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Chairs!: A Mobile Game for Organic Chemistry Students To Learn the Ring Flip of Cyclohexane

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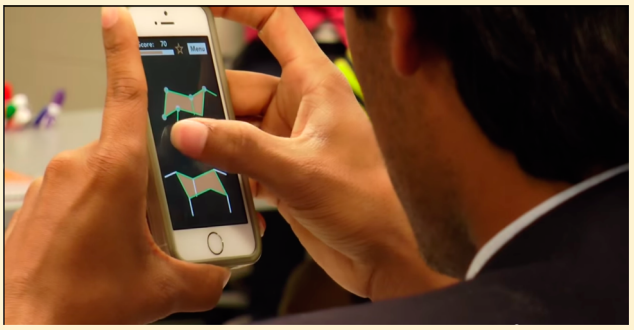
ABSTRACT: The hallmark of game-based learning is that students discover concepts through trial and error as they play. With the digital landscape in higher education shifting to mobile-first, new tools for learning chemistry are both possible and needed. Interactive games for chemistry bring intuitive content directly to students through their devices. The game Chairs! was created to teach the ring flip of cyclohexane. The development of this new mobile learning tool for organic chemistry and its implementation in classrooms are described.



KEYWORDS: *Second-Year Undergraduate, Organic Chemistry, Humor/Puzzles/Games, Computer-Based Learning, Alkanes/Cycloalkanes, Student-Centered Learning*

Organic chemistry in college can be difficult for students.[1] The spatial understanding required for success in organic chemistry is not readily accessible via traditional textbook and lecture delivery systems.[2] In a study correlating spatial ability with test performance in organic chemistry, it was found that students with a better ability to manipulate three-dimensional images as two-dimensional pictures had a higher probability of success on exam questions which required this kind of mental manipulation.[3] The question becomes how to help students make sense of the spatial reasoning of organic chemistry to achieve success in the class.

Conformational analysis of alkanes, either with Newman projections or with cyclohexane chair conformers, is a topic taught early in the organic chemistry curriculum. These visual-spatial concepts are often presented to students through the use of hands-on chemical modeling sets.[4] In organic chemistry classes at Detroit Country Day School, author Julia Winter used a whiteboard game with students to practice discerning between cyclohexane substituent directions and positions, either pointing upward or downward or in an axial or equatorial orientation. The quick tempo of this activity made for an engaging method for students to understand the topic and served as the basis for development of the mobile game application Chairs![5] (The exclamation point was necessary as the name, Chairs, had already been taken in the AppStore.)

Game-based learning, especially through touchscreen mobile applications, is a rapidly emerging field, with smartphone technology widely available only in the past few years. The use of video games in education has been much heralded as a means to reach "digital natives", yet the variety of game-based educational approaches and what elements constitute a "game" has muddled tests of efficacy.[6] In a different review in which comparisons could be made directly between game-based and traditional teaching methods, it was found that the game approach was more effective in terms of learning outcomes. Those games that incorporated heightened game design with elements of aesthetics and psychology were even more effective.[7]

Game design weaves these elements into development with the goal of creating intrinsically motivating experiences, whether for learning or for entertainment. Game-based learning activities must maneuver through a narrow channel between anxiety and boredom (Figure 1). If the application is too difficult and too conceptual, especially at initial levels, it risks being viewed like homework and will not be effective as a game.[8]

Few chemistry-related mobile applications are in a game format.[9] The games that do exist (Mahjong Chem from Stetson University,[10] ChemCrafter by Chemical Heritage Foundation,[11] and Collisions from Playmada Games[12]) target introductory chemistry topics. Sokobond by Alan Hazelden and Harry Lee[13] uses chemistry as a metaphor for its puzzles. To our knowledge, Chairs! is the first game-based mobile application in wide release specifically geared toward organic chemistry teaching and learning.

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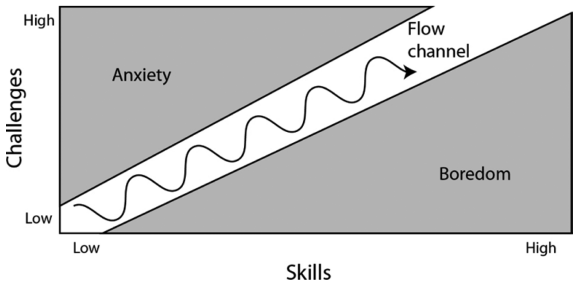

Figure 1. Flow channel of gameplay (Figure reprinted by permission. Copyright Taylor and Francis Group, CRC Press.).

CHAIRS!: CYCLOHEXANE AS A PUZZLE

Gameplay

In the game, players are presented with the two different conformational isomers of cyclohexane (Figure 2). A bond is shown on one of the conformers, and a pulsing circle marks the corresponding position on the other conformer. The player must draw the bond on the other conformer with the correct angle, either axial or equatorial. If the bond that is drawn is not within a narrow range near the correct angle, then it is shown in red. When the bond being drawn is at the correct position the bond turns green, as does the outline of the conformer. There are 13 levels to the game: in the first 6 levels, a white circle pulses to indicate where the bond should be drawn. Each new level adds an additional bond. In levels 7 through 13, the white circle is taken away.

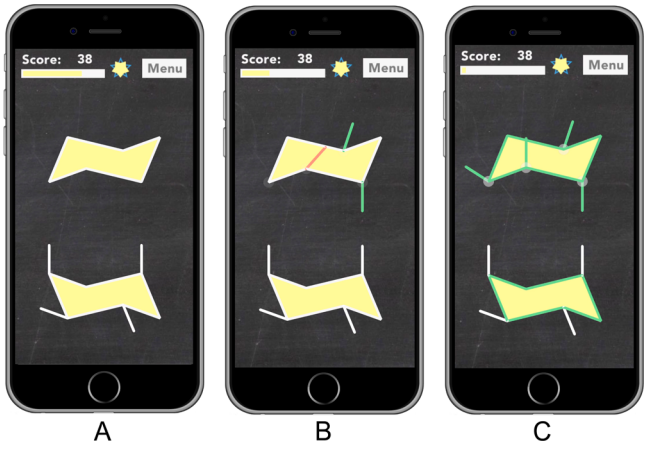

Figure 2. Three screenshots from Chairs! showing A: an initial level 4 puzzle, B: an incorrect move in red, and C: a correctly completed level 4 puzzle.

The scoring system is straightforward: for every correct bond that is drawn, the player earns a point. The play time is limited by a bar at the top of the screen which counts down at each new level. A mistake on an earlier level will affect the amount of time given for a later level, thus increasing the pace and challenge of the game. A badge is earned for a level when the level is completed with five correct puzzles in a row. A 100-point game is an achievable, though difficult, benchmark.

Use in High School Organic Chemistry Class

In the fall of 2014, the learning outcomes for Chairs! were measured in a classroom trial at Detroit Country Day School. Forty-one organic chemistry students in three classes were taught the cyclohexane concept during the first day with a traditional discussion method. The students were then divided into two groups: some of whom could access the game as an assignment, and the remaining students could not. On the second day of the trial, the students were assessed with a four-point drawing quiz (Figure 3).

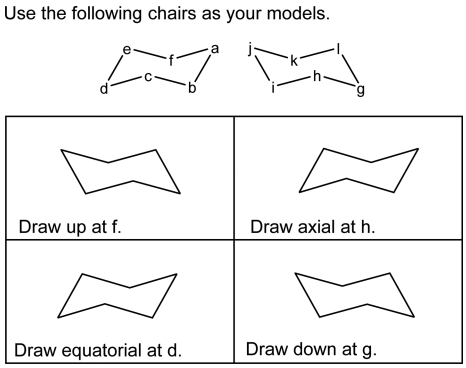

Figure 3. Drawing quiz used to measure student understanding of axial and equatorial positions of the cyclohexane chair conformers.

The students played the game application during the class period and were given a second assessment. All students except for one improved or earned a perfect score on the second quiz. The data from this trial are shown in Figure 4. These results have been confirmed anecdotally by other instructors.

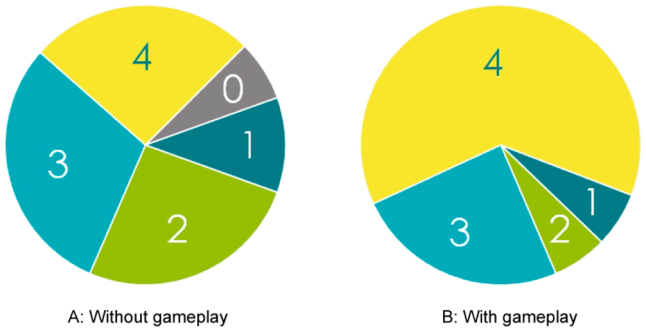

Figure 4. Distribution of scores on a four-point quiz with and without gameplay of Chairs! (A) After lecture, without gameplay, $N = 24$; (B) After lecture, with gameplay, $N = 17$.).

Though these outcomes were very positive, the population tested was a rather small sample size of students in an independent high school. More controlled studies on larger, more diverse populations of students will be constructed and implemented to assess the capabilities of the game on conceptual understanding of conformational isomers.

Use in a College Classroom

In 2015, author Michael Wentzel developed a lesson for his second-year undergraduate Organic Chemistry 1 students at Augsburg College. The course was divided into 2 sections with 50 students total with a constituency of mostly pre-health science majors. Conformational analysis was in the first unit of the course, and in the past, students have had difficulty with the spatial reasoning necessary to understand ring flips. The concept was presented to students using a flipped or active learning approach. A video tutorial on conformational isomers was assigned for students to watch before the in-class lesson. Students were also instructed to download the Chairs! game

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application. During class, students were given an abbreviated lesson on ring flips as well as a demonstration of the game. They were then allowed to practice with their own devices for 30 min and work together in gameplay. During this time, students came to the front of the class to compete with both the instructor and classmates for high scores.

The first unit exam for the class had 16% of the points dedicated to ring flip conformational analysis and a bonus question about a disaccharide molecule in a particular chair conformation. The overall exam average was 71%. However, students earned an average of 13.2 points out of 16 (82.5%) on the problems associated with cyclohexane. The bonus question was completed correctly by 60% of the students. In an informal survey following the exam, 90% of the Augsburg students surveyed felt that using the Chairs! game application had helped them understand the concept. Below is a representative comment from the survey:

> *"It was helpful because I was able to visualize the chair flips, and I thought while playing I understood the angles of equatorial and axial better."*

■ FUTURE DEVELOPMENT

The Chairs! game has had a positive effect on both student engagement and learning outcomes in both a high school and college setting for this relatively small concept within the curriculum. Development work on the application is continuing with a focus on updated graphics, an interactive tutorial feature, and a chair-drawing scaffold tool. Other concepts that lend themselves to mobile-enabled, game-based learning in chemistry are being explored, including mechanisms, resonance, and structural symmetry.

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Notes

The authors declare the following competing financial interest(s): The game application Chairs! is a product of Alchemie Solutions, Inc, and Julia Winter is a majority owner of the company.

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