EXPLORING THE ROLE OF VIEWING TECHNOLOGIES IN THE CHEMISTRY CLASSROOM

Kassem Ayman Omar* & Vivian Mozol

University of Calgary

Spatial ability is an important tool in chemistry and this ability can be improved. Various technologies have been used to improve spatial ability. However, it is not clear if viewing technologies should take the place of the model kit; the traditional method of learning about molecular structures. Our research aims to address this gap. In our study, we aimed to take advantage of student affinity to technology to drive spatial ability improvements (in the context of chemistry) by having students experience molecules in virtual space using modern viewing technologies (WBVE, AR, and VR). Students were first engaged with the technologies then were assessed to see if their ability to solve problems relating to 3D-molecular structure improved. The mean spatial ability of students improved over the course of the semester (permutation test, $p < 0.05$) and students using model kits scored higher than those using the technologies (t-test, $p < 0.05$). The collection and assessment of anonymous, aggregated, student responses for this study was conducted with the approval of the University of Calgary ethics board (REB13-0724).

"Education is our passport to the future, for tomorrow belongs only to the people who prepare for it today", as it was put by Malcom X at the 1964 Founding Rally of the Organization of Afro-American Unity (BlackPast, 2007). Indeed, these words ring true as those who pursue education are the same ones as those who will one day drive change in our world. Our students are our future, and as educators we must continually look for better ways to engage and teach them. In 2019, we find ourselves to have been rapidly thrust into a new age; one made of silicon and lead. That is to say that we find ourselves in a new age of technology. However, the up and coming have been born into this age and thus present an extraordinary affinity for technology. Kennedy, Judd, Churchward, and Gray (2008) conducted a study on more than 2000 first year university students, exploring the degree to which they liked and used technology. The researchers found that virtually all students have and use some form of technology every day (mobile phones or computers). The researchers also found that 84% of students responded that they would like their technology incorporated into their studies (Kennedy, Judd, Churchward, & Gray, 2008). It seems that Robert Kvavik (2005, para. 1) was on to something when he said that our current cohort of students is "characterized as preferring teamwork, experiential activities, and the use of technology". The question then is how, and where, can we implement such strategies? In our study, we aimed to take advantage of student affinity to technology to drive spatial ability improvements (in the context of chemistry) by having students experience molecules in a virtual space using modern viewing technologies.

To be able to "see" molecules students must make use of the ability to picture the descriptions of the objects in their mind. This relates to the idea of "spatial ability" or "spatial intelligence". Work in this field goes back to the 1800s with the work of Sir Frances Galton

*Corresponding author - kaomar@ucalgary.ca

Omar, K. A., & Mozol, V. (2020). Exploring the role of viewing technologies in the chemistry classroom. *Papers on Postsecondary Learning and Teaching, 4*, 68-75.

(1880) where he used simple mental activities and a series of questions to explore an individual's capacity to see something unseen. Research has shown that some individuals are more capable (faster and more correct) than others when it comes to tasks involving spatial ability. For example, significant differences have been suggested to exist between males and females with regards to spatial ability (Casey, Nuttall, Pezaris, & Benbow, 1995; Maeda & Yoon, 2013). However, recent studies have highlighted the importance of considering things like age, experience, and implicit stereotyping before jumping to such conclusions (Guizzo, Moè, Cadinu, & Bertolli, 2019; King, Katz, Thompson, & Macnamara, 2019; Lauer, Yhang, & Lourenco, 2019). In the study of chemistry, it has been shown that spatial ability is linked with higher grades in chemistry courses (Harle & Towns, 2011; Sorby, 2009). Naturally, the thought after this discovery is: can spatial abilities be improved? There is evidence to suggest that they can be. A study by Lord (1985) illustrated that with "weekly intervention sessions", students improved their spatial ability. For us to be able to raise stronger and better chemists it will be beneficial to include and improve more measures for improving spatial ability in our educational strategies. One strategy to aid with this is the use of model kits.

Model kits are readily available and recommended in undergraduate introductory chemistry courses. Perhaps this is because one of the most abstract concepts in chemistry, for the beginner, is trying to picture molecules and understand them in our minds. In a study by Hyman (1982), two treatments were administered on university level organic chemistry students: 1) extra lectures that involved watching someone manipulate molecular models, followed by time for the students to manipulate the molecules themselves and 2) the same lectures that involved watching the manipulation of the models, but with no subsequent manipulation time. Hyman (1982) stated:

> This study was designed to determine if students in an organic chemistry course would perform higher on different levels of cognitive achievement if they attended sessions where they were given tasks to manipulate molecular models to facilitate comprehension of the concepts. An additional purpose of the study was to determine the role of spatial visualization ability on achievement in organic chemistry and to investigate the effect attending the sessions had on improving spatial visualization ability. (pg.1)

Surprisingly, Hyman (1982) found that there were no significant differences in terms of "achievement" (as referred to by Hyman, 1982) between the two groups. Another study by Blatnick (1986) found similar conclusions in which a very similar experiment was conducted on grade 9 students in the context of chemistry. The results also indicated that there were no significant differences between the two treatment groups (model interaction and no model interaction). However, Blatnick (1986) did state:

> Models add interest and clarity to science instruction. Models are fun to use and provide needed variety in the instructional process. It is possible that the use of models contributes to instructional outcomes that were not measured in the present study. (p. 33-34)

From the studies of Hyman (1982) and Blatnick (1986), as well as that of Rafi, Anaur, Samad, Hayati, and Mahadzir (2005), it appears that students benefit from having the opportunity to see or view objects, but there does not seem to be any added benefit of physically manipulating these model kits. While the model kit has its uses, technology has come a long way since its development. The question is: do certain technologies have a place beside the model kit?

Technology has been applied in the educational setting with promising results. Researchers have tested the use of technology to improve spatial ability. In a study by Rafi et al. (2005), the use of a web-based virtual environment (WBVE) was utilized to test if regular spatial ability training would improve participants' performance on questions requiring the use of their spatial ability skills. WBVE consists of projecting a 3D image of an object on a computer screen and having the ability to manipulate that object with a mouse or trackpad. In this study researchers had undergraduate students make use of a WBVE system to complete various questions requiring the use of one's spatial ability. The participants were allowed access to this technology over a span of five weeks, and researchers found significant improvements when compared to controls (controls were traditional pen and paper spatial ability teaching techniques) (Rafi et al., 2005). As we can see, there is room for technology to play a role in helping our students improve their spatial ability skills in a time period as short as five weeks. Applying this to chemistry education could help teach our students necessary skills to succeed.

Other viewing technologies also exist, such as augmented reality (AR) and virtual reality (VR) technologies. In a study by Asai and Takase (2011), it was demonstrated that the use of an AR system helped participants identify molecular structures faster and more accurately when compared with pc-desktop viewers. VR is different from AR in that, with AR, objects are projected and incorporated into life as we know it, whereas in VR the user wears a specialized head piece and immerses themselves in a virtual world. In a study by O'Connor et al. (2018), the researchers found that participants using their VR system to complete molecular structure related tasks, were able to do so quicker than those who did the same using a WBVE like setup.

From the afore mentioned studies, it seems to be that there is a benefit to making use of viewing technologies in the chemistry classroom (Asai & Takase, 2011; O'Connor et al., 2018; Rafi et al., 2005). The viewing technologies discussed hold the benefit of allowing the students to view and experience molecules or objects. They are also tools that students can use and manipulate anywhere and anytime. In our digital age, where virtually everyone has a smartphone only inches away, technology has become much more accessible than traditional resources such as the model kit. However, not all viewing technologies have been created equal. While it has been demonstrated that high end and expensive viewing technology tools have good utility, can the same be said about cheaper and more realistically attained versions? And if so, can they replace the model kit?

RESEARCH QUESTION

In our study, we aimed to test the application of VR in chemical education. As stated before, undergraduate chemistry students are usually encouraged to buy molecular model kits and use them to supplement their understanding of the unseen chemical world. We put these traditional model kits to the test against a basic $25 VR/AR/WBVE system via a smartphone app called Sketchfab. In the research conducted by O'Connor et al. (2018), sophisticated VR systems were used that involve headpieces and controllers. Systems like these can cost up to hundreds of dollars. Here, we tested the utility of a $25 VR/AR/WBVE system that requires only a smartphone and a cardboard VR headset (which costs about $25). This is perhaps a more realistic application of VR to chemical education due to the cost. Ultimately, the question we answered is: will a basic $25 VR/AR/WBVE system better equip a chemistry student to learn concepts, pertaining to molecular structures, better than a traditional model kit will. The effectiveness of both the VR/AR/WBVE system (via sketchfab) and the model kit as spatial ability interventions were also examined in this study. The collection and assessment of anonymous, aggregated, student responses for this study was conducted with the approval of the University of Calgary ethics board (REB13-0724).

METHODS

To test our research question, we ran a series of experiments on a first-year engineering cohort within the bounds of an introductory chemistry class (CHEM 209) at the University of Calgary. We administered a baseline assessment of spatial ability via a student engagement tool called TopHat. TopHat involves the projection of a question on the lecture hall screen, and students answer the question using their smartphones or computers. For the baseline assessment we used the Vanderberg and Kuse style spatial ability assessments (as used in the study by Caissie, Vigneau, & Bors, 2009) and we made similar questions using molecules to match.

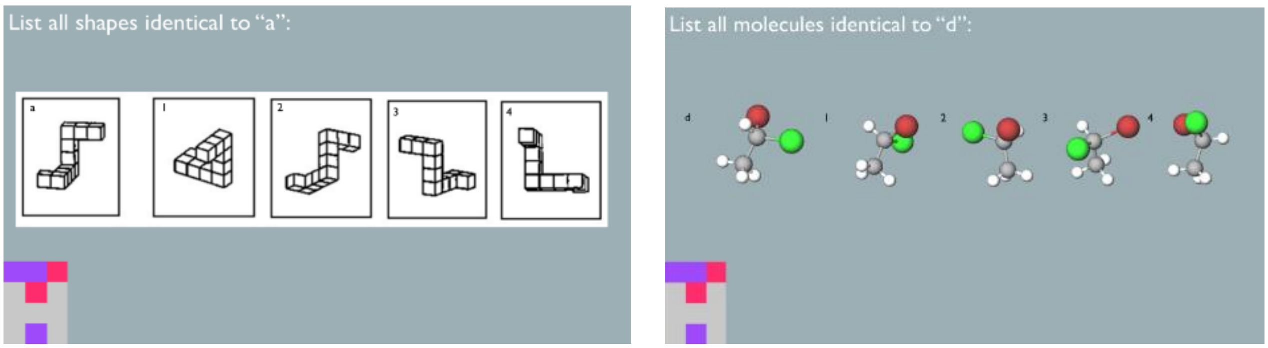

Figure 1. The exact slides used for the base line assessment. The first image from the left contains Vaderberg and Kuse models adapted from Caissie et al. (2009) the second image shows our own images made using molecules.

We then ran experiments in one week's worth of tutorial sections. Our main educational interventions (for spatial ability improvement) were incorporated into one week's worth of tutorial sections of the CHEM 209 course (there were 11 total tutorial sections and each section contained 30 students on average). This resulted in a total of 343 participants who were included in this study. The tutorials regularly consist of a 35-minute group activity and a 15-minute independent assessment. Six tutorial sections were randomly assigned to the first educational intervention and five were assigned to the second. The first intervention had students use the VR/AR/WBVE system as an aid for the group activity, and the second intervention had students use a traditional model kit. The group activity had students complete a variety of molecular structure questions requiring the use of spatial ability (see figure below). The VR/AR/WBVE system gave students access to any of the VR, AR, and WBVE technologies through their mobile phones.

Figure 2. These images depict the VR and AR aspects of the VR/AR/WBVE system. The first image from the shows a cardboard headset that the mobile phones were inserted into, and the top right of that image shows an example of what students saw (in our case the students experienced only one molecule in the virtual environment). The second image depicts a molecule augmented onto a physical surface (very similar to what students experienced). WBVE consisted of a molecule on a phone screen that could be manipulated by swiping the screen.

This was made possible by the Sketchfab app that students were required to download. The use of the VR/AR/WBVE system and the model kit were not allowed during the 15-minute tutorial assessment. The same assessment was administered to all sections.

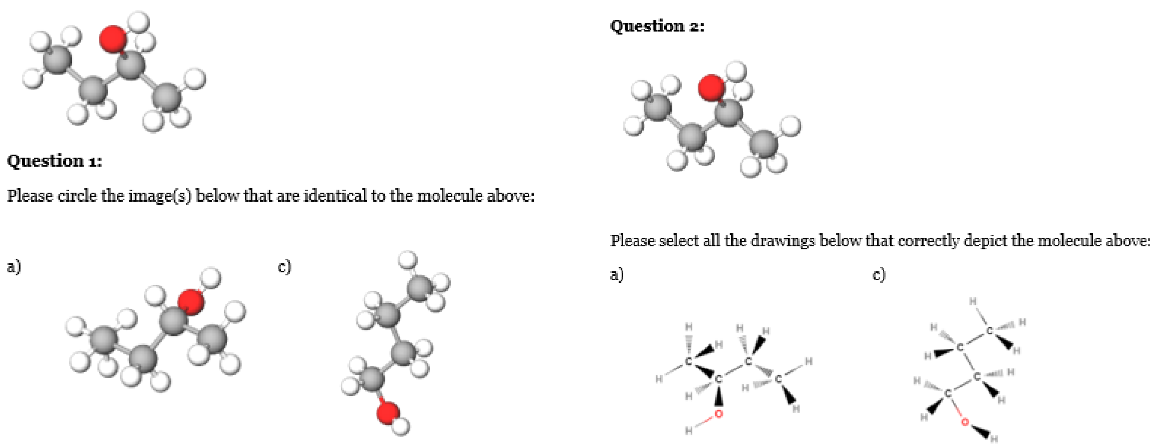

Figure 3. These images are two of the questions that were posed in the assessment. The question on the final exam was similar to these.

A final assessment was also administered as a question on the final exam (question similar to assessment question).

RESULTS

We conducted a t-test to compare the mean scores of the assessments of the two treatments. The students who underwent the VR/AR/WBVE treatment had a mean score of 6.45 and a standard deviation of 1.82. and those of the model kit treatment had a mean score of 7.21 with a standard deviation of 1.64. Our null hypothesis stated that the two means are equal. The t-test resulted in a t value of -4.35 and a p value less than 0.05, allowing us to reject our null hypothesis that the means are equal. Thus, we conclude that the model kits helped students perform significantly better on a standard molecular structure spatial ability assessment.

We also conducted a permutation test to compare the mean baseline assessment score to the mean final assessment score. The students scored a mean of 1.04 with a standard deviation of 0.47 on the baseline assessment and a mean of 1.71 with a standard deviation of 2.41 on the final assessment. Our null hypothesis stated that both means are independent of their respective treatment (making them interchangeable i.e. no difference). The permutation test resulted in a z score of -3.945 and a p-value less than 0.05. Thus, we conclude that students had significantly higher scores after having gone through spatial ability assessments.

	Statistical analysis	Test value (t or z)	p value	decision
Main Experimental treatment	t-test	-4.35	<0.05	Means are significantly different
Baseline Assessment	Permutation test	-3.945	<0.05	Means are significantly different

Figure 4. Table depicting the results of the main statistical analyses performed.

DISCUSSION

We have observed that the findings displayed in the study by Lord (1985) have been replicated in our study. Student scores on spatial ability tests were significantly higher at the end of the term, after our own spatial ability interventions. This is true for individuals from both treatment groups, meaning that both the model kit and the VR/AR/WBVE system were effective tools for improving spatial ability. However, this then begs the question: which is better?

In terms of which strategy is more practical, arguments can be made for both the model kit and the viewing technologies. However, in present day time it is safe to say that the vast majority of students are carrying their technology everywhere, whether it is a mobile phone or computer. As a result, the viewing technologies are more accessible than the model kit. However, in terms of effectiveness for the sake of learning, the answer is less clear. In our study we found the mean assessment scores of those participants who had the model kit available as an aid to be significantly higher than those who had the VR/AR/WBVE system. This leads us to conclude that the model kit has helped students more in terms of being an aid to improving spatial ability. This is to say that the more economical versions of the VR or AR or WBVE tested here have not proven to be a sufficient replacement of the model kit. While more expensive versions of these technologies have established their place in the classroom, these results have not yet translated to the lower tiers of technology that are more accessible to students. There is still room for improvement for these technologies and improved upon they should be as their practicality is clear.

While the model kit did outperform the VR/AR/WBVE system, the discrepancy is not that large. The difference between the means is less than 1 point with the mean of the VR/AR/WBVE group (plus its standard deviation) extending beyond the mean of the model kit group. This means that it is common for deviant data points (from the mean in the VR/AR/WBVE group) to score higher than the mean of the model kit group. These results suggest that the group who used the viewing technologies are not far off from the group who used the model kit. Furthermore, our study was limited in that it did not randomly assign individual participants or separate technologies in the VR/AR/WBVE system. Improving upon these aspects would give us more insight as to the exact relationship between spatial ability improvement and emerging technologies.

As the literature quoted above suggested (Blatnick, 1986; Hyman; 1982), we are inclined to say that it is not necessarily the physical manipulation that is likely to have been important, but rather that the model kit was a better learning tool than the VR/AR/WBVE system. This may be due to the learning curve associated with using the technology as opposed to the intuitive use of the model kit. While students using the technology were tutored in the use of the technology, we did observe that many students still needed time to become proficient with the technologies. This is compounded by the fact that there is the option of using three different technologies, each of which the student needs to be acquainted with. This process of learning to use the technology took time and thus took time away from actual spatial ability learning time. Students using the model kit were able to jump right into spatial ability learning as using the model kit is intuitive and already recommended and instituted in chemistry classrooms in university and even high school.

Another important thing to note here is the fact that the viewing technologies were all clumped into one experience. We also left it to students to decide what they wanted to use of the three technologies; thus it is not a completely fair comparison of the individual technologies, but rather it is an evaluation of the Sketchfab system. Thus, in future studies, it would be important and interesting to separate these technologies and give more time for learning to use the technology and evaluate their individual utility.

CONCLUSION

Research has demonstrated that individuals who can efficiently and accurately use their spatial abilities (that is to mentally identify, manipulate, and reason with 3D objects) achieve higher scores in chemistry related evaluations (Harle & Towns, 2011; Sorby, 2009). Thus it is important to find ways to help students improve their spatial abilities. One such way is to involve a tool that has become very important to the modern student experience: technology. Our study has demonstrated that there is a benefit in having “spatial ability aids” both traditional and technological. In our study, lower tier viewing technologies have not unequivocally surpassed the model kit, but they are not far behind. We also acknowledge some of the aspects of experimentation that can be improved upon from this study that perhaps may give the viewing technologies a fairer evaluation. In conclusion, it is important that we look at lessons learned from our past and apply them to our future. Our past tells us here that spatial ability is important and needs to be looked after and improved, and technology may be our greatest tool to accomplishing this.

REFERENCES

Asai, K., & Takase, N. (2011). Learning molecular structures in a tangible augmented reality environment. *International Journal of Virtual and Personal Learning Environments. 2*(1), 1-18. https://doi.org/10.4018/jvple.2011010101

BlackPast, B. (2007) *(1964) Malcolm X’s Speech at the Founding Rally of the Organization of Afro-American Unity.* Retrieved from https://www.blackpast.org/african-american-history/1964-malcolm-x-s-speech-founding-rally-organization-afro-american-unity/

Blatnick, R. A. (1986). *The effect of three-dimensional models on ninth-grade chemistry scores*: visualization, molecular models. (Doctoral dissertation). Available from ProQuest Dissertations and Theses database. (UMI No. 8626739)

Caissie, A. F., Vigneau, F., & Bors, D. A. (2009). What does the Mental Rotation Test measure? An analysis of item difficulty and item characteristics. *Open Psychology Journal*, *2*(1), 94-102. https://doi.org/10.2174/1874350100902010094

Casey, M. B., Nuttall, R., Pezaris, E., & Benbow, C. P. (1995). The influence of spatial ability on gender differences in mathematics college entrance test scores across diverse samples. *Developmental Psychology*, *31*(4), 697.

Galton, S. F. (1880). Mental imagery. *Fortnightly Review, 28*, 312-324.

Guizzo, F., Moè, A., Cadinu, M., & Bertolli, C. (2019). The role of implicit gender spatial stereotyping in mental rotation performance. *Acta psychologica*, *194*, 63-68. https://doi.org/10.1016/j.actpsy.2019.01.013

Harle, M., & Towns, M. (2011). A review of spatial ability literature, its connection to chemistry, and implications for instruction. *Journal of Chemical Education*, *88*(3), 351-360. https://doi.org/10.1021/ed900003n

Hyman, B. S. (1982). The role of student manipulation of molecular models and spatial visualization ability on achievement in college level organic chemistry. (Unpublished doctoral dissertation). Teachers College, Columbia University, New York City, New York.

Kennedy, G.E., Judd, T.S., Churchward, A., Gray, K. (2008). First year students' experiences with technology: Are they really digital natives? *Australasian Journal of Educational Technology*, *24*(1), 108-122.

King, M. J., Katz, D. P., Thompson, L. A., & Macnamara, B. N. (2019). Genetic and environmental influences on spatial reasoning: A meta-analysis of twin studies. *Intelligence*, *73*, 65-77. https://doi.org/10.1016/j.intell.2019.01.001

Kvavik, R. B. (2005). Convenience, communications, and control: How students use technology. *Educating the Next Generation*, *1*, 7-1.

Lauer, J. E., Yhang, E., & Lourenco, S. F. (2019). The development of gender differences in spatial reasoning: A meta-analytic review. *Psychological bulletin*, *145*(6), 537.

Lord, T. R. (1985). Enhancing the visuo-spatial aptitude of students. *Journal of research in science teaching*, *22*(5), 395-405. https://doi.org/10.1002/tea.3660220503

Maeda, Y., & Yoon, S. Y. (2013). A meta-analysis on gender differences in mental rotation ability measured by the Purdue spatial visualization tests: Visualization of rotations (PSVT: R). *Educational Psychology Review*, *25*(1), 69-94.

O'Connor, M., Deeks, H. M., Dawn, E., Metatla, O., Roudaut, A., Sutton, M., ... & Wonnacott, M. (2018). Sampling molecular conformations and dynamics in a multiuser virtual reality framework. *Science advances*, *4*(6), eaat2731. https://doi.org/10.1126/sciadv.aat2731

Rafi, A., Anuar, K., Samad, A., Hayati, M., & Mahadzir, M. (2005). Improving spatial ability using a Web-based Virtual Environment (WbVE). *Automation in construction, 14*(6), 707-715. https://doi.org/10.1016/j.autcon.2004.12.003

Sorby, S. A. (2009). Educational research in developing 3-D spatial skills for engineering students. *International Journal of Science Education, 31*(3), 459-480. https://doi.org/10.1080/09500690802595839