Playing with chemistry

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How do we introduce games into our classrooms and what kind of learning outcomes can we expect?

My best days in the classroom were when the learning happened on autopilot. Students worked together to solve open-ended problems and even cheered when tasks were completed. By way of example, I offer the following three examples from my own classroom:

- A challenge to each lab group to produce exactly 40.0 ml of hydrogen gas, with those that came closest receiving some extra credit but, more importantly perhaps, bragging rights! The gas laws became a spectator sport as students would return throughout the day to check on the results of other classes.
- Students were asked to sort a group of 20 unrelated objects (shell, pencil, can, rock, plastic toy, brush, glove, game die, etc.) into two distinct groups based on their attributes. This exercise was given on the first day of a unit on stereochemistry, and our intention was that objects would be sorted according to their symmetry properties.
- A game looking at the spatial arrangement of cyclohexane substituents. With two large chair conformation cyclohexanes drawn on a board, I would point at a vertex and prompt the class with a verbal 'up/down' or 'axial/equatorial'. The students would respond with the corresponding word. The pace would increase as the game progressed. It is a loud, but effective, method to present a spatial concept and was the precursor to our Chairs game app (http://www.alchem.ie/chairs).

These self-directed activities all have a gaming aspect to them: they are engaging because of the playfulness. There are rules and goals, but they are also designed to be enjoyable and fun.

None of the lessons listed above have a digital component; all are 'analogue' activities. Games in the classroom don't need to have a video or screen interface. But the current cohort of students have grown up with smartphones and computers; their paradigm of gaming is, for the most part, that of video or digital games.

A well-designed video game can captivate a user with progressively more difficult challenges. The user moves through the game levels using trial and error, and the rules of engagement become learned until goals are achieved. The question is then: how can we harness the power of games — in which making mistakes is part of the process — to help students learn? The goal of this article is to present recent developments in game-based learning applications for chemistry and look to the future with immersive chemistry applications using virtual reality interfaces.

There is a spectrum to learning games. At one end is a 'gamified' approach, in which game elements, such as rewards and achievements, are added to existing content. A response system, such as Socrative (https://www.socrative.com/) or Kahoot (https://kahoot.com/), for quizzing students is one example of 'gamification'. Even digital badging for laboratory practical skills assessment can be considered gamification. At the other end of the spectrum is game-based learning (GBL), in which the content itself becomes the game. There are four interrelated aspects of game design that are required to achieve the flow that makes the experience compelling: storyline, aesthetics, technology and mechanics (Schell J. *The Art of Game Design: a Book of Lenses*, CRC Press, Burlingame, MA, 2008). A true GBL activity will incorporate all of these. Both gamification and GBL approaches have a place in an active-learning classroom environment. The products for chemistry discussed below all fall within this spectrum.

Credit: Elizabeth Gross, Alchemie

Chirality 2

This is a gamified approach to reviewing stereochemical concepts. Produced by professors at RMIT (Royal Melbourne Institute of Technology, Australia), this app is available for iOS (https://itunes.apple.com/us/app/chirality-2/id1251289926?mt=8) and Android (https://play.google.com/store/apps/details?id=rmit.edu.au.oliverjones&hl=en). Players can use Chirality 2 to practice concepts such as functional groups, different types of isomers and the recognition of chiral carbons all using either a drag and drop or multiple-choice interface. The approach is useful for students as part of homework, because the answer to each of the questions can be revealed readily by pushing the app's eyeball icon. Thus, students have a built-in assessment as they play and review.

Backside Attack

Professor Neil Garg of UCLA (University of California, Los Angeles) developed this iOS game (https://itunes.apple.com/us/app/backside-attack/id1278956096?mt=8) to teach the concepts of the S_N2 reaction. The game has an initial, fun non-chemistry activity in which the player must learn to shoot a molecule from a syringe into a beaker to unlock a reaction activity. On completion of this task, players then have to draw the mechanistic curly arrows for attack of a nucleophile on an electrophile and then for cleavage of a leaving group. The interface recognizes the curly arrow notation very precisely with correctly placed arrows unlocking the 'transition state mode'. Here the game presents a novel approach to understanding energy and reaction coordinate: the player must add energy by tapping the screen to help a molecule over the transition state. Higher energy barriers require faster tapping; I was never able to achieve a quick enough tapping rate with a fluoride ion as nucleophile, yet it was very easy to achieve with an alkoxide ion.

Labster

This Danish company has produced a collection of laboratory simulations to be used by college science students (https://www.labster.com/simulations/). The simulations cover topics from acids and bases to viral gene therapy, incorporating realistic renderings of instruments, techniques, and reagents. The simulations use a storyline and mission to keep students interested and involved. For example, in one GBL activity, students must solve a murder mystery using forensic chemical techniques and laboratory equipment available to them within the simulation. Labster has also developed a virtual reality (VR) version of this game activity using the relatively accessible mobile GearVR interface to create an immersive laboratory experience.

SuperChemVR

The team at Schell Games is producing this laboratory GBL experience for a fully immersive VR system (https://www.schellgames.com/games/superchem-vr), such as the Oculus Rift or HTC Vive. These systems differ from GearVR in that the player requires handsets and must learn to pick up and use lab equipment correctly with both hands. The story of the game is one of a stranded space station and the player must perform specific chemical reactions correctly — for example, the synthesis of a fluorescent substance — in order to survive. In addition to making this game available to schools and universities, the Schell Games team plan to release this chemistry game on the commercial game market. Playing with chemicals with SuperChemVR is encouraged, fun and completely safe.

Mechanisms

This game aims to transform curly arrow notation from a pen and paper activity to an interactive experience for both touch-screen and web, and is being developed by my own company, Alchemie (http://www.alchem.ie/mechanisms). In early 2016, we received National Science Foundation funding through the Small Business Innovative Research (SBIR) programme to develop this game and the data platform to capture and analyse student moves within the game. Mechanisms will be released in spring 2018 and will include game levels appropriate for introductory courses in organic chemistry. We plan to pilot the game and platform in ten college classrooms this summer and add another twenty institutions in the fall semester.

The research portion of our SBIR grant involves work to capture and analyse the moves users make within Mechanisms, as they decide how to manipulate bonds and electrons to move reactants to products. The Alchemie data platform will use machine learning algorithms to make the game 'smarter' and personalize the experience for each user. The data platform will map student progress in real-time and compare these mechanism maps with those of subject matter experts, predicting when and how a student understands a concept. These assessment data will be provided both to the student in gameplay and to instructors through a dashboard. The wealth of data that will be collected as students play the game is intended to help guide teaching practices. We are collaborating with chemistry education researchers to mine this trove of data to better understand how students learn organic chemistry.

The emerging field of games for learning, including those that incorporate the next wave of technology of virtual and augmented reality, has been heralded as a method to reach students who have grown up immersed in digital media. The question remains as to whether these activities are an effective means of delivering content, and the wide variety of what constitutes a game-based learning experience seems to be one of the issues in efficacy studies (Vandercruysse, S. et al. in *Handbook of Research on Serious Games as Educational, Business, and Research Tools* (ed. Cruz-Cunha, M. M.) (IGI Global, Hershey, PA, 2012). One of the key pieces of our research study with Mechanisms will be to test the transfer of content understanding as students use the game in college classrooms.

In my classroom games brought engagement, collaboration and a spirit of joy that was difficult to attain with a more traditional teaching method. Playful learning rewarded academic risk-taking and encouraged experimentation, useful practices for students in and beyond the chemistry classroom.

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Competing interests

Julia Winter is the founder and CEO of Alchemie Solutions, Inc., which produces the Chairs and Mechanisms apps.