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Chirality-2: Development of a Multilevel Mobile Gaming App To Support the Teaching of Introductory Undergraduate-Level Organic Chemistry

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Supporting Information

ABSTRACT: Mobile technology is increasingly prevalent in higher education. Chemistry-related software applications (apps) on touchscreen computers are emerging as a popular platform in many areas, including in the chemistry classroom. In this work, a new game-based app designed for hand-held and portable touch-controlled devices is presented. Chirality-2 covers multiple aspects of introductory undergraduate organic chemistry. The app allows users to earn chemistry-type medals related to his or her score for each stage, track progress, and post scores and compete with peers on social media. The app is free to download on both the iOS and Android operating systems and aims to help reinforce important chemical concepts necessary for introductory undergraduate chemistry courses worldwide. The target audience includes teachers and students at the final year of high school and introductory undergraduate level.

KEYWORDS: *Organic Chemistry, Humor/Puzzles/Games, Computer-Based Learning, Student-Centered Learning, General Public, Hands-On Learning/Manipulatives, Molecular Properties/Structure, High School/Introductory Chemistry*

INTRODUCTION

Technology has transformed nearly all areas of modern life, and education is no exception. The modern chemistry undergraduate student (in common with society in general) is now rarely without a smart phone, laptop computer, or tablet. In a classroom context, mobile phones and tablets are often seen as a problem because use of these items can easily distract students and disturb the learning process.[1] Nevertheless, in recent years there has been a growing movement to harness digital technology to benefit education by helping students acquire knowledge though interactive learning.[2,3]

There are currently a number of chemistry applications (apps) available for students, chemical professionals, and teachers.[4,5] The majority of these are purely functional in nature, for example, visualizing and processing NMR spectroscopy[6] or mass spectrometry data,[7] calculating molar concentrations (e.g., the Molarity App from Sigma-Aldrich), and/or accessing journals[8] and online databases such as ChemSpider (search for ChemSpider at iTunes or see ref 9) while on the move. There are also a number of online homework systems (such as those paired with most textbooks), which can offer very similar content, but these are often only available to students enrolled in specific courses and/or universities who have paid for the required publisher access code.

Apps can be effective in the classroom, especially when used in a blended learning approach.[10] They can be integrated into practical sessions, for example to replace the standard international chemical data book or to share the results of an experiment with a large class. While undoubtedly useful, such apps still present the information in a standard text-based format with limited user interaction. This way of presenting information is not very different from traditional textbooks and notes. Several authors have recently suggested that incorporating aspects of gaming into teaching apps could be more effective in terms of improving learning outcomes,[11,12] and a small (but growing) number of game-based educational apps have started to appear.[12,13]

A game has the advantage of "making learning fun" and offers a powerful tool for "learning through doing", while gamification (the process of game-thinking and game mechanics to engage users and solve problems) can encourage learning and enhance student interest.[14,15] A recent review noted that while gamification can provide benefits, these are greatly dependent on the context in which the gamification is being implemented

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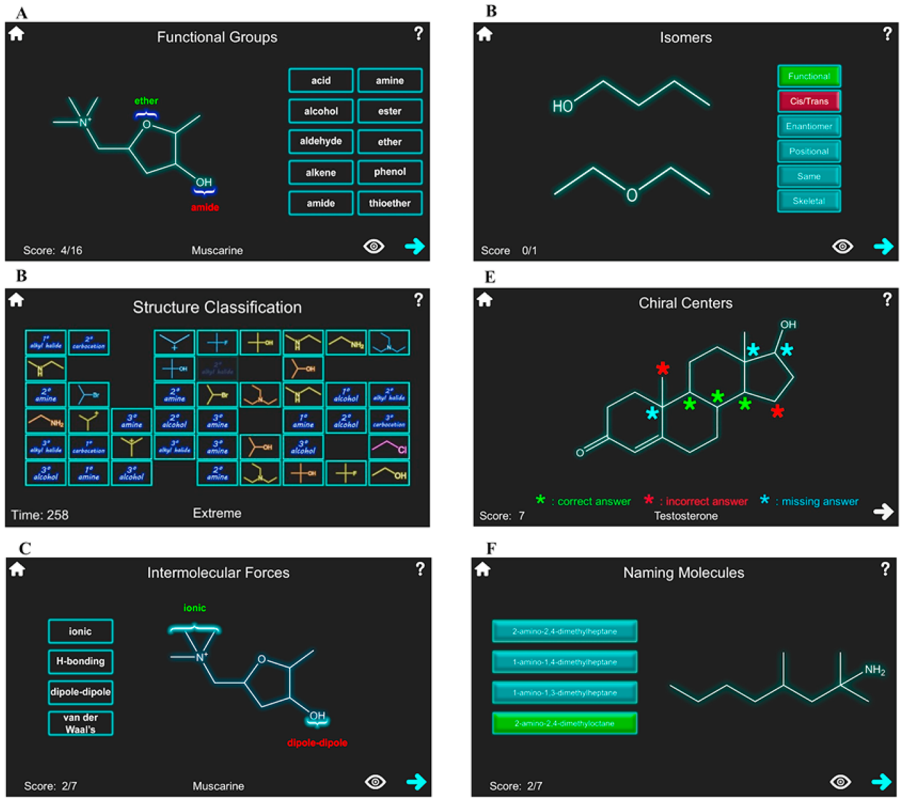

Figure 1. Screenshots from the app showing levels 1−6. Correct and incorrect answers are shown in green and red, respectively.

as well as on the user(s).[16] Good design is essential if gamification is to be useful in a teaching context.[17]

A recently developed gamified learning app for accounting has shown positive effects on student academic performance, engagement, and retention.[12] Similar work has also detailed positive effects of the organic chemistry educational game app Chairs!.[13] The latter is designed to teach one aspect of organic chemistry (it is focused on the ring flip of cyclohexane) and does this very well. It is available on both Apple and Android operating systems and cost $1 to download at the time of writing.

In this paper, the app Chirality-2 is presented. This app is designed to supplement classroom teaching of a range of topics in organic chemistry at the introductory undergraduate level. It may also be of use/interest for those in their final year of high school as well as for students revising introductory organic chemistry. Chirality-2 is one of the first purpose-built mobile applications in general release specifically developed to teach organic chemistry and the only one to feature multiple levels, a reward system, and social media integration. There are six levels in Chirality-2. Users earn medals for each level and are able to post scores on social media or track their progress. The underlying design also enables extra content and levels to be added easily in the future. It is available for free worldwide on both the Apple (iOS)[18] and Android (Google Play)[19] operating systems.

METHODS

Gameplay

The app uses drag-and-drop touch-screen interfaces for users to solve puzzles and answer questions. The topics covered are functional groups, structure classification, intermolecular forces, isomers, chiral carbons, and naming of molecules. An overview of each level is given below. Further details on the design and programming of the app are given in the Supporting Information.

L1 Functional Group Identification (Figure 1A). Users are presented with a picture of a molecule and use a drag-and-drop interface to move tiles with the name of functional groups to the correct location. After tapping the arrow icon in the bottom right of the screen, the game checks if the player has answered the question correctly and displays appropriate feedback. A random fact containing more information about the molecule is displayed before moving on to the next molecule. Five molecules are presented each time the level is played. The molecules are drawn from a pool of structures. One point is given each time a functional group is identified correctly. Incorrect answers earn a score of 0.

L2 Structure Classification (Figure 1B). A grid of tiles displaying names and structures is shown to the player, who must then match pairs of tiles (i.e., the structure with its name). The pairs contain images/names for simple 1°, 2°, and 3° amines, alcohols, alkyl halides, and carbocations. Correct pairs are removed when selected. Incorrect pairs are not removed. Different difficulty settings (through different timed modes) are provided for this level as follows.

- Standard: The timer counts up until the level is complete. The shorter the time left on the counter, the better the score.
- Time trial: The timer starts on 10 s and counts down; 2 s is added for every correct pair. The longer the time left on the counter at completion, the better the score.
- Extreme: The timer starts on 300 s and counts down until the level is complete. The longer the time left on

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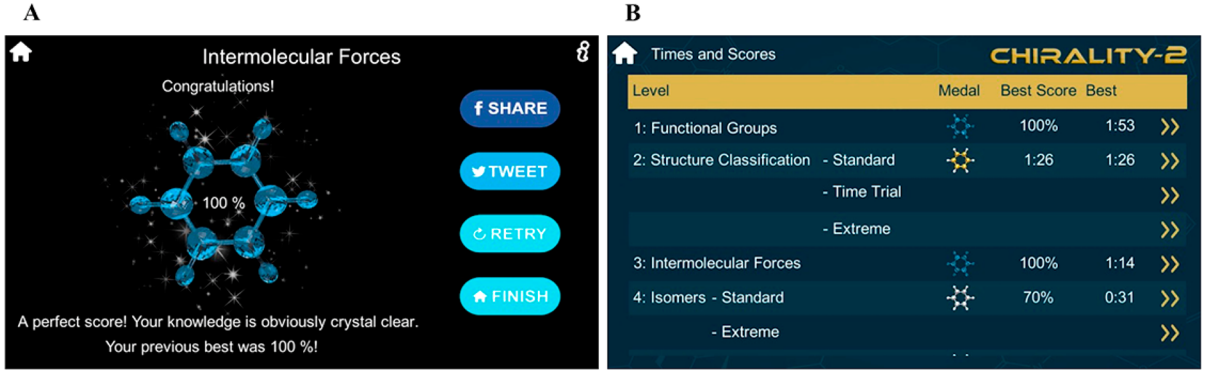

Figure 2. Screenshots from the app showing a user getting the blue crystal medal on level 3 of Chirality-2 (left panel) and checking progress (right panel).

the counter after completion of the level, the better the score.

L3 Intermolecular Forces (Figure 1C). This level is similar to level 1, but players identify intermolecular forces rather than functional groups. A random fact containing more information about the molecule is displayed before moving on to the next question. Five molecules are drawn randomly from a pool each time the level is played. One point is given each time a functional group is identified correctly, while incorrect answers earn a score of 0.

L4 Isomers (Figure 1D). The player is presented with five pairs of isomers (from a pool of 18) and must identify what type they are. After the answer has been submitted, the player is given instant feedback on whether their choice was correct. Two playing modes are possible. In standard mode, 1 point is given for each correct answer, while incorrect answers earn a score of 0. In extreme mode, the timer starts on 10 s and counts down. The level is over if a time of 0 s is reached or an incorrect answer is given.

L5 Chiral Centers (Figure 1E). Players are presented with a molecule and must identify the chiral centers. The game shows which of the selected atoms are correctly or incorrectly identified as well as those that should have been identified but were not. An additional question asks how many stereoisomers the molecule has. Five molecules are drawn randomly from a pool each time the level is played to ensure that the player has a different experience each time. In this level, 2 points are awarded for a correct selection and 1 point for getting the additional question correct. Incorrect answers earn a score of 0.

L6 Naming of Molecules (Figure 1F). The player is shown pictures of 10 organic molecules (from a pool of 30) and must select the correct name from four options. In this level, the set of answers for each molecule are shuffled randomly so that the player cannot simply learn the position of the correct answer by multiple attempts at the level. One point is given for each correct answer, and incorrect answers earn a score of 0.

Earning Medals and Checking Results

Earning badges for progress has been shown to have a positive effect on learner motivation.[17] Chirality-2 allows users to gain badges that reflect knowledge and understanding of the topics covered in each level. These take the form of medals made of differently colored, stylized, benzene molecules created using POV-Ray (version 3.7) and Adobe Photoshop (Cs6). If a user gains a perfect score (100%), he/she is awarded the blue crystal medal. Scores of 90−99%, 70−89%, and 50−69% get gold, silver, and bronze medals, respectively. A score below 50% on a level results in a "rusty" medal indicating the improvement is needed.

Once the user has completed any level, he/she is presented with the game-over scene. This displays the player's score, the corresponding medal, and the option to share the result on various social media platforms (Figure 2). The app also keeps track of the best score and best time for each level, with the data being accessed by clicking on the rosette in the bottom right corner of the home screen. The best score and time are shown for each level (and sublevel). Clicking on the gold arrow at the end of the row for each level will bring up details of the last 50 attempts on that level. This allows a user to see how he/she is progressing over time. This functionality could also be used to assess students if the game levels are utilized as part of the assessment schema of the course, perhaps contributing a certain percentage to the overall grade.

To assess how students enjoyed the Chirality-2 app, a survey was conducted with student volunteers in December 2012. Students played the game for approximately 40 min and then filled in a survey on the app.

RESULTS AND DISCUSSION

Feedback from student test users at RMIT has been universally positive, with second- and third-year undergraduates commenting that the app helped them remember concepts they had forgotten from introductory organic chemistry.

The results of the student survey on the app conducted at RMIT are shown in the Supporting Information (Table S1). The aspects that were found most enjoyable and interesting were:

- Design and playability
- Ease of use
- Relevance of content
- Scoring system
- Easy-to-understand navigation (user interface)
- Music
- Difficulty level, comparing the difficulty level of Chirality-2 to Chirality-1
- Calm feel, pressure level for casual play/learning
- Timed challenges
- Good alternative to usual revision

The Chirality-2 game has also been very favorably received at academic conferences and online. A selection of comments from students and teachers demonstrates the pedagogical value of the app.

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"Wow, I love Chirality 2. I can't wait to share it with my students this fall to help them memorize these important concepts so we can work on applying them in class..." [Comment from a U.S. academic from the University of Illinois[20] (N.B.: A LinkedIn account is required for access to this comment)]

"I'm downloading it now...I'm sure I'll use it in OChem I in the Fall." [Comment from a U.S. academic from Central New Mexico Community College[20] (N.B.: A LinkedIn account is required for access to this comment)]

"I have to say well done on this. Easy to understand and use. Beautiful app." [Comment from a postdoctoral research associate, Kannapolis, NC, USA]

"I use both Chirality apps in a high school organic chemistry elective course for seniors. Mostly the Functional group option. In Chirality 2 it's a bit advanced but they use it". [Comment from a teacher at John Burroughs School in St. Louis, MO, USA]

"Great app—will be using with my students!" [Chirality-2 user review from an Australian academic on the Google Play Store]

"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." [Excerpt of an independent review of Chirality-2 in *Nature Reviews Chemistry*[21]]

"[I] found this game to be challenging (in a good way.) It's great as a refresher or as a way to test concepts learned in class. It would probably serve students well to check incorrect answers with professors or TAs to better understand concepts. Great learning tool!" [Chirality-2 student user review on the Apple store]

"The app is fantastic and I love that there are people who believe in the idea of gamifying topics!" [Feedback from an RMIT University chemistry undergraduate student]

"I liked the design and playability of it overall as it was easy to just turn on and start playing." [Feedback from an RMIT University chemistry undergraduate student]

Chirality-2 is designed to support, not replace, classroom learning. The content in the app is the same as students see in lectures and thus reinforces ideas and lets students put into practice ideas and concepts to which they have already been exposed. While the app can of course be played by itself, doing so may not be ideal if no external context is given. For example, in levels 1−3 the learner can potentially learn what the correct answer is in assigning the different functional groups, intermolecular bonding type, and structural categories without really knowing why (although in practice this is quite difficult to do). Similarly, in level 5 a potentially useful exercise is to have the students play the app and then discuss with the teacher in class how some molecules, for example, tartaric acid, do not fit the general 2^n rule and why. This helps students engage with the material as well as learn the additional concept of meso compounds.

No technology is a panacea, and many of the traditional problems associated with educating students will remain, no matter how amazing the game or sophisticated the smart phone. It is important, however, that when new technologies are developed educators do not shy away from testing their abilities to enhance and encourage learning. Academics are in an ideal situation to help develop these systems by incorporating their background knowledge with personal experiences in lecturing and teaching science to help develop the best outcome. The development of Chirality-2 is continuing on the basis of user feedback from both students and teachers. Future expansion of the app will be based around adding more content and structures to each level and introducing new concepts such as assignment of chiral centers as *R* or *S*. In general, electronic games and apps have great potential for teaching and learning fundamental chemistry concepts, particularly if both chemists and game designers are involved from the start. It will be interesting to see how these systems are further developed in the future.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.7b00856.

Details of the content, development, programming, and design of the Chirality-2 app and results of the student survey (PDF, DOCX)

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Notes

The authors declare no competing financial interest.

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