Board 109: BYOE: Laboratory Exercise using Augmented Reality and Virtual Reality for Environmental Engineering Curriculum

Dr. Azadeh Bolhari P.E., University of Colorado Boulder

Dr. Bolhari is a professor of environmental engineering in the Department of Civil, Environmental and Architectural Engineering (CEAE) at the University of Colorado Boulder. Her teaching focuses on fate and transport of contaminants, capstone design and aqueous chemistry. Dr. Bolhari is passionate about broadening participation in engineering through community-based participatory action research. Her research interests explore the boundaries of engineering and social science to understand evolution of resilience capacity at family and community level to sustainable practices utilizing quantitative and qualitative research methods.

BYOE: Laboratory Exercise using Augmented Reality (AR) and Virtual Reality (VR) for Environmental Engineering Curriculum

Abstract

This bring-your-own experiment (BYOE) paper details a hands-on laboratory exercise to introduce Augmented Reality (AR) and Virtual Reality (VR) to environmental engineering students. A broad goal of adopting Artificial Intelligence in engineering curriculum is realizing its full potential in infusing a mindset to shift students from formulary thinking to innovative thinking. This arming individuals with a new mindset has the capacity to be seeds of transformation towards an innovative-focused engineering curriculum and workplace which will contribute to an engineering profession that will transform the engineering design process. This BYOE paper is written with the goal of making the implementation of this activity straightforward and accessible for instructors. This BYOE paper consists of a lesson that introduces AR and VR in a hands-on setting utilizing VR headsets for the virtual reality experience and Merge Cube for the augmented reality experience.

Introduction

In recent years, the capacity to utilize virtual reality and augmented reality software to enhance productivity within the field of engineering has increased significantly as this technology continues to become more sophisticated. A broad goal of adopting Artificial Intelligence (AI) in engineering curriculum is realizing its full potential in infusing a mindset to shift students from formulary thinking to innovative thinking. This mindset shift has the capacity to be seeds of transformation towards an innovative-focused engineering workplace. As a result, this effort will strengthen the profession's ability to be more attentive and responsive to the needs of an increasingly complex society. Therefore, it is imperative to incorporate AI in the Environmental Engineering curriculum. Many environmental engineering students entering the engineering field suffer from poor spatial visualization skills. Spatial visualization or reasoning skills are defined as "visualizing three-dimensional objects and perceiving what they will look like from different viewpoints or what they would look like if they were rotated or transformed in space" (Sorby et al., 2013). The aid of spatial visualization is imperative in larger engineering projects that involve designing 3D objects in computer programs such as CAD and MATLAB.

Water Chemistry is a required upper-level course at University of Colorado Boulder, where students build on previous chemistry knowledge and focus on the fundamentals of inorganic aqueous compounds and contaminants. This course was selected as a case study for implementation of the AR/VR. Water Chemistry course is a foundational course that our students take prior to their senior design (capstone design) course. As a result, the AR/VR technology will

assist the students in their capstone projects. From the information presented, the reader should be able to take the concepts listed and apply them to their unique instructional roles.

Pedagogical Context

To meet the goals of this case study, the study of Artificial Intelligence (AI) and usage of AR/VR is built into the Environmental Engineering Water Chemistry course. The main course that integrated this learning module is the Water Chemistry & laboratory. Water Chemistry & Laboratory has historically been difficult for students in the department especially in visualizing the modules and chemical reactions that are taught within the course. The usage of AR/VR to visualize these difficult concepts and structures is thought to be an effective tool to implement and enhance the learning experience.

This exposure and usage are depicted through a hands-on laboratory session within the course which is provided for instructors in the next page. This activity entails a short lesson which introduces the concepts of AR/VR to the students with some built-in small discussion points to reflect upon how these technologies can be applied to the real world. Next, the students then get to experience VR through the Merge Headset and lesson plans (e.g., “Make Carbonic acid”). For the AR sections, students use the Merge Object Viewer app to project molecules (e.g., alum) onto the Merge Cube. Within both AR/VR sections, students are asked to reflect on their experience and their thoughts on the usage of this technology within the industry and in their careers. To receive credit for and complete the lab session/assignment, students can be asked to submit an informal lab report with their reflections and thoughts about this technology. The following VR/AR lab and was designed utilizing databases from Schmid *et al.*, 2020 and Abdinejad *et al.* 2021.

Virtual Reality & Augmented Reality Lab – "Getting Real"
Due Date: *1 week from the date of posting*
Assignment format: Group (teams of 2-4), submit one document per group.

Glen Keane is the Oscar-winning artist who is behind Disney classics such as The Little Mermaid and
The Beauty and The Beast. He is described as ***"one of the best animators in the history of hand-drawn animation"***, suffering from a medical condition called Aphantasia. Aphantasia is a phenomenon in which people are unable to visualize imagery. While most people can conjure an image of a scene or face in their minds, people with Aphantasia. Approximately 2-5% of the population suffers from this condition and remains an unspoken issue (like color blindness).

Recently Glen and his family members have been falling sick very often and want to know why. He somehow finds out some anomaly in the way the water tastes. He hires you to investigate the issue and help get some insights. Glen is a curious person and wants to understand everything under the sky. He wants to understand the compounds and structures that make water unsafe to drink. Knowing his condition, you cannot draw the diagram of the respective compound and expect him to understand. It is upon you to help him "visualize" the compounds and help him understand the technicalities. Thankfully you have a week to work on this task and will require you to use some basic Virtual Reality Tools to help Glen imagine. Glen decides to award you with something exciting if you meet his requirements in the grading rubric and secure the highest amongst your colleagues.

Knowing that you have no prior experience in Augmented Reality (AR) or Virtual Reality (VR) below are some curated steps for you to get your hands on and work on it:

Complete Prior to Lab:

1. Use this link (Cube Maker: https://mergecube.com/paper-pdf), to print out the cube and assemble it. Follow this video for assembly instructions: Making the Merge Cube: https://www.youtube.com/watch?time_continue=52&v=HdEG8VUNVfA&feature=emb_logo

2. Download MEI VR app
    - IOS: https://apps.apple.com/us/app/mel-vr-science-simulations/id1369900784
    - Google Play Store: https://play.google.com/store/apps/details?id=com.melscience.melchemistry&hl=en_US&gl=US

3. Download the Merge Object Viewer App:
    - IOS: https://apps.apple.com/us/app/merge-object-viewer/id1367544362
    - Google Play Store: https://play.google.com/store/apps/details?id=com.MergeCube.ObjectViewer&gl=US

4. Explore The Freie University of Berlin database on AR difference 3D structures compatible with the Merge cube. Database Link: https://www.bcp.fu-berlin.de/en/chemie/chemie/forschung/InorgChem/agthiele/Augmented-Reality/Strukturdatenbank.html

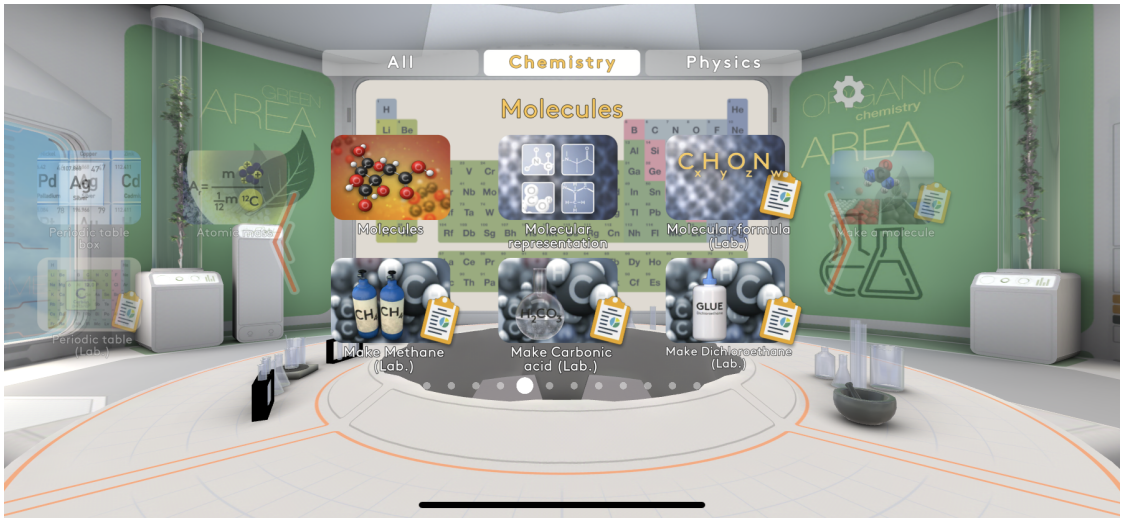
5. Bring a computer or a piece of paper to answer the questions (refer to the Deliverables section). This will be the report that your group will submit (one document per group).

Visual Reality Task:

1. Now let's explore the virtual reality (VR) world.

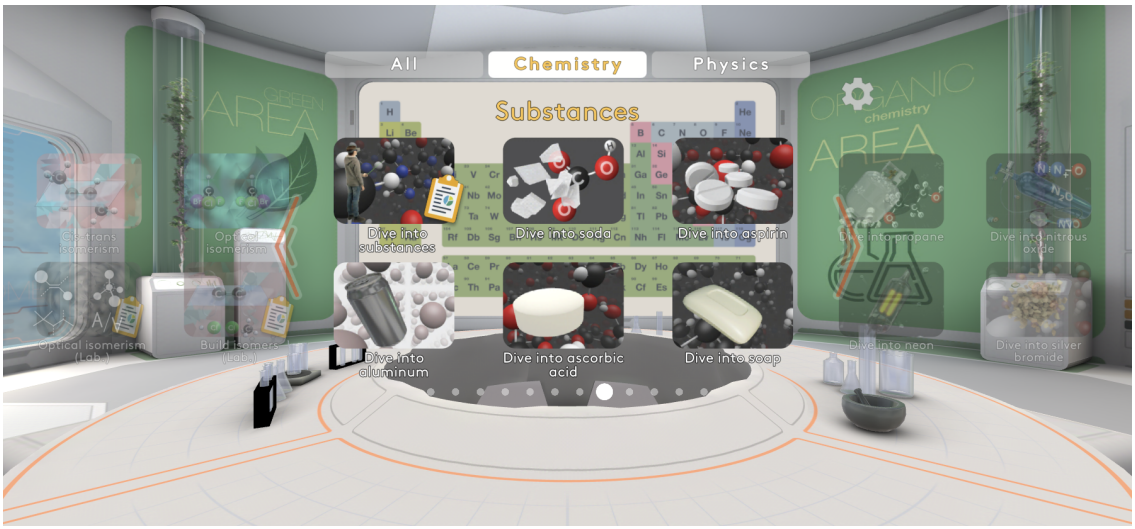
2. Download the MEl VR Science simulations app if not done so already.
    - IOS: https://apps.apple.com/us/app/mel-vr-science-simulations/id1369900784
    - Google Play: https://play.google.com/store/apps/details?id=com.melscience.melchemistry&hl=en_US&gl=US

3. Select the module "Make Carbonic acid (Lab.)" under the Chemistry tab, within the Molecules sections (screenshot below):



4. Follow the lesson plan and illustrate the interactions between carbon dioxide and water by drawing the structure of each species involved in ocean acidification. Now comment on how carbon dioxide emissions act as a driver of this process.

5. Next select the “Dive into ascorbic acid” Module under the Chemistry tab, within the Substances sections:



6. Discuss with your lab group and brainstorm/write down how VR can help visualize the acid chemistry in nature, molecular structure, and other applications.

7. Feel free to explore other modules in the application and experience VR.

Augmented Reality Task:

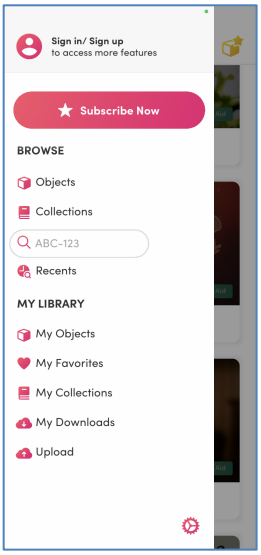
1. Now create a fun object to explore the features of the Merge Object Viewer.

2. Move the Merge cube in front of the camera of the mobile device. The structure will be projected onto the Merge cube automatically.

3. Use this database from Freie Berlin University to find object codes that can be inputted into the app which will be later displayed on the cube. For instance, the code assigned to Alum is 92K-RYQ, which forms a crystalline structure. Quartz is assigned an 8EX-858 code: https://www.bcp.fu-berlin.de/en/chemie/chemie/forschung/InorgChem/agthiele/Augmented-Reality/Strukturdatenbank.html

4. Zoom in and out of the projection by moving your finger up and down on the screen.

5. To view models via AR, open the app and insert the “Object Code” via the “Search Code” function. Download the object to the mobile device (screenshot below):



6. If the merge cube is unavailable, models can be viewed in a 3D model or projected directly in the world around.

7. Choose at least 2 new compounds from the database provided. Take screenshots of various angles and views of the compounds. List out something interesting that you have observed.

8. Now that you have experience with both AR and VR, discuss what are the differences between the two.

Deliverables:

Submit your response in an assignment format (not a lab report format).

1. **Visual Reality Task:**
   a. Follow the lesson plan (Make Carbonic acid). Illustrate the interactions between carbon dioxide and water by drawing the structure of each species involved in ocean acidification. Now comment on how carbon dioxide emissions act as a driver of this process.
   b. Summarize and write up how VR can help visualize the acid chemistry in nature, molecular structure, and other applications.
2. **Augmented Reality Task:**
   a. A fun selfie with a MergeCube model!
   b. Choose at least 2 new compounds from the database provided. Take screenshots of various angles and views of the compounds. List out something interesting that you have observed.

c. Now that you have experience with both AR and VR, discuss and write down what are the differences between the two and write down three different applications this new technology will be used for.
d. **Extra Credit:** For every additional compound that you explore and perform analysis on within Task B, you will receive a 5-point bonus for each extra compound.

Grading Rubric:

Sr No	Description	Credits
1	Attended class demo	10
2	Virtual Reality Task a. Illustrate the interactions of carbon dioxide and water in relation to ocean acidifications (10) b. Comment on the implications of climate change on this process (5) c. Summarize how VR can help visualize the acid chemistry in nature, molecular structure, and other applications (10)	25
3	Augmented Reality Task: a. Selfie of you and your MergeCube (5) b. Compound from database: ● Set up the object (5) ● View it on the mobile application (5) ● Screenshots from various angles and views (10) ● At least 2 interesting observations made from the compound (10) c. Compare and contrast AR & VR and discuss 3 different application of theses technology (10)	45
4	**Extra Credit:** +5 points for any extra compound analyzed (cap of 3 compounds)	5*n
Total Points:		80 (max of 95)

Happy Visualizing

****

Virtual Reality & Augmented Reality Lab – "Getting Real" (Teacher/TA notes)
Due Date: *1 week from date of posting*
Assignment format: Group (teams of 2-4), submit one document per group.

This lab will be done in-person. The lab includes an introduction/presentation and demo in class for students given by the professor or teaching assistant (TA). The lab needs to be posted onto Canvas for students to view before coming into the lab and students need to complete the "Preparation" section prior to this lab. The following tasks and estimated time of completion is down below.

For TA and Professor:

1. **Preparation & Presentation to students in classroom:** Estimated time: **30-60 mins**

Task for TA/Professor (before class - 10 minutes):

a. Print out extra Merge Cube paper (Cube Maker) for student to assemble (# of copies depended on number of students in lab)
b. Gather scissor, tape and glue to aid in building the Merge Cube
c. Ideally get familiar with the apps and VR headsets (run through the lab) and identify any potential problems and troubleshoot.
d. Prior to coming to lab, review the assignment.
e. Present the assignment and then start the lab (provide demonstrations of the lab in class).

For Students:

2. **Preparing and prerequisites:** Estimated time: **10 mins**

This is a prerequisite phase where the students read through the lab and download the appropriate application on their phones.

3. **Visual Reality Task (ONLY In-Person):** Estimated time: **40 mins** (needs to run through the carbonic acid set up)

This is only intended for in-lab in-person activity. Students will need to download the app and set up the VR goggles to ensure things are working properly before starting this task. Students will be asked to explore 2 lesson plans within the app through the VR headset, reflect upon their experience, and answer the lab questions.

4. **Augmented Reality Task (In-Person or Remote):** Estimated time: **30 – 40 mins**

This is a transition phase for the students. Students can complete this lab in-person or remote to their choosing. Students will need to come to lab with the printed and assembled Merge Cube paper (additional cubes will be available by TA for any students who did not do it). Students will later use the app and Merge cube to experience the AR through different objects.
For the In-person portion, the Professor/TA needs to be familiar with the app and how to view content as the first time may be confusing to use.

Student Experience

Students' reflection on this AR-lab was extracted from the submitted lab reports in fall 2022 validating the need for such AI-focused learning modules in the environmental engineering curriculum. For instance, teams stated:

"...had no previous experience doing AR but thought it would be interesting as it has a future in engineering. it did open my eyes to the thought of AR and the implications it could have for the future. That was a very valuable lesson as I had no previous experience or knowledge. I feel that the lab was overall beneficial and a great thought as maybe some other students, like me, have not had exposure to AR and don't know the potential it has for the future and learning in the future."

"AR was a wonderful way to show the same concept to all students at the same time. Also, some concepts, especially models of atomic structures, are difficult to convey in a 2D format, and can be shown better using a 3D format."

"[After we graduate], if we end up tutoring students or becoming a teacher this app would be extremely helpful. This app could also be used for teaching the community about different environmental systems as well."

"Not only may the Merge Cube be used for scientific knowledge, but it also contains aspects of fun."

Conclusion / Future Work

Augmented and virtual reality software will continue to be developed to enhance productivity and efficiency within the field of engineering. This future will require (soon-to-be) professionals to be familiar with this technology. Therefore, to adequately prepare for this future, the education and usage of this technology for students are implemented into the EVEN curriculum.

Acknowledgments

Funding for this research was provided by the University of Colorado Boulder's Engineering Education and AI-Augmented Learning Interdisciplinary Research Theme (EE-AI IRT) program. Research students Sasha Rubenfeld, Connor Ellertson, Joe Zhaobang Ning, and Nihal Thirunakarasu assisted in experimenting with AI goggles and the design of the curriculum.

References

M. Abdinejad, C. Ferrag, H. Qorbani, S. Dalili, "Developing a Simple and Cost-Effective Markerless Augmented Reality Tool for Chemistry Education," *J. Chem. Educ.*, 2021.

D. Carney, 'Make Your Own Cardboard VR Goggles," 2020. Retrieved January 2022: https://www.designnews.com/makergadget-freak/make-your-own-cardboard-vr-goggles

R. B. Guay, "Purdue spatial visualization test: Rotations," West Lafayette, IN, Purdue Research Foundation, 1977.

J. Schmid, M. J. Ernst, G. Thiel, "Structural Chemistry 2.0: Combining Augmented Reality and 3D Online Models," *Jonas R., J. Chem*. Educ. 97, pp. 4515−4519, 2020.

S. Sorby, B. Casey, N. Veurink, A. Dulaney, "The role of spatial training in improving spatial and calculus performance in engineering students, "*Learn Individ Differ*, 26: pp. 20-29, 2013. https://doi.org/10.1016/j.lindif.2013.03.010.

N. Veurink, S. A. Sorby, "Comparison of Spatial Skills of Students Entering Different Engineering Majors," *Eng. Des. Graph. J,* 76, 3, 2012.