

When asked about the aspect of the Virtual Reality lecture that can be improved, most student responses were categorized as related to 'VR layout', 'content', and 'technology issues' (Fig. 7). The layout and content categories in VR-based lecture are similar to those that emerged in the slides-based lecture in Fig. 5.

Within the VR layout category, the largest sub-category for improvements to VR was the visual aspect. The other sub-categories included improvement to the structure of the VR module, better audio narration to support the visuals, and using descriptive text to support the 360° view within VR.

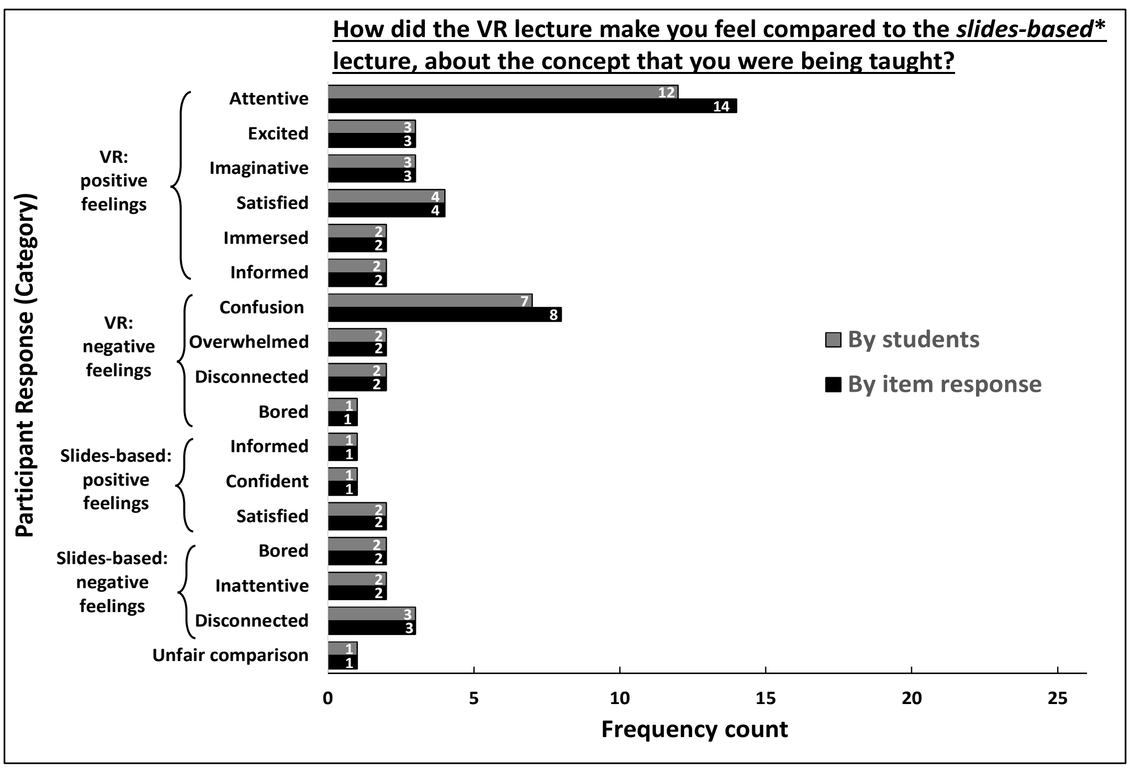
For the VR content category, the responses focused on the content curation and relevance sub-categories, similar to the slides-based lecture. However, unlike the slides-based lecture, there was no content delivery sub-category for the VR-based lecture. This is because the delivery of the lecture in VR is included as part of the layout and design of the VR module.

Two other categories related to 'technology issues' and 'accessibility issues' emerged within the improvement of the VR-based lecture. The technology issues included hardware complications related to fitting smartphones inside the VR viewer, software app setup for smartphones, and the concerns related to internet streaming. From a wide range of possible accessibility issues related to VR, the one that was mentioned by a student in this study was related to using the VR viewer while wearing spectacles or eyeglasses.

One response was categorized as 'acceptance' of VR due to student satisfaction and no improvement that is needed. A remaining response was categorized as the 'instructor availability' within the VR environment, which is something that was not available to students in this study. This could be similar to the slides-based lecture responses where students mentioned that they liked the 'instructor availability' (Fig. 4).

D. *Student reflection of learning with Virtual Reality compared to traditional slides*

Fig. 8 explains the categories of student responses when comparing the VR-based and slides-based lectures. In general, students associated a higher number of positive feelings with the VR-based lecture compared to the slides-based lecture. Among 26 students, 21 of them expressed positive feelings (28 times) about concepts learned in the VR-based lecture compared to only 3 students showing positive feelings (4 times) about learning from the slides-based lecture. The number of students for each feeling sub-category is also shown in Fig. 8.



**In the survey question, the name of the slides-based presentation program was used*

Fig. 8. Category and frequency of participant responses to the question "How did the VR make you feel compared to the *slides-based** lecture, about the concept that you were being taught?"

Within the VR-based lecture, there were more positive feelings indicated (by 21 students) than the number of negative feelings (by 9 students) about learning the concept. Among the positive feelings categorized in the VR-based lecture, the students felt more attentive/engaged, excited, imaginative, satisfied, immersed, and informed. On the other hand, the students expressing negative feelings about the VR-based lecture felt confused, overwhelmed, disconnected, and bored.

Comparing this to learning from the slides-based lecture, only 3 students indicated positive feelings (4 times) and 6 students communicated negative feelings (7 times). The positive feelings expressed were those of feeling informed, confident, and satisfied. The negative feelings included students feeling bored, inattentive, and disconnected.

One student thought that it was an unfair comparison between the VR-based and slides-based lectures due to different amounts of time that the students spent in the slides-based lecture (15 minutes) as compared to the VR-based lecture (3-10 minutes).

In Fig. 9, student responses to the reflection question 'Did the VR lecture help you learn better?' show that 58% of them thought that they learned better using VR, compared to 19% of the students who thought that they did not learn better using VR. Among the other responses, 19% of the students were unsure/uncertain if they learned better or not, and 4% (1 participant) gave no response to this question.

The response trends in Fig. 9 are similar to the motivation level among participants in Fig. 3, when comparing motivation and self-reported learning in participants before and after the VR intervention. From the IMMS survey, 14 participants (54%) showed positive *above-average* motivation after VR, which is close to results obtained from reflection questions where 15 participants (58%) responded saying that they learned better in the VR lecture. In the IMMS survey, 6 participants (23%) showed positive *below-average* motivation after VR, which is similar to 5 participants (19%) expressing through reflection

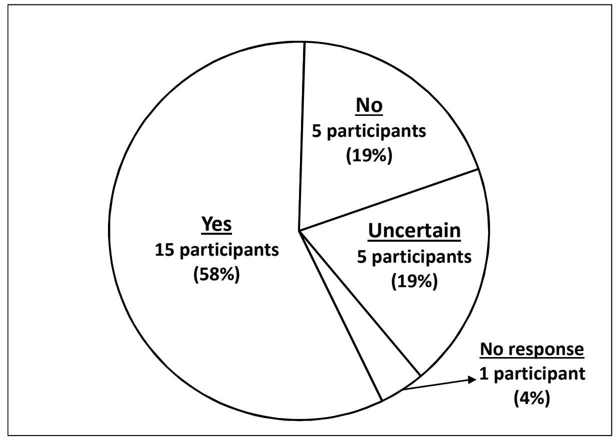


Fig. 9. Count of participant responses to the question "Did the VR lecture help you learn better?" The range of responses received to this question were: yes, no, uncertain, or no response.

questions that they were uncertain whether the VR helped them learn better. The remaining 6 participants (23%) showed negative or no change in motivation after the VR intervention from the IMMS survey, which closely matches the 5 participants (19%) who said in reflection questions that the VR lecture did not help them learn better and 1 participant who did not respond to this question.

After responding with yes, no, and uncertain responses to the question 'Did the VR lecture help you learn better?', the students further explained their responses—how the VR lecture helped them learn better if it did, or how could the VR lecture help them learn better if it did not (Fig. 10). From the 'yes' responses for the VR lecture helping with learning, the students liked clear concepts in VR mostly due to visualization, and in some cases due to general conceptual understanding. The students also responded with 'yes' responses when VR captured their attention and provided an immersive experience to the participants.

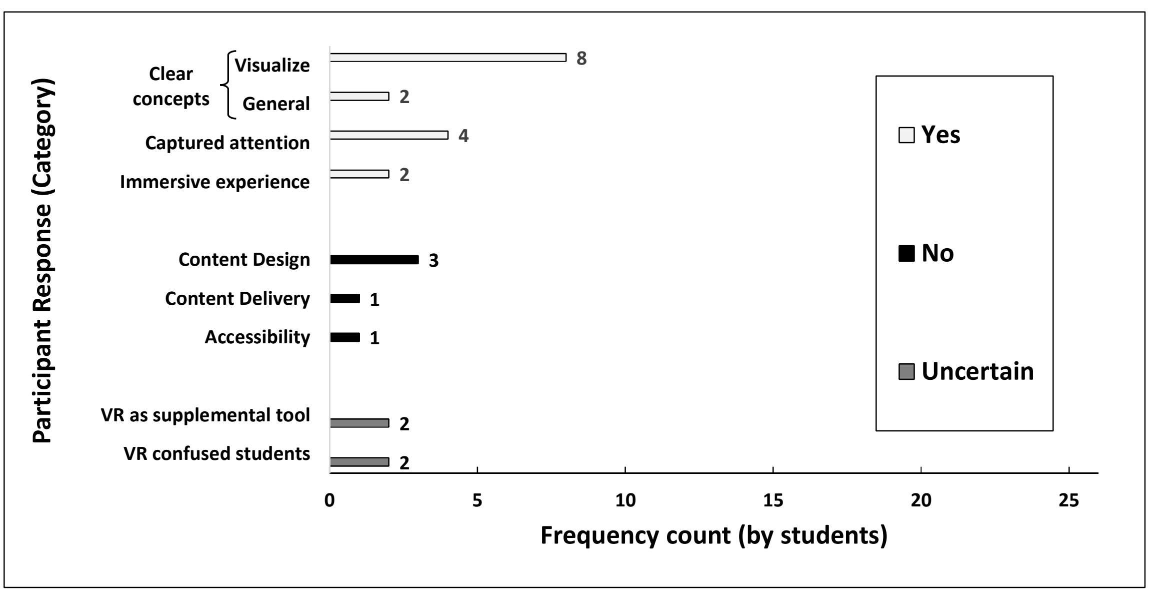


Fig. 10. Category and frequency of participant responses for students answering with 'yes', 'no', or 'uncertain' to the question "Did the VR lecture help you learn better? If so, describe how? If not, how can VR lecture help you learn the concept better?"

On the other hand, the students responding with 'no' to the VR lecture helping with their learning described challenges with the visual quality of VR and content design. Additionally, one student described content delivery being a challenge for them, while another student had accessibility issues with using VR over their glasses that kept them distracted.

The students who were 'uncertain' about the VR lecture helping with their learning mentioned that VR could be used as a supplemental method to the slides-based lecture. Some students were also confused due to a lack of conceptual clarity in the VR module. Among the 'uncertain' responses that are not shown in Fig. 10, three students described a positive student engagement/excitement and better visualization through VR.

IV. Conclusions

Overall student motivation increased significantly after the VR intervention compared to the slides-based lecture. Among the four components of motivation in John Keller's ARCS model, the attention and satisfaction components increased significantly after the VR intervention, while the relevance and confidence components remained unchanged. This is because the VR has an excellent ability to capture attention and provide satisfaction compared to the slides, as evident from qualitative student responses. The 'exciton' topic in VR did not build relevance or boost confidence among the students in this course, which lead to unchanged values from the slides to VR intervention. The student motivation could be further improved in the future by increasing relevance and confidence through the re-design of the VR module (content and layout), and by assigning tasks to test/demonstrate learning success.

In the classroom, VR increased student motivation in a large number of students. About 54% of students showed a *high* increase in motivation which was above the average levels for this group, while in parallel 58% also thought that they learned better using the VR lecture. Similarly, 23% of students showed a *slight* increase in motivation which was below the average levels for this group, while 19% of students also thought that they were uncertain whether the VR helped them learn better. Within this uncertain group of students, some of them also reported positive student engagement and visualization through VR. This means that VR may still boost motivation in 19-23% of students but not to the same level as the other 54-58%. The uncertain responses with a *slight*-increase in motivation could be improved to yes responses with a *high*-increase in motivation by re-designing the content and layout in VR.

The remaining 23% of students included those who showed *negative* or no change in motivation after the VR lecture, while in parallel 19% of the students thought that VR did not help them learn better. For the 19-23% of students who had a negative impact on motivation in VR, a significant number of challenges could also be resolved by focusing on VR content and layout.

As shown in this study, content and layout are two of the most important factors to be considered when designing instruction using both slides-based and VR-based lecture methods. According to students, a well-designed slides-based lecture is one that includes a lot of graphics, has organized structure, and provides easy access to the instructor. The instructor's style is important as observed in student responses. However, there are other factors to be considered for the slides-based lecture method, which include the pre-conceived displeasure associated with this method along with challenges in motivational instructional design using slides. These directly impact the student's motivation to learn in the classroom.

On the other hand, the VR-based lecture was not associated with pre-conceived negative feelings, rather students were more excited, engaged, and satisfied due to the visualization, attention, interaction, and immersion capabilities of VR. The major categories of improvement for the VR-based lecture include the VR content, layout, and technology issues, which could address the challenges for some students feeling confused, overwhelmed, and disconnected afterwards. When designing the VR-based instruction, the technology and accessibility-related issues should be considered as reported by students. The technology issues include the hardware, software, and internet connectivity, while accessibility issues include the VR use with eyeglasses. The availability of the instructor is important even for the VR-based lecture as reported by one student.

Finally, when comparing the slides-based and VR-based lecture formats, it is important to consider that some students preferred the familiarity that comes with the slides-based lecture, even though overall motivation was significantly higher after the VR-lecture. Instead of using only the slides-based method, it could be supplemented with VR-based instruction for improving motivation in students as shown in this study. This was also reported in student responses where one student mentioned 'alternative setting/use' category for the slides-based lecture, and two students who were uncertain about learning in VR described using 'VR as a supplemental instructional tool'.

A limitation of this study is that an advanced materials science concept was taught in an introductory materials science course to sophomores, juniors, and seniors from other STEM majors. In teaching an advanced concept using VR, students needed the background knowledge which was provided using the slides-based lecture. Although this was an advanced topic, the students showed a significant improvement in motivation when the slides-based lecture was supplemented by the VR-based lecture, as compared to the slides-based lecture only. The students may perceive VR as a supplemental tool to other instructional styles because the slides-based lecture provided them the background they needed for this advanced topic. Future studies will investigate the impact of VR on learning outcomes and the use of VR as a stand-alone instructional tool while considering the topic and the course in which it is being taught.

Based on the quantitative increase in motivation and qualitative emergent responses, VR could be used to strengthen student motivation to learn complex 3D concepts for a large number of students. Low-cost and easy setup of VR cardboard viewers is an advantage for scalability when teaching in engineering classrooms.

Acknowledgment

We thank Dr. Terry Creasy and Dr. Ji Ma in Materials Science and Engineering for their support of this study. We also acknowledge the Center for the Integration of Research, Teaching, and Learning at Texas A&M University, and the Division of Marketing and Communications for their support.

REFERENCES

[1] L. Freina and M. Ott, "A Literature Review on Immersive Virtual Reality in Education: State Of The Art and Perspectives," in *eLearning and Software for Education*, Bucharest, Romania, 2015.

[2] M. M. Bowen, "Effect of Virtual Reality on Motivation and Achievement of Middle-School Students," Ph.D. dissertation, Dept. Instruction and Curriculum Leadership, The Univ. of Memphis, Memphis, TN, 2018.

[3] S. Kavanagh, A. Luxton-Reilly, B. Wuensche, and B. Plimmer, "A Systematic Review of Virtual Reality in Education," *Themes in Science and Technology Education*, 10 (2), pp. 85–119, 2017.

[4] R. Moreno and R. E. Mayer, "Virtual reality and learning: Cognitive and motivational effects of students' sense of presence," in the *Ninth International Conference on Human-Computer Interaction*, New Orleans, LA, pp. 65–67, 2001.

[5] T. Wang, "The Effect of Virtual Reality on Learning Motivation and Academic Performance," Master's thesis, Dept. Instructional Design and Technology, Emporia State University, Emporia, KS, 2017.

[6] B. D. Lund and T. Wang, "Effect of Virtual Reality on Learning Motivation and Academic Performance: What Value May VR Have for Library Instruction?," *Kansas Library Association College and University Libraries Section Proceedings*, 9 (1), 2019.

[7] E. Loup-Escande, S. Herbulot, A. Ngandjong, R. Lelong, G. Loup, and A. A. Franco, "Effects of a virtual reality game on learning performances and motivation: example of Nanoviewer in the field of energy storage," *Psychology and Education*, 57 (2), pp. 111–116, 2020.

[8] M. U. Sattar, S. Palaniappan, A. Lokman, N. Shah, U. Khalid, and R. Hasan, "Motivating Medical Students Using Virtual Reality Based Education," *International Journal of Emerging Technologies in Learning*, 15 (2), pp. 160–174, 2020.

[9] G. Makransky, S. Borre-Gude, and R. E. Mayer, "Motivational and cognitive benefits of training in immersive virtual reality based on multiple assessments," *Journal of Computer Assisted Learning*, 35 (6), pp. 691–707, 2019.

[10] J. Parong and R. E. Mayer, "Learning Science in Immersive Virtual Reality," *Journal of Educational Psychology*, 110 (6), pp. 785–797, 2018.

[11] J. Batra, R. Webb, and R. Richardson, "Virtual Reality technology as an instructional tool in Materials Science and Engineering classroom," Poster presented at *The 6th National CIRTL (Center for the Integration of Research, Teaching and Learning) Forum*, Drexel University, Philadelphia, PA, 2019.

[12] W. S. Alhalabi, "Virtual reality systems enhance students' achievements in engineering education, " *Behaviour & Information Technology*, 35 (11), pp. 919–925, 2016.

[13] J. M. Keller, "Development and use of the ARCS model of instructional design." *Journal of Instructional Development*, 10 (3) pp. 2–10, 1987.

[14] J. M. Keller, *Motivational Design for Learning and Performance: The ARCS Model Approach*. Springer, 2009.

[15] R. V. Small, "Motivation in Instructional Design," *ERIC Clearinghouse on Information and Technology*, Syracruse, NY, 1997.

[16] A. D. Serio, M. B. Ibanez, and C. D. Kloos, "Impact of an augmented reality system on students' motivation for a visual art course," *Computers & Education*, 68, pp. 586–596, 2013.

[17] B. Huang and K. F. Hew, "Measuring learners' motivation level in massive open online courses," *International Journal of Information and Education Technology*, 6 (10), pp. 759-764, 2016.

[18] J. M. Keller and K. Suzuki, "Learner motivation and E-learning design: a multinationally validated process," *Journal of Educational Media*, 29 (3), pp. 229–239, 2004.

[19] N. Loorbach, O. Peters, J. Karreman, and M. Steehouder, "Validation of the Instructional Materials Motivation Survey (IMMS) in a self-directed instructional setting aimed at working with technology," *British Journal of Educational Technology*, 46 (1), pp. 204–218, 2015.

[20] Classic V2 version, *I Am Cardboard*, Accessed April 2020. http://www.imcardboard.com/.

[21] D. Nabok et al, "A 360° movie by NOMAD: An Exciton in Lithium Fluoride - Where is the electron?" *Fritz Haber Institute of the Max Planck Society*, Berlin, Germany. Accessed April 2020. https://www.youtube.com/watch?v=XPPDeeP1coM , https://th.fhi-berlin.mpg.de/site/index.php?n=Movies.ScientificMovies.

[22] M. T. H. Chi, "Quantifying qualitative analyses of verbal data: A practical guide," *The Journal of the Learning Sciences*, 6 (3), pp. 271-315, 1997.