Integration of Virtual Reality in Secondary STEM Education

Eric Nersesian, Adam Spryszynski, Michael J. Lee
Department of Informatics
New Jersey Institute of Technology
Newark, NJ USA
{eric.nersesian, as2569, mjlee}@njit.edu

***Abstract*—While the next generation of educational technologies (ET), such as monitor-based (MB) and virtual reality (VR) applications, are still in their infancy, they do show promise for improving education. In this study, we compared MB and VR educational technologies as alternative supplemental learning environments to traditional classroom instruction using lectures, textbooks, and physical labs. We conducted the study in four high school chemistry classes, as chemistry education is well-suited for visually enhanced explanations for learning abstract concepts, and provides a solid testing situation for current and extended reality ET. Ultimately, this research project serves as a foundation to determine whether ETs have the potential to engage high school students in their STEM classes. Successful integration of ET into the public school system curricula may be a viable solution to engage students in STEM education.**

***Index Terms*—STEM Education, Educational Technology, Computer Aided Instruction, Virtual Reality, Chemistry**

Introduction

Recent research shows educational technologies having documented improvements over traditional educational media to a student's visual short-term memory, abstract reasoning, spatial cognition, and multitasking abilities [7]. Modern educational approaches require these student skill sets to be well-developed [6], and has led to the United States Office of Educational Technology to identify the need for better implementations of immersive, and engaging technologies with proven capability to integrate into classrooms and their curricula [30]. Educational delivery methods will need the option to supplement the traditional methods of live teacher and textbook instruction with technological alternatives, especially for students entering Science, Technology, Engineering, and Mathematics (STEM) fields since they are more likely to be engaged with high-end technologies [19].

Global comparisons of STEM education show that the United States (US) ranked in the top 13 countries globally at the elementary school level [28]. US global ranking drops 6% when compared at the middle school level, and drops an additional 11% when compared at the high school level [28]. This decrease of US global STEM rankings as students mature, with the largest decrease occurring at the high school level, places the US below the global average. Research points to many factors contributing to this reduction in STEM education performance, and recognizes that a major factor is the discrepancy in the high number of multimedia experiences focusing on entertainment, compared to education [11]. Successful integration of educational technology into the public school system curricula may be a viable solution to engage students in STEM education and help the United States keep pace with global standards for STEM education.

The current generation of monitor-based (MB) educational technologies, such as simulations, animations, and video games, has been well explored as learning tools within the STEM fields [18], [26]. While the next generation of educational technologies, such as virtual reality (VR), are still in their infancy, they do show a strong inclination toward education [24], collaboration [29], and simulation applications [10]. VR has the potential for strong content immersion [33], allowing the user to interact directly with a simulation and focus on the information presented to them. This new educational medium may help shape how educators express ideas and how students acquire them.

There is, however, a lack of research into extended realities as a learning tool for widespread educational technology applications [11]. Research shows that simulations and visualization of the topic improves understanding and engagement [35]. Therefore, we believe that visualizing chemistry processes will have enormous benefits to chemistry learners, and provide a solid testing situation for current and extended reality educational technologies in STEM education, since simulation has proven to be beneficial for students to engage and comprehend chemistry lessons [15], [35].

These learning challenges, that educational technology simulations can aid, indicate that chemistry represents an immediately comparable domain for measuring the likelihood of educational technology benefits for STEM as a wider field. Comparing well-researched MB simulations against the less researched VR simulations within a simulation-oriented educational environment, may yield necessary research data to examine viability of VR as an educational technology. To address this gap in research, we conducted a study in public high school chemistry classes, grades 9-12, comparing the effectiveness of three modes of supplemental instruction: 1) a VR educational technology, 2) a MB educational technology, and 3) traditional textbook, and physical lab work. This research seeks to examine the educational value of educational technology within a formal STEM classroom.

Related Works

Issues with contextualizing—or effectively demonstrating and visualizing—chemistry content is a constant concern for educators, and is characterized as a disconnect between the student's perspectives and the pedagogical frameworks of the topic [9], [22], [37]. Attempts to resolve this contextual disconnect range from instructional frameworks [32], to social media integration [23], and other educational technologies. Laboratory work is another solution to these contextualization issues as it provides a connection between the chemistry content and "the real world" [20].

When used properly, non-lecture based physical laboratory work (or labs) improve overall learning outcomes [34], positively effect student engagement [4], and contextualize the topic [40]. Yet there are challenges to overcome with implementing labs, including safety and cost. A common solution to these challenges is virtual simulations designed to mimic the experience of physical lab work [31]. An extensive review by Brinson suggests that non-traditional labs, such as virtual and remote implementations, are as effective as traditionally implemented physical labs [12]. Even partial emulations of lab experiences are shown to have positive effects on the learning process. For example, Herga used animations and dynamic simulations of chemistry models to positively impact students' formation of mental models [21].

MB Educational technologies often provide virtual laboratory simulations, where certain parts of the physical lab experience are emulated digitally to help achieve a specific learning goal. Some examples are labSimuLab, ChemVLab+, MatLab simulations, and Multimodal Virtual Chemistry Laboratory (MMVCL). MMVCL is a multimodal simulation experience designed for easy procedure guidance where students can get feedback on their chemical mixing procedure from either textual or tactile modes of interaction [39]. ChemVLab+ is a desktop MB application that allows students to solve real-world lab problems [16]. Designers of ChemVLab+ focused on integrating science practices into an authentic context while providing immediate feedback with simulated measuring tools. labSimuLab is a MB learning tool where certain lab processes are accelerated to allow more time for interpretation of results by students [25]. Al-Moameri studied an approach of using MatLab simulations as an core around which the textbook was designed. Using MatLab for the simulations was proven to be an practical solution given it's availability and ease of integrating computing with visualizations [2].

Gamification is also used in MB educational technology to contextualize chemistry and increase student engagement with curricula. For example, "Say My Name" is a gamified MB educational technology designed to help learners practice chemistry nomenclature [14]. Other examples include Bayir's three gamified MB educational technologies aimed at different categories of chemistry concepts, which were well received by both teachers and students, and supported the author's aim of increasing exposure to chemistry terms and facilitating contextualization of chemistry learning [8].

Beyond MB implementations of laboratory simulations, augmented reality (AR), mixed reality (MR), and VR-based 360 video technologies emulate the laboratory experience and can also be used as standalone learning media. For example, Akcayir demonstrated a physics laboratory AR experience, and showed it was effective in increasing laboratory skills, improved students' work speed, and allowed for more discussion time [1]. AR applications can also support learning in scenarios that do not require fully immersive environments. An example of this is a chemistry AR educational technology for colorimetric titration, which was proven to be effective while remaining cost-efficient [38].

These results align with existing literature as confirmed by Cheng & Tsai, whom compiled a literature review of AR educational technologies classifying them into image and location-based AR [13]. Image-based AR delivers affordances including spatial ability, practical laboratory skills, and conceptual understanding. Location-based AR provides opportunities for supporting inquiry-based learning using collaborative role-play gaming [13]. MR is yet another educational technology that Barrett described as providing a more tactile experience. In his study, he implemented an MR table as a collaborative educational technology tool for undergraduate laboratory sessions [4]. Finally, VR-based 360 videos in the classroom showed to be a viable educational alternative to standard videos with stronger student immersion for contextualization [3].

Method

This study had three teaching conditions: MB, VR, and traditional. It compared MB and VR educational technologies as a supplemental educational medium, specifically for comprehension and engagement of chemistry topics, to the traditional educational medium of textbook, and physical lab work. It spanned a total of 18 weeks, and divided four chemistry classes semi-randomly into three subject groups per educational medium. The study used educational technologies, textbooks, and physical lab work that have been developed by professionals using established K-12 chemistry curriculum concepts. We used standardized metrics to quantitatively compare all three of our teaching methods.

Environment

The study took place in Dwyer Technical Academy (DTA), an urban technology magnet school in Elizabeth, NJ, USA. DTA has a total of 1,208 students, with approximately 300 students per each of the four grade levels. The student population is a diverse mixture of ethnic backgrounds in a lower income urban district with a high percentage of immigrants and first-generation Americans. 70% of the school's student population is Hispanic, with 61.8% stating Spanish as the primary language spoken at home.

The participants were third-year students at DTA enrolled in the four chemistry classes running that year. All chemistry classes had the same teacher, whom agreed to have the study run in his classes and helped integrate the weekly experiment time into his course. Students in the classroom already had regular access to technology, which were school-supplied laptops. The four chemistry classes met for 90 minutes on alternating days of the week, two in the morning and two in the afternoon. Experimental learning time occurred for 18 weeks when the weekly curriculum aligned directly with the learning content of the MB and VR educational technologies. Experimental usage of supplemental learning materials occurred twice a week during this 18 week period in 20 minute self-contained sessions at the end of the class' lab time. During the experiment, the students covered the following topics: Atoms as Building Blocks of Matter, Arrangement of Electrons in Atoms, Periodic Law, and Chemical Bonding. Each week during this period, the researchers met with the teacher to align the experimental learning time with that week's lesson plans.

Inclusive Semi-Randomized Subject Groups

The teacher requested to make all students feel included in the study and to limit the impact of the study on the students' educational experience. He was concerned that students who wanted to be involved in the study, but could not get their parents' permission (since they were minors) would feel left out of the study. To help mitigate this issue, we integrated all of the study-related assessments into the regular class structure (i.e., anyone could participate in the voluntary assessments). Then we randomly assigned participants into the VR or MB experimental conditions, and had the remaining students take the class undisturbed (i.e., in the control condition). The teacher anonymized all the student information, including grades, before sending the information to us.

We used a two step sampling method for subject placement in the experimental groups. Both phases were based on probability sampling, and therefore the samples are demographically representative of the larger population of DTA. The first phase was based on the school administration's course enrollment procedure. They used a simple random sampling method to assign third-year students, who wanted to take chemistry, into one of the four available course time slots[1]. Next, we collected consent and assent forms from students (from all four classes). From these, we randomly assigned these participants into either the VR or MB groups. Students who opted out, left the study, or transferred late into class, participated in the unmodified version of the course as the control group. Each class had 24-27 students within it, for a total chemistry student population of 103. We placed 29 students in the MB educational technology group, and 29 students in the VR educational technology group. By the end of the study 23 from the MB group and 24 from the VR group remained (5 and 4 students dropped out of their groups during the duration of the study, respectively). Of the 45 control group participants, 8 did not participate in the voluntary assessments (for a total of 37 participants). Unfortunately, in the excitement before the commencement of the study, the teacher (erroneously) informed the students about which groups they were assigned to (before we could give them them the pre-test).

[1]This may have not been completely random, as the administration adjusted individual schedules based on a student's conflicts with other courses.

Classroom Experiment Structure

When experimental learning time was hosted, it was initiated with a class discussion on current learning topics. The class was then split into the three concurrently-running subject groups: traditional educational mediums (control), MB educational technology, and VR educational technology. The teacher, assistants, and researchers then circulated between the groups, hosting conversations with the students as they used the supplemental learning materials. Before the study, we trained the teacher and assistants on best practices for each of the educational mediums, so that everyone was prepared to help guide students with learning or technical issues. This was meant to provide fair and equal evaluation of all three educational mediums based on how their respective educational capabilities were designed. Prior to the study, we talked with representatives from each of the software companies to learn about their preferred methods of using their educational technology products in a classroom environment, and were granted their approval for using their products in our study. The teacher, whom was informed on all the medium's best practices, created the final classroom structure for using these educational mediums as to not change the pedagogical nature of the existing chemistry class.

We used a standard, nationally recognized textbook that was already used in the classroom, called "Modern Chemistry" by Holt et al. [17]. The teacher selected physical labs from a list

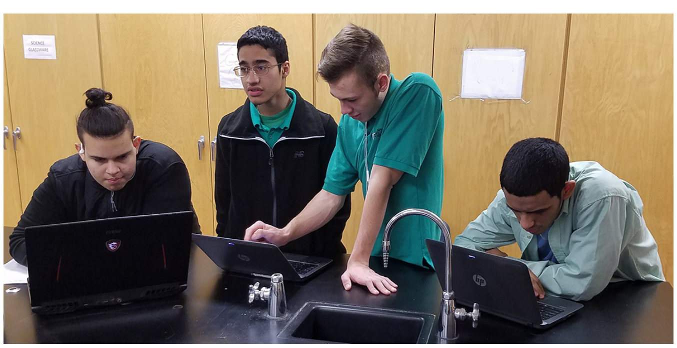

Fig. 1. Subjects in the MB educational technology group, using their laptops to access their MB chemistry application.

Fig. 2. Subjects in the VR educational technology group, using VR headsets to access their VR chemistry application.

of regularly run labs in his chemistry classes. For the MB educational technology, we used *Collisions*[2] by PlayMada Games, which is a collection of 2-dimensional MB games, grounded in the rules of chemistry, that can be used to introduce, teach, and review key concepts in secondary chemistry education. Collisions aims to help students visualize and interact with chemistry concepts through fun and challenging games that integrate into class curriculum and is available on web, iPad, and Android tablets.

For the VR educational technology, we used *MEL Chemistry VR*[3] by MEL Science, which is a collection of interactive lessons that start in a lab setting and zooms into the molecular level, seeking to connect the macro and micro worlds into an overall concept that can be understood by the chemistry student. MEL Chemistry VR is available on Samsung GearVR, Oculus Go, Google Daydream, and Google Cardboard, and aims to remove the student from their physical environment so that they can focus on the chemistry lessons without distractions. The teacher selected the textbook chapters, physical labs, and modules of the educational technologies to use each week. He designed the use of each of the educational mediums as self-contained lab time relating to the current class topic, and meant to be used as supplemental learning tools alongside instructor-led lessons.

Engagement and Knowledge Assessments

All students completed three sets of assessments as voluntary, non-graded classroom assignments. They completed one assessment one week prior to the experiment starting (the pre-test), one week after the experiment concluded (the post-test), and again eight weeks after the experiment concluded (the retention-test). These sets of assessments included an attitude test and knowledge tests. The teacher also provided the researchers with anonymized, final exam scores and final class grades at the end of the school semester.

[2]PlayMada Games' Collisions: http://app.playmadagames.com/Collisions/
[3]MEL Science VR: https://melscience.com/vr/

To create the knowledge assessment test, we consulted with the high school chemistry teacher to select an existing, validated chemistry assessment. The teacher designed the learning assessments from a bank of standardized test preparation questions in the class textbook. We used the same 23 multiple choice question learning assessment for the pre, post, and retention assessments. These assessments only covered the topics that were taught across all three study conditions. Aside from the timing (and ordering of questions and answer choices to avoid ordering effects), all knowledge assessments were identical. Two example questions:

Which particle has the least mass?
a. electron c. proton
b. neutron d. all have the same mass

Which is the maximum number of electrons that can occupy a 3s orbital?
a. 1 c. 6
b. 2 d. 10

We used pre-existing chemistry attitude assessments [5]. The chemistry assessment included eight questions on a seven-point Likert-like scale from negative (-3), neutral (0), and positive (+3) value choices. Three example questions:

Chemistry is... {hard(-3)...neutral(0)...easy(+3)}
{frustrating(-3)...neutral(0)...satisfying(+3)}
{complicated(-3)...neutral(0)...simple(+3)}

RESULTS

We provide quantitative results comparing the learning outcomes from our three groups. Throughout this analysis, we use nonparametric Chi-Squared and Wilcoxon rank sums tests with $\alpha = 0.05$ confidence, as our data were not normally distributed. For post-hoc analyses, we use the Bonferroni correction for three comparisons: ($\alpha/3 = 0.0167$).

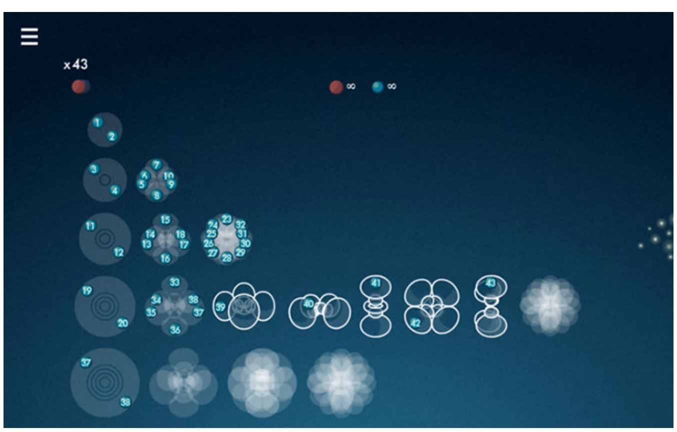

Fig. 3. A screenshot of the MB app covering electron orbits.

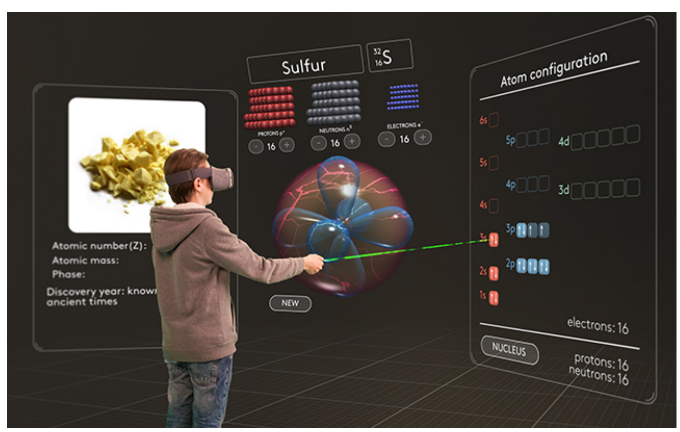

Fig. 4. A representation of the VR app covering atom configuration.

VR Students Initially Have Highly Positive Attitudes

We compared the students' self-reported rating about their attitudes toward chemistry prior to the beginning of the study. Each students' attitude score was calculated as the sum of their responses to the 8 attitude questions. Examining the students' pre-test attitude scores reveal that there is a significant difference in chemistry attitudes between conditions ($\chi^2(2, N = 86) = 7.3517, p < .05$). Post-hoc analysis with Bonferroni correction revealed that the VR vs. control conditions ($W = 10.0858, Z = 2.47398, p < .05/3$) were significantly different (with the VR group students scoring higher). However, comparing scores within the post-test ($\chi^2(2, N = 86) = 3.6609, n.s.$) and the retention-test ($\chi^2(2, N = 86) = 2.7779, n.s.$) did not show a significant difference between groups.

Next, we compared students' chemistry attitudes between assessments, to see if there were changes in attitudes over the course of the study, by condition. Comparing the difference between students' post-test and pre-test attitude scores across the conditions did not reveal statistically detectable differences in chemistry attitudes between conditions ($\chi^2(2, N = 86) = 5.5220, n.s.$). We also did not find any statistically detectable differences in chemistry attitudes between students retention-test vs. pre-test scores ($\chi^2(2, N = 86) = 5.9434, n.s.$) or retention-test vs. post-test scores ($\chi^2(2, N = 86) = 2.4132, n.s.$).

No Differences in Learning Assessments

Overall, participants did poorly on the pre-test exams, with a median score of 5 out of 23 questions correct (21.7%) across all three conditions. This was expected, as the assessment tested students' chemistry knowledge before they started their first chemistry class. We compared the pre-test scores across the conditions and found no significant difference ($\chi^2(2, N = 86) = 0.5126, n.s.$), confirming that all of our participants' chemistry knowledge was roughly equivalent prior to the learning activities.

Although the median scores rose slightly (indicating learning), students also did poorly overall on the post-tests, with the highest median score among the conditions (which was the VR group) being 7 out of 23 questions correct (30.4%). Comparing the post-test scores ($\chi^2(2, N = 86) = 3.1695, n.s.$) and the retention-test scores ($\chi^2(2, N = 86) = 0.9533, n.s.$) across the conditions do not reveal that there any significant differences between conditions.

Next, we compared students' chemistry knowledge between assessments, to see if there were changes in knowledge scores (i.e., learning) over the course of the study, by condition. First we compared the difference between the post-test and pre-test attitude scores. Comparing the difference between students' post-test and pre-test scores across the conditions did not reveal statistically detectable differences in chemistry knowledge between conditions ($\chi^2(2, N = 86) = 3.2252, n.s.$). We also did not find any statistically detectable differences in chemistry knowledge between students retention-test vs. pre-test scores ($\chi^2(2, N = 86) = 5.9434, n.s.$) or retention-test vs. post-test scores ($\chi^2(2, N = 86) = 2.4132, n.s.$).

VR Students Score Higher in Final Exams & Class Grades

Finally, we compared students' exam scores and final grades, by condition. First, comparing their final exam scores (see Figure 5) revealed that there is a significant difference in final exam scores between conditions ($\chi^2(2, N = 83) = 8.3005, p < .05$). Post-hoc analysis with Bonferroni correction revealed the VR vs. control condition ($W = 11.80556, Z = 2.568715, p < .05/3$) pair was significantly different (with the VR group scoring higher), from comparisons of the other pairs. Next, comparing the students' final grades (see Figure 6) revealed that there is a significant difference in chemistry attitudes between conditions ($\chi^2(2, N = 85) = 15.313, p < .05$). Post-hoc analysis revealed the VR vs. control condition ($W = 8.7094, Z = 1.9696, p < .05$) pair was significantly different (with the VR group scoring higher), from comparisons of the other pairs.

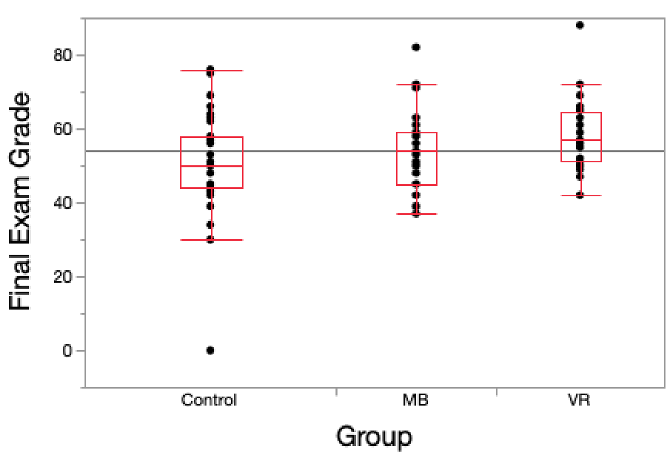

Fig. 5. Boxplot of students' final exam scores, by condition.

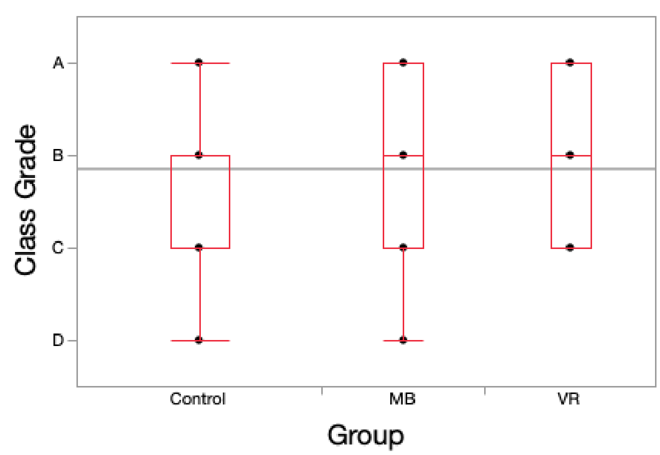

Fig. 6. Boxplot of students' class grades, by condition.

DISCUSSION

Attitude Assessment Interpretation & Observations

Our analysis of chemistry attitudes revealed that the VR group participants reported significantly higher attitudes than their control group counterparts in the pre-assessment. This is likely due to the fact that the chemistry teacher erroneously informed subjects which technology they would be using prior to the study beginning. It is interesting to report that students (especially those in the VR group) were so excited to try out new technologies that it had an impact on their perception of chemistry. However, As we saw in our study results, it may be difficult to maintain this novelty effect, especially when the content might not live up to users' expectations. For our study, the content was closely tied to the medium (i.e., a game for MB, or an application for VR), so we are unable to say conclusively that either the medium or the content, individually, was responsible for our results.

Based on informal student feedback, VR group students exhibited initial excitement with the new technology which decreased over time as their expectations adjusted to the existing content. It seems there was audience misalignment in the VR software, as students mentioned that they could not connect or relate with the British narrator, who starkly contrasted the learner demographics. As with all software, the design of educational technology cannot serve all user needs perfectly. We observed advantages and disadvantages to each educational technology platform in the study and how its content was designed. For example, we overheard the MB group students saying that the game was difficult to play at first, but once they got used to the interface, it was fun for them to race other students to complete the levels. Students in the VR group talked about it being interesting to zoom down to the size of atoms, but that the application lacked the level of interactively they were accustomed to with video games.

We observed a mixed reaction toward educational technologies from the teachers during conversations in the teacher break room. Most teachers had a reluctant optimism as they have experienced instances of technology improving an aspect of classroom management, but also poor implementations increasing their workload. Before starting this study, the chemistry teacher had reservations about using VR in the classroom since it is was a largely untested educational technology. He openly talked about his hesitance with new educational technologies since previous technology implementations from his administration has resulted in extra work for him. He also referenced the usefulness of the math teacher's class management software and wished that a similar software product existed for chemistry education. Over the course of the study, his attitude become more positive towards educational technology and he excitedly discussed ideas about implementing virtual labs to mitigate physical costs, and including MB chemistry gaming time in his regular class.

The experience of this study showed that an effective way to incorporate educational technology into the classroom is to let the teacher experiment with the technology and find their own use cases as the class progresses through the learning material. Once the teacher became more experienced with the technology later in the study, we found that he was much better able to integrate the supplemental learning time with his lectures. As he discussed the coming week's agenda with his teaching aid, he would pause in his lesson description and used the educational technologies to visualize the content to the teaching aid. The teacher commented that every class will be different so effective technology will need to be highly flexible to teachers' needs. Even in the four chemistry classes with the same teacher, we observed differences in progress through curriculum, class management issues, teaching techniques, and student attitudes.

Learning Assessment Interpretation & Observations

Our analysis revealed no significant differences when comparing students' learning assessment sums and differences. The low scores on assessments and teacher feedback indicated issues with voluntary non-graded quizzes. Future studies will integrate the assessments as graded class assignments so students will be incentivized to take them seriously. Learning metrics will be improved by integrating assessments directly into the educational technology. Future work will explore how to best integrate assessments into VR, as research in MB games have shown conflicting results [27], [36].

Both grade items sent from the teacher—the final exam and final class grades—showed the VR group participants did score significantly higher than their control group counterparts. The final exam included a significant number of questions covering the topics taught in the study conditions. Unlike the voluntary knowledge assessments, where all students did poorly, many students performed well in the final exam (see Figure 5), suggesting that students took this exam more seriously. This also suggests that those in the VR condition retained the information they learned during their VR sessions better than those of the other groups.

Our discussions with students indicated that VR improved their chemistry contextualization issues. VR students reported that they were able to understand the chemistry concepts better by visualizing the microscopic chemical interactions. VR and MB students indicated an effective activity in their respective applications was the sandbox mode of freely being able to build atoms and molecules after a lecture to understand the lesson material better. Another contextualization issue came up in conversations with students, teachers, and administrators, that while not connected to this research, still warrants a brief note. There is a consistent misinterpretation from students of what scientists and engineers are and what they do for society since the students do not have to opportunity to learn about STEM careers from members of their community. This gives the impression to the students that this knowledge does not have worth to them and further compounds the contextualization issues. Administrators and teachers point toward using video recordings and in-person visits from STEM professionals to correct these assumptions.

Finally, the final grades—where VR group participants did significantly better than those in the control group—are likely reflective of the final exam grades, as final exam scores make up a significant part of the class grade. Although our experimental design cannot reveal the specific reason why VR group students did better than their other classmates, we will explore this in future work.

Study Limitations & Future Work

As the first major use of education technology in this classroom, it was a success for the researchers, teacher, and students. The data that was collected from this research is viable to report on, yet confounding variables restrict explanation reporting of the data. Educational technology research operates within the classroom environment and is impacted by the variables of that operating condition. Despite this limitation, data trends in the study show a positive academic impact with the educational technologies and call for further classroom experiments to validate these claims.

Future research will seek to evaluate and isolate some of the confounding variables. The observer effect, which is well known in educational technology research, cannot be verified in the research even though there is anecdotal evidence to support its existence. Future studies will be conducted without researchers in the classroom to remove the observer effect on the subjects. The participating teacher will be trained to use the technologies effectively and integrating the training of the students into their curriculum. The study will separate the four classes completely into experimental and control groups to verify the educational technologies influence on the students' attitudes and comprehension of the class materials.

It is important to recognize that the time limitations on students within a classroom complicate data collection with established methods such as interviews and focus groups. In the future, we plan to develop metrics to analyze student perspectives in a time-efficient manner. These will be necessary to develop a detailed understanding of the student needs on which effective educational technologies can be built. Observations of the different platforms and content deliveries of the educational technologies used in this study confirmed the need for further user analysis to increase the effectiveness of integrating the technology into the teacher's curriculum. While we did observe an effect on the technologies, we cannot distinguish the impact of the platform separate from the content. If we were to run the study again, we would need to define custom-built or modify existing technologies that could leverage the same content in all experimental technology platforms to isolate variables relating to platform and content.

Conclusion

This research compares MB and VR educational technologies as learning environments, specifically comprehension and retention of chemistry topics, to traditional educational mediums of textbook, lecture, and physical lab work. We specifically focused on chemistry education, as the subject matter is well-suited for visually enhanced explanations to support the learning of abstract concepts. It is vital to understand the scope of these research questions to enable further clarification of the problem space within the classroom.

Ultimately, this research project serves as a foundation to determine whether educational technologies have the potential to engage high school students in their STEM classes. This high-level view of technology in the classroom enables us to see if there is viability to continue this stream of research. Even with this level of confounding variables in the classroom, we were able to see changes to students' academic performances. It is worthwhile to spend effort in isolating factors in future classroom experiments with the end result of confirming data which is vital for education research.

Acknowledgment

We thank the Elizabeth School System and Oculus Education for their support of this research. Any opinions, findings, conclusions, or recommendations are those of the authors and may not reflect the views of either of these parties.

References

[1] Murat Akçayır, Gökçe Akçayır, Hüseyin Miraç Pektaş, and Mehmet Akif Ocak. 2016. Augmented reality in science laboratories: The effects of augmented reality on university students' laboratory skills and attitudes toward science laboratories. *Computers in Human Behavior* 57 (2016), 334–342.

[2] Harith H Al-Moameri, Luay A Jaf, and Galen J Suppes. 2018. Simulation Approach to Learning Polymer Science. *J. Chem. Educ* 95 (2018), 27.

[3] Alvita Ardisara and Fun Man Fung. 2018. Integrating 360° Videos in an Undergraduate Chemistry Laboratory Course. *Journal of Chemical Education* (2018).

[4] Rainier Barrett, Heta A Gandhi, Anusha Naganathan, Danielle Daniels, Yang Zhang, Chibueze Onwunaka, April Luehmann, and Andrew D White. 2018. Social and Tactile Mixed Reality Increases Student Engagement in Undergraduate Lab Activities. *Journal of Chemical Education* (2018).

[5] Christopher F Bauer. 2008. Attitude toward chemistry: A semantic differential instrument for assessing curriculum impacts. *Journal of Chemical Education* 85, 10 (2008), 1440.

[6] Daphne Bavelier and C Shawn Green. 2016. The brain-boosting power of video games. *Scientific American* 315, 1 (2016), 26–31.

[7] Daphne Bavelier, C Shawn Green, Alexandre Pouget, and Paul Schrater. 2012. Brain plasticity through the life span: learning to learn and action video games. *Annual review of neuroscience* 35 (2012), 391–416.

[8] Eylem Bayir. 2014. Developing and Playing Chemistry Games To Learn about Elements, Compounds, and the Periodic Table: Elemental Periodica, Compoundica, and Groupica. *Journal of Chemical Education* (2014).

[9] Judith Bennett, Fred Lubben, and Sylvia Hogarth. 2007. Bringing science to life: A synthesis of the research evidence on the effects of context-based and STS approaches to science teaching. *Science Education* (2007), 347–370.

[10] Mark Billinghurst and Andreas Duenser. 2012. Augmented reality in the classroom. *Computer* 45, 7 (2012), 56–63.

[11] Matt Bower, Cathie Howe, Nerida McCredie, Austin Robinson, and David Grover. 2014. Augmented Reality in education - cases, places and potentials. *EMI. Educ. Media Int.* 51, 1 (2014), 1–15.

[12] James R. Brinson. 2015. Learning outcome achievement in non-traditional (virtual and remote) versus traditional (hands-on) laboratories: A review of the empirical research. *Computers & Education* 87 (9 2015), 218–237.

[13] Kun Hung Cheng and Chin Chung Tsai. 2013. Affordances of Augmented Reality in Science Learning: Suggestions for Future Research. *Journal of Science Education and Technology* (2013).

[14] Jose Nunes Da Silva and Davi Jano Nobre. 2018. Interactive Computer Game That Engages Students in Reviewing Organic Compound Nomenclature. *Journal of Chemical Education* (2018).

[15] Barney Dalgarno, Andrea G Bishop, William Adlong, and Danny R Bedgood Jr. 2009. Effectiveness of a virtual laboratory as a preparatory resource for distance education chemistry students. *Computers & Education* 53, 3 (2009), 853–865.

[16] Jodi L. Davenport, Anna N. Rafferty, and David J. Yaron. 2018. Whether and How Authentic Contexts Using a Virtual Chemistry Lab Support Learning. *Journal of Chemical Education* 95, 8 (8 2018), 1250–1259.

[17] Raymond E Davis, Jerry Sarquis, Mickey Sarquis, and Regina Frey. 2009. *Modern Chemistry*. Holt, Rinehart, and Winston.

[18] James Paul Gee. 2003. What video games have to teach us about learning and literacy. *Computers in Entertainment (CIE)* 1, 1 (2003), 20–20.

[19] Angel Gurria. 2012. *PISA 2012 Results in focus: what 15-year-olds know and what they can do with what they know.* Technical Report.

[20] Ahmet Gürses, Metin Açıkyıldız, Çetin Doğar, and Mustafa Sözbilir. 2007. An investigation into the effectiveness of problem-based learning in a physical chemistry laboratory course. *Research in Science & Technological Education* 25, 1 (2007), 99–113.

[21] Nataša Rizman Herga, Branka Čagran, and Dejan Dinevski. 2016. Virtual Laboratory in the Role of Dynamic Visualisation for Better Understanding of Chemistry in Primary School Evaluating different approaches to problem based learning View project VPMed: Developing a VP for interprofessional education View project. *Article in Eurasia Journal of Mathematics* (2016). DOI:http://dx.doi.org/10.12973/eurasia.2016.1224a

[22] Dietmar Hottecke and Cibelle Celestino Silva. 2011. Why Implementing History and Philosophy in School Science Education is a Challenge: An Analysis of Obstacles. *Science & Education* (2011).

[23] Glenn A Hurst. 2018. Utilizing Snapchat To Facilitate Engagement with and Contextualization of Undergraduate Chemistry. *Journal of Chemical Education* (2018).

[24] Larry Johnson, Samantha Adams Becker, Michele Cummins, Victoria Estrada, Alex Freeman, and Courtney Hall. 2016. *NMC horizon report: 2016 higher education edition*. The New Media Consortium.

[25] Jens Josephsen and Agnieszka Kosminska Kristensen. 2006. Simulation of laboratory assignments to support students learning of introductory inorganic chemistry. *Chem. Educ. Res. Pract.* 7 (2006).

[26] Michael J Lee. 2013. How can a social debugging game effectively teach computer programming concepts?. In *Proceedings of the ninth annual international ACM conference on International computing education research*. ACM, 181–182.

[27] Michael J Lee, Andrew J Ko, and Irwin Kwan. 2013. In-game assessments increase novice programmers' engagement and level completion speed. In *Proceedings of the ninth annual international ACM conference on International computing education research*. ACM, 153–160.

[28] Ina VS Mullis, Michael O Martin, Pierre Foy, and Alka Arora. 2012. *TIMSS 2011 international results in mathematics.* ERIC.

[29] Michael Narayan, Leo Waugh, Xiaoyu Zhang, Pradyut Bafna, and Doug Bowman. 2005. Quantifying the benefits of immersion for collaboration in virtual environments. In *Proceedings of the ACM symposium on Virtual reality software and technology*. ACM, 78–81.

[30] U.S. Department of Education. 2018. *Teaching - Office of Educational Technology*. Technical Report.

[31] Veljko Potkonjak, Michael Gardner, Victor Callaghan, Pasi Mattila, Christian Guetl, Vladimir M. Petrović, and Kosta Jovanović. 2016. Virtual laboratories for education in science, technology, and engineering: A review. *Computers & Education* 95 (4 2016), 309–327.

[32] Gjalt T. Prins, Astrid M. W. Bulte, and Albert Pilot. 2016. An Activity-Based Instructional Framework for Transforming Authentic Modeling Practices into Meaningful Contexts for Learning in Science Education. *Science Education* 100, 6 (11 2016), 1092–1123.

[33] Eric D Ragan, Doug A Bowman, and Karl J Huber. 2012. Supporting cognitive processing with spatial information presentations in virtual environments. *Virtual Reality* 16, 4 (2012), 301–314.

[34] Norman Reid and Iqbal Shah. 2007. The role of laboratory work in university chemistry. *Educ. Res. Pract* 8, 2 (2007), 172–185.

[35] Nico Rutten, Wouter R Van Joolingen, and Jan T Van Der Veen. 2012. The learning effects of computer simulations in science education. *Computers & Education* 58, 1 (2012), 136–153.

[36] Valerie J Shute. 2011. Stealth assessment in computer-based games to support learning. *Computer games and instruction* 55, 2 (2011), 503–524.

[37] Jesper Sjostrom and Vicente Talanquer. 2014. Humanizing Chemistry Education: From Simple Contextualization to Multifaceted Problematization. *Journal of Chemical Education* (2014).

[38] Nicholas Yee Kwang Tee, Hong Seng Gan, Jonathan Li, Brandon Huey-Ping Cheong, Han Yen Tan, Oi Wah Liew, and Tuck Wah Ng. 2018. Developing and Demonstrating an Augmented Reality Colorimetric Titration Tool. *Journal of Chemical Education* (2018).

[39] Sehat Ullah, Numan Ali, and Sami Ur Rahman. 2016. The Effect of Procedural Guidance on Students' Skill Enhancement in a Virtual Chemistry Laboratory. *Journal of Chemical Education* (2016).

[40] Neslihan Ültay and Muammer Çalik. 2012. A Thematic Review of Studies into the Effectiveness of Context-Based Chemistry Curricula. *Journal of Science Education and Technology* 21, 6 (2012), 686–701.