2020 Provost's SOLER Seed Grant
Project Summary Report

Project Title: Evaluation of virtual reality for learning biochemistry and enhancing student engagement.

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Summary

While some students have the necessary foundational knowledge to effectively learn biochemistry through traditional modalities, a sizable group of students struggle to understand key concepts and apply them effectively to solve biochemistry problems. Small group discussion with the instructor and classmates can be a crucial part of the learning process for these students, likely because it exposes the misconceptions they have but are not aware of. Such discussion is difficult to replicate online, even in a video chat format such as Zoom (Wladis et al., 2015).

In this project, Professor Stockwell and colleagues examined the potential of virtual reality (VR) technology to improve student engagement in a small group discussion format by creating an immersive experience where attention is focused on challenging concepts in biochemistry. We noted that VR affords the use of realistic 3D structures to illustrate key biochemical concepts more effectively than with 2D tools in Zoom or even with textbooks and a whiteboard in discussions on campus (Garcia-Bonete et al., 2019). We therefore reasoned that holding small group discussions in VR might enhance student experience relative to being on campus or current online formats. Accordingly, we endeavored to evaluate the impact of holding weekly small group discussions on Zoom versus in VR on student outcomes such as exam performance and perceptions of the usefulness of the

technology. We hypothesized that the immersive nature of small group discussions in VR would enhance student outcomes as assessed by these metrics.

To test our hypothesis, we recruited approximately a quarter of the students enrolled in Professor Stockwell's Fall 2020 **Biochemistry I** course to participate in a research study through an Institutional-Review-Board-approved informed consent process. Participants were randomly assigned to either the VR condition or the Zoom condition, which served as the control group. Both conditions consisted of six weekly 30-minute discussion sessions attended by roughly a dozen students and led by Professor Stockwell. The content of the sessions aligned with weekly course learning objectives. The seven sessions (including one introductory practice session) spanned the latter two-thirds of the semester, from mid-October to early December.

Participants completed normal course assessments (*e.g.*, exams) throughout the semester and a survey at the conclusion of the study (see Appendix 1). The survey was adapted from a validated tool for measuring attitudes about the usability of novel health information technology (Yen et al., 2010) – respondents rated their agreement with various positive-valence statements on a scale from 1 (strongly disagree) to 5 (strongly agree). In free-response fields of the survey, students in the VR condition wrote many positive and thought-provoking comments about their experience. We measured no enhancements in their performance on standard course assessments or their ratings of the usefulness of the technology relative to the control (Zoom) group.

In the rest of this report, we describe the course and the study in more detail, elaborate on student feedback, and discuss the insights we gained that will guide future iterations of this line of innovation and inquiry.

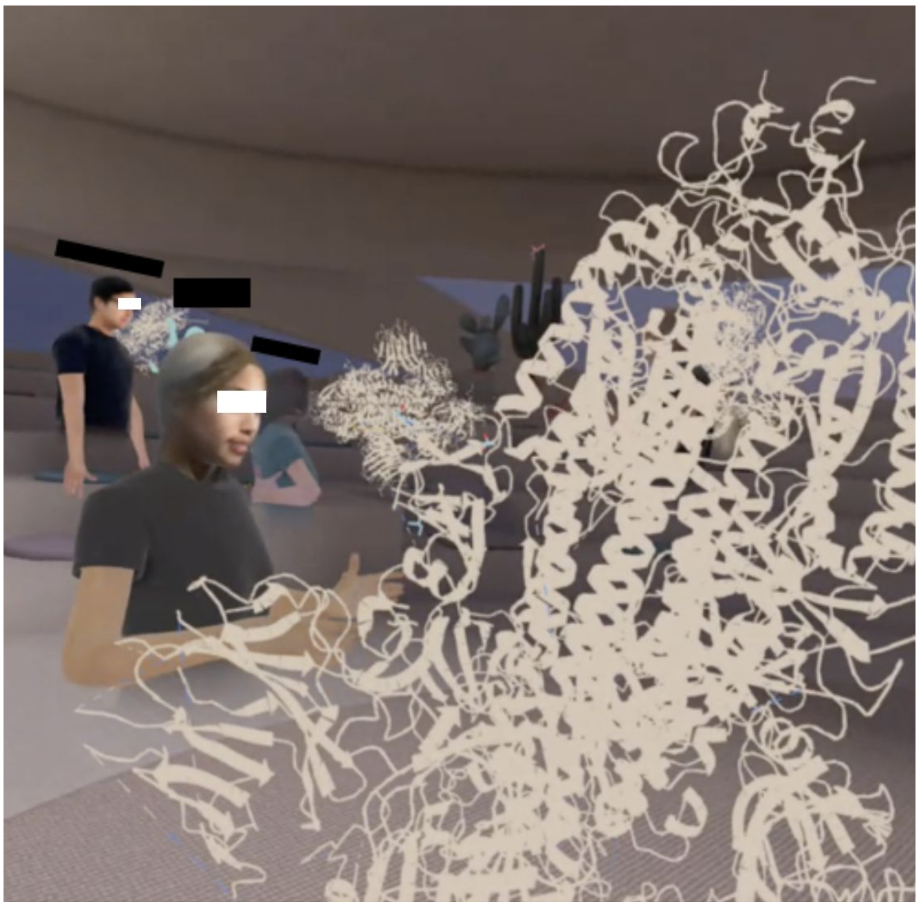
The Course: Biochemistry I (GU4501)

Biochemistry I explores the basic biochemistry of living systems and how this knowledge can be harnessed to create new medicines. Students learn how living systems convert environmental resources into energy through metabolism, and how they use this energy and these materials to build the molecules required for the diverse functions of life. We discuss the applications of this biochemical knowledge to mechanisms of disease and to drug discovery. We look at examples of drug discovery related to neurodegeneration, cancer, and the SARS-CoV-2 COVID-19 pandemic. This course satisfies the requirement of most medical schools for introductory biochemistry, and is suitable for advanced undergraduates, and some beginning graduate students. The Fall 2020 course enrolled approximately 120 students. The course is traditionally taught on campus but was adapted to an online format for Fall 2020 due to the COVID-19 pandemic.

The Innovation: Oculus Quest Headsets + Spatial Meeting Platform

The generous Emerging Technology Grant (a part of the Provost's Teaching and Learning Grants series overseen by the Emerging Technologies Consortium [ETC]) allowed us to purchase approximately 40 Oculus Quest VR headsets for use in this study. We selected these headsets because they are wireless, self-contained (no other devices need to be used in conjunction), lightweight, and powerful enough to meet our computing needs. Students who were able to do so picked their headsets up on campus; we shipped devices to the other students at their home addresses. In the image below, Professor Stockwell sports his headset.

Headsets alone are not sufficient for creating an educational VR experience; they must be used in conjunction with a virtual meeting platform. We selected Spatial (also called Spatial.io), a platform used primarily for collaborative work in professional settings with an emphasis on creativity and visual design elements. Running the Spatial app on the Oculus device, participants can congregate and interact in real time in a virtual meeting space. We selected an open office-like space for the first few sessions, and then switched to an amphitheater in the Arizona desert when that new feature became available, as it offered seating and a larger space. Professor Stockwell, the student participants, and the observers (Madiha, Eman, and Adam) created quite realistic avatars through Spatial's photo-based avatar-generation tool. During the sessions, Professor Stockwell led discussion of material related to weekly learning objectives – crucially, he chose to focus each session on concepts that require a 3D or spatial awareness in order to grasp them (*e.g.*, understanding the orientation of some molecule as it is bound by a protein). To illustrate such concepts, Professor Stockwell downloaded 3D models of proteins and small molecules (obtained from the Protein Data Bank or created in Chemdraw), used the software Blender to decimate the models (*i.e.*, reduce their complexity while retaining key structural features), and then saved them as GLB files that could be imported into Spatial. In Spatial, users can move, rotate and resize objects, enabling a rich and immersive 3D experience. In the screen capture below, one of the students inspects a protein model. Two other students and more copies of the model are visible in the background. Names and faces are obscured to protect student privacy.



Each week, Professor Stockwell also held similar sessions over Zoom for another set of student participants (*i.e.*, the control group). Those sessions addressed the same topics using the same materials and descriptions, and emphasized similar visual/spatial elements, but with 2D images rather than immersive 3D VR experiences.

Results and Discussion

In the free-response fields of the end-of-semester survey, students in the VR group reported an array of positive reactions to their experience with the technology, as well as a number of important concerns that could be addressed in future VR teaching. Those comments are discussed in detail at the end of this section.

However, as noted above, students in the VR group did not exhibit any enhancement in exam performance (as measured by the course exams) relative to the Zoom group. This should not be taken as an indication that there is no potential for VR to enhance student learning in biochemistry; it simply means that we did not detect any such effect in our trial. We suspect that two primary factors limited the efficacy of the VR experience and/or our ability to detect its impact:

1. We held only six official VR sessions. The limited impact of the VR experience was compounded by the challenge of learning the technology (for both the instructor/collaborators and students) and finding and teaching relevant content. In particular, for the first several sessions, it was not possible to import chemical models into Spatial, so Professor Stockwell had to draw sketches of the molecules in the 3D VR drawing application TiltBrush. Importing these sketches into Spatial reduced their quality substantially, making them difficult to interpret for students. With assistance from the Spatial tech support specialist, Professor Stockwell was able to learn how to decimate protein structures in Blender below the 30 MB GLB file size limit required for Spatial while retaining enough structural information to make them useful tools. The students reported these structures as being the most useful in the VR sessions, but they only had access to them for the last few VR sessions.
2. Student performance on exams was very strong (with students earning about 95% of exam points on average) in both groups and among students who did not participate in the study. This is because the advanced teaching methods utilized for the course have been refined over the years, resulting in very high student performance and learning even without VR. As such, there was likely a “ceiling effect” – when student learning is already very strong, scores are already high “at baseline” (*i.e.*, with just Zoom sessions or no small group sessions at all), it is difficult to detect the impact of an intervention designed to enhance performance beyond the high level of performance realized for most students. This point could potentially be addressed in the future by introducing advanced graduate-level

biochemistry concepts that would be especially difficult to learn in a Zoom format (but which might be easier to learn in VR).

Additionally, the VR students did not rate the usefulness of the technology for learning biochemistry any higher than the Zoom students did on the end-of-semester survey that we devised – both groups rated their respective technologies approximately 3.5/5 on average. As with exam performance, this parity could be explained in part by the "learning curve" challenges of implementing VR for biochemistry education. Indeed, students in the VR group rated their technology significantly lower on the dimension of *perceived ease of use* on average than did the Zoom group (3.8/5 for VR vs. 4.9/5 for Zoom; $p < 0.01$). Again, note that students were already very acclimated to remote learning via Zoom; VR, in contrast, was a novel and in some cases challenging experience for many students. To determine whether students perceived any difference in Professor Stockwell's commitment to ensuring the quality of two session types, we added the following item to the survey: "My professor made an effort to effectively implement the technology used during my small group discussions." Students in the two groups rated this item similarly on average: 4.6/5 for VR and 4.8/5 for Zoom ($p > 0.05$).

We believe that future iterations of this work will improve upon the technical and pedagogical elements sufficiently to yield measurable positive impacts on student learning and engagement. Our conclusions are outlined below along with our plans for improvements and our reflections on student comments.

- **Conclusion #1: The greatest utility of VR lies in the illumination of particular disciplinary elements. Effective implementation therefore depends on the development of high-quality 3D assets (*e.g.,* protein models in the context of biochemistry) and appropriate matching of VR activities and learning objectives.**
    - Steps for improvement:
        - Work closely with ETC and perhaps third-party services or consultants to develop optimal 3D assets. Assets need to be detailed enough to represent key structural features but small enough to meet file size limits (currently 30 MB per GLB file).
        - Continue the process of identifying key concepts that align with immersive 3D experiences and plan sessions around the corresponding learning objectives; focus assessment analysis on

exam questions that relate to the highlighted concepts. Identifying a VR educational consultant might be valuable, if any yet exist.

- Relevant student comments:
  - "It was helpful that we could each have our own molecule to look at and manipulate...Prof. Stockwell could point to exactly where in space a reaction occurred."
    - This highlights the potential positive impact of VR, as students clearly gained a new degree of understanding once they overcame the technology hurdles.
  - "The ability to visualize complex molecules and look at the arrow pushing mechanisms is so helpful to understanding how particular reactions work."
    - Part of the challenge of measuring the increased learning indicated by this type of statement is how to create questions that specifically probe the 3D understanding of mechanism and structure. Most questions and problems for exams have historically been developed around 2D models. Thus, we need to rethink the assessment tools relevant to probing the 3D understanding provided by VR.
  - "The 3D protein models and stereochemistry of reactions was very helpful in understanding selectivity [and] helped me retain concepts better. Being able to move and resize the models was also helpful for gaining a different perspective."
    - We realized by the last session that it was feasible and valuable to provide each student with their own model to examine, rather than having everyone look at one model in the middle of the room. Had we done this from the beginning, we might have detected increased performance on some exam questions.
  - "It would be nice if we could learn something and then [do] a lab-like portion where we are able to use the virtual space to do things like practice choosing small inhibitor molecules that could fit into an active site."
    - This comment highlights the laboratory/interactive aspect of VR. We can try to leverage this aspect in future teaching by designing the VR that sessions are more project-based than discussion/lecture-based.

- **Conclusion #2: Students need time to get used to the VR experience in order for its advantages to become apparent. Furthermore, VR is immersive on an individual level but less so on an interpersonal level.**
    - Steps for improvement:
        - Reserve the initial session for explicitly training students in the use of the controls for movement around the 3D space, controlling the view, and manipulating objects. Teach them how to interpret 3D molecular structures so that they understand what they are viewing.
        - Foster an inclusive and comfortable learning environment by reiterating the appropriateness of asking questions, allocating time for interactions between students, etc. More one-on-one time would be beneficial to draw out student questions.
    - Relevant student comments:
        - “Getting used to [VR] took some time and felt...awkward at first.”
        - “The most effective parts of the discussions were later in the semester when Professor Stockwell, as well as the students, had become more comfortable with engaging with the material in 3D. There was definitely a learning curve at first, but as the process became more comfortable, so did the discussion.”
        - “It would have been nice to have an orientation session at the beginning, since some controls were difficult to learn and get used to.”
        - “Since we are only represented by our VR avatars, it is difficult to ‘read the room’ and communicate through nonverbal actions. This issue, which is not usually an issue with Zoom, is particularly noticeable when people are trying to ask questions.”
            - Future technology in which avatars can mimic facial expressions of users may mitigate this issue to some extent.

- **Conclusion #3: VR presents unique challenges.**
    - Steps for improvement:
        - Schedule a brief (perhaps 5-minute) break in the middle of the session (or perhaps every 15 minutes for longer sessions) during which students can remove their headsets to jot down notes, rest their eyes if experiencing discomfort, and refresh for the remainder.

        - Related to Conclusion #2 above, take time during the training session to ensure that students know how to adjust the fit and focus of their headsets in order to maximize the visual quality of the experience and minimize discomfort.
    - Relevant student comments:
        - “It is not possible to take notes of the important material Prof. Stockwell is discussing in VR because we cannot access any paper notes with the headset on. Therefore, it was difficult to ask questions and connect new material brought up during the VR session to the previous material learned.”
        - “The VR headset makes it difficult to look at [the 3D content] and take notes [simultaneously].”
        - “I had a lot of trouble adjusting my VR headset to become comfortable. The discomfort after about 15 minutes of wear would sometimes take my focus away from the discussions.”
            - Lighter headsets might mitigate this issue in the future.

- **Conclusion #4: Similar VR activities have great potential in other disciplinary contexts.**
    - Steps for improvement:
        - Share insights at Columbia and elsewhere to encourage similar explorations in related academic settings.
        - Develop “hands-on” activities that hybridize discussion sessions and lab experiences (see last student comment under Conclusion #1 above)
    - Relevant student comments:
        - “Hopefully this can be implemented in future biochemistry courses and even organic chemistry classes.”
        - “I think this technology would be really good for a lab class! My lab class last semester wasn't great online and would have been much more engaging and useful in VR.

In summary, we learned a great deal about how to effectively use VR in a classroom, both in terms of technical implementation and VR-specific pedagogical elements. A future study, currently under consideration for summer 2021, could build on these findings and further develop VR as a powerful tool for teaching.

References

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Appendix 1: Student Survey

Adapted from Yen et al. (2010), this survey addresses attitudes about novel technology across three dimensions: (1) *impact*, (2) *perceived usefulness*, and (3) *perceived ease of use.* We focused our analysis on the latter two dimensions as explained above. Items 17-20 were added to the survey to address our other questions about student experience.

STRONGLY DISAGREE 1 2 3 4 5 STRONGLY AGREE

Impact	
1	The technology used during my small group discussions would be a positive addition for biochemistry students.
2	The technology used during my small group discussions is an important part of meeting my needs related to learning biochemistry.
Perceived Usefulness	
3	The technology used during my small group discussions makes it easier to learn biochemistry.
4	The technology used during my small group discussions enables me to manage my learning more quickly.
5	The technology used during my small group discussions makes it more likely that I can learn biochemistry.
6	The technology used during my small group discussions is useful for learning biochemistry.
7	I think the technology used during my small group discussions presents a more equitable process for helping with learning biochemistry.
8	I am satisfied with the technology used during my small group discussions for learning biochemistry.
9	I am able to learn biochemistry in a timely manner because of the technology used during my small group discussions.
10	The technology used during my small group discussions increases my ability to learn biochemistry.
11	I am better able to learn biochemistry with the technology used during my small group discussions.

Perceived Ease of Use	
12	I am comfortable with my ability to access the technology used during my small group discussions.
13	Learning to operate the technology used during my small group discussions is easy for me.
14	It is easy for me to become skillful at operating the technology used during my small group discussions app.
15	I find the technology used during my small group discussions easy to operate.
16	I can always remember how to operate the technology used during my small group discussions.
Additional Items	
17	My professor made an effort to effectively implement the technology used during my small group discussions. (Rated as above)
18	What aspects of your small group discussions were most useful or valuable? (Free response)
19	How would you improve your small group discussions? (Free response)
20	Please share any additional comments here. (Free response)