# A Virtual Reality Teaching and Learning Environment for Chemistry

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**Abstract:** In the 2016-2017 academic year, a virtual reality (VR) developer created a VR learning environment to help undergraduate chemistry students understand cubic and hexagonal close packing. This topic was chosen for visualization in virtual reality because it is difficult for undergraduate chemistry students to learn. The completion of the VR prototype took approximately 9 to 12 months, and involved conceptualization, design, development, and testing with members of the target population. This Pecha Kucha presentation presents the VR environment created and describes some of the technical, visual, and instructional design considerations encountered by the developer.

## Introduction

Introductory Chemistry is a notoriously difficult subject for college students. As a gateway course for health and STEM majors, students must pass the course in order to progress in their intended major. Some students, especially those who are unable to visualize chemical structures, have great difficulty with chemistry. Students view chemistry as a subject that is difficult, complex, and abstract, requiring special abilities and a great deal of effort to successfully master the course content (Cardellini, 2012). Estimates of the student failure rate in basic chemistry courses range from 18.2% (Ahlstrom & McGuire, 2013) to 21.7% (Atwood, Casselman, & Ohlsen, 2015). To address a similar failure rate among its chemistry students, a large university in the mid-Atlantic region of the United States partnered with a virtual reality developer (T.M. Wilcox) in 2016-2017 to create a virtual reality environment that would enable students to visualize crystal lattices, and cubic and hexagonal close packing.

Today's college students struggle with chemistry for several reasons. First, chemistry is often delivered in a medium (lecture) they find boring and uninspiring. Second, the content is difficult to understand for many students because it is unlike other course content they have encountered in the past, and requires abstract rather than concrete thinking (Cardellini, 2012). Third, spatial ability is required in order to perform the mental feats associated with mastery of the course content. Chemistry students must be able to visualize chemical structures, rotate the structures in their minds' eye, and translate three dimensional (3-D) images into two dimensional (2-D) representations of the chemical compounds, lattices, and models (Harle & Towns, 2010). Finally, students struggle because often they do not understand the scientific language used, the instructional method used does not align with their learning approach, and they have difficult time envisioning the invisible (Cardellini, 2012).

This Pecha Kucha offers some of the design and technical considerations faced by the developer when creating the ChemSim-VR environment and reports some of the students' perceptions of their virtual reality experience. This project is part of an ongoing research endeavor, which will inform the development of additional virtual reality projects in related STEM fields.

## Theoretical Framework and Justification for the Project

The development of the ChemSim-VR environment, while a collaborative design effort with Chemistry faculty members, was largely an independent project carried out by T.M. Wilcox. The design of the ChemSim-VR environment was based on the notion that students must construct their own knowledge and that meaningful learning occurs through active cognitive engagement. For this reason, constructivist learning theory, discovery learning (Jerome Bruner), social cognitive theory, cognitive load, and connectivism were used to inform the design of

ChemSim-VR and explain learners' interaction with elements in the VR environment. Future development will explore the use of social cognitive theory to explore the use of avatars in a VR environment, and connectivism to explain learning from others in a multi-user VR environment.

Chemistry instruction at the college level traditionally is lecture-based and uses 2-dimensional images to convey 3-dimensional information, creating cognitive dissonance for Millennial (born between 1982 and 1996) and Post Millennial (born after 1996) learners who have been immersed in technology since early childhood and regularly use smartphones, tablets, and laptops to access course materials. According to Jiang of Pew Research (2018), 92% of Millennials own smartphones, 85% use social media, 54% use a tablet computer, and 73% feel the Internet has improved society. This group of learners is more likely to take online courses, access courses via a smartphone, play computer games, and be open to the idea of using innovative technology-based courses like virtual reality environments. In addition, Post Millennials prefer on-demand independent learning (not collaborative learning like Millennials); face-to-face communication that involves full sight, sound, and motion (Skype); constant connectivity, video that is available on demand, and curated global information (Jenkins, 2017). Clearly, the technology and learning preferences of these two generations provide a reasonable justification for the use of virtual reality in college-level introductory chemistry courses.

In addition, recent research on the use of virtual reality in education indicates that it may be beneficial in developing students' knowledge, skills, and abilities in a variety of content areas. Merchant, Goetz, Cifuentes, Keeney-Kennicutt, and Davis (2014) conducted a meta-analysis of the literature on the effectiveness of virtual reality on student learning outcomes in K-12 and higher education. Their meta-analysis of 67 studies revealed that overall virtual reality was very effective, but that the results of the studies varied depending on the kind of intervention (game, simulation, or virtual world) and the kind of learning outcome expected. In general, they found that game-based virtual environments were more effective than simulations or virtual worlds, but that both games and virtual worlds were equally effective in promoting knowledge-based, skill-based, or abilities-based learning outcomes. Lee and Wong (2014) found that the use of a virtual reality environment had a greater positive effect on biology students with low spatial ability than on those with high spatial ability. Merchant, Goetz, Keeney-Kennicutt, Cifuentes, Kwok, and Davis (2013) found that the use of a 3-D virtual environment coupled with spatial training enabled chemistry students with low spatial ability to think in 3-D and then translate 3-D images into 2-D. Together these studies indicate that, given sound instructional design, virtual reality has the potential to enhance student learning in a variety of content areas.

## Design Process

The design of the virtual reality environment was informed by the VR developer's 25 years of experience in computer game and interface design, and by research in learning and motivational theories, virtual reality, instructional design, and educational technology. The project involved discussions with chemistry faculty to establish learning objectives and instructional content, and design discussions with an educational psychologist to establish a learning theory paradigm. In addition, the design project involved many hours of independent research and development on the part of the VR developer to select a development platform, develop the necessary programming skills, conceptualize the interface, design and develop 3-D graphics, and test ChemSim-VR with members of the target population.

The design process used in the project was based on the ADDIE framework, which is a derivative of the ISD model (Hannum, 2005). During the Analysis phase, the virtual reality developer met with chemistry professors and an educational psychologist to establish project goals and learning outcomes. During this time, he also evaluated the different development platforms and software applications to establish a project development protocol. During the design phase, the developer met with subject matter experts, created storyboards, created a graphic look-and-feel for the project, and began building a prototype of the first module of ChemSim-VR. The design phase was followed by an extensive asset development phase where the project assets were created in 3-D Studio Max and then used to populate the virtual reality environment. Once the first module of ChemSim-VR was complete, it was pilot tested (serving as both the Implementation and Evaluation phases) with several members of the target population. Students in basic chemistry were interviewed during and after their immersive VR experience to gather their perceptions of their experience in world.

## Script for Pecha Kucha

ChemSim-VR is a virtual reality teaching and learning environment by T. M. Wilcox. As proof of concept, it demonstrates chemistry basics in an awe-inspiring, navigable 3-D world. The design of the product was based on the latest research in virtual reality, learning theory, motivation, and educational technology, and integrates 28+ years of experience in multimedia design and development.

Without a headset, ChemSim-VR behaves like a typical computer game experience. It works with tablets, feature phones, and low-cost wireless headsets. It capitalizes on the current state of virtual reality hardware and affords users the opportunity to become immersed in a captivating learning environment where students can take control of their own learning.

ChemSim-VR has an intuitive user interface with unique VR navigation controls. Employing a “balloon flight” mental model, players move about with an Xbox controller. The interface enables users to experience a virtual world that is not bound by the rules of the physical world, resulting in a fantastic and memorable learning event. Users can fly over and through objects to gain an intimate view of molecular structures.

ChemSim-VR inspires revelatory insights difficult or impossible to convey in other mediums. Ball-and-stick models scaled to monumental proportions evoke a fantastic parkland. This deliberate choice of a parkland metaphor and the liberal use of color, shape, and form were informed by research on motivational aspects of computer games and many years of computer game design experience.

The prototype learning module demonstrates two concepts: cubic and hexagonal close packing. Students and teachers observe and control animated simulations of close packed spheres. Close packed spheres were chosen as the subject matter because first year chemistry students find this concept notoriously difficult to visualize. ChemSim-VR enables students to walk through and around close packed spheres.

ChemSim-VR design accommodates multiple discreet learning modules. Learning modules demonstrate essential chemistry concepts well suited to virtual reality. As many chemistry concepts are difficult to visualize, the learning modules of ChemSim-VR enable students to become part of a virtual chemistry world where they can see and experience the structure of different chemical compounds and molecules.

Long-term objectives for ChemSim-VR include a multi-user environment for group instruction. Brick-and-mortar chemistry lecture halls are re-imagined as virtual reality learning labs. Virtual labs capitalize on social cognitive learning theory, enabling students to bolster their motivation as they learn from others in a completely immersive, rich and robust virtual environment.

Not seen in this presentation is an animated character; the chemistry professor avatar. The avatar is an AI-driven, conversational assistant for student drill and practice. Educational research shows that the use of avatars in VR environments may boost student motivation, increase engagement, and improve students’ attitudes about subject matter.

ChemSim-VR explores what distance learning can be in virtual reality. It tests and validates user navigation controls, learning module design, and VR reference hardware. Pilot tests with university chemistry students show that learner engagement is increased when the hardware is easy to use, the virtual world is easy to navigate, and the design of the VR world is grounded in learning theory and sound instructional practices.

T. M. Wilcox uses Unity as a primary development environment and the C# programming language. Additional tools include Autodesk 3D Studio Max and Fusion 360, Adobe Photoshop, and ProTools. These software applications are state-of-the-art for the design and development of virtual reality, enabling developers to create a media-rich, fantastic environment that fosters the complete suspension of disbelief.

Target platforms are Oculus Rift and HTC Vive fixed and wireless head mounted displays. Distribution candidates are configured for Oculus and Steam App Stores. Designing for several platforms simultaneously makes innovative virtual reality environments more widely available to a greater number of users, thus increasing product marketability and potentially decreasing the cost of purchase for educational institutions.

ChemSim-VR is suitable for realtime instruction streaming on Twitch and YouTube Live. Unity's animation tools and VR180 output support omnidirectional, stereoscopic video. As VR technologies continue to improve, distribution channels like Twitch and YouTube Live will continue to expand, creating additional opportunities for instructional applications of virtual reality that will be less costly to schools.

Cognitive psychology and learning theory inform ChemSim-VR design decisions. Jerome Bruner's ideas about modes of representation are particularly useful. Other relevant learning theories include social cognitive theory and connectivism, which we are using to investigate the use of avatars and VR learning labs on students' mastery of specific subject matter, behaviors, and interpersonal skills.

It appears chemistry students with low spatial reasoning ability benefit from ChemSim-VR. It is probable all learners benefit from VR representations of complex 3D concept models. As spatial ability is required for success in STEM fields, we plan to research how virtual reality may be used to improve spatial ability and subsequent entry into STEM. This research is especially important for females and minorities who are underrepresented in STEM.

Research is necessary to identify why this type of instruction works and how to improve it. Toward that end, ChemSim-VR records user input and headset orientation 30 times per second. These data can be analyzed, along with results of focus group testing, to determine how VR may be used effectively for specific content areas.

Researchers can also change the position and rotation of any ChemSim-VR 3D object in real time. Copilot navigation and presentation controls allow for mediated VR experiences. This type of mediated experience may prove especially useful for younger and less experienced learners, or for teaching content that is procedural in nature.

VR technological hurdles like latency, optical resolutions, and refresh rates are disappearing. Virtual reality is now poised for rapid evolutionary refinement, creating opportunities for educators. With current VR technology, students are less distracted by low resolution and slow refresh rates, creating a much more refined interactive and engaged learning experience where they can focus on the content presented.

ChemSim-VR Prototype development at James Madison University ended June 30, 2017. Special thanks to faculty and students in JMU's Department of Chemistry for their input, feedback, and support. The ChemSim-VR Prototype provided the foundation for the conceptualization of a VR learning lab, and a VR environment for developing spatial ability.

28 years ago, T. M. Wilcox developed the reference prototype of a computer game with a disruptive innovation called 24-bit color. He designed the user interface for *Where in the World is Carmen Sandiego, Deluxe Edition,* published by Broderbund Software, Inc., 1991. His early work as a Research and Development artist and interface designer for educational software has informed his vision for VR development.

Since the 1980s, we have seen educational media transition from equipment that enabled 2-bit color and pixelated graphics, to the present where VR technology enables complete immersion in a fantastic, multidimensional virtual world filled with smoothly rendered forms. Wilcox Media is poised to research and design VR worlds that have the potential to change education. Will you join us?

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