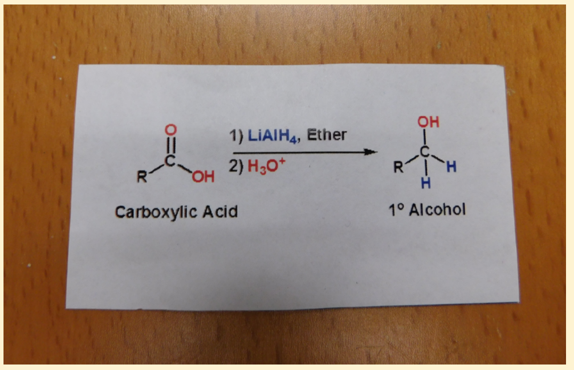
JOURNAL OF CHEMICAL EDUCATION
Activity
pubs.acs.org/jchemeduc

A Simple Card Game To Teach Synthesis in Organic Chemistry Courses

Steven C. Farmer* and Molly K. Schuman

Department of Chemistry, Sonoma State University, 1801 East Cotati Avenue, Rohnert Park, California 94928, United States

Supporting Information



ABSTRACT: The sheer number of reactions covered in an undergraduate organic chemistry course can be overwhelming. Students are expected to demonstrate a thorough knowledge of these reactions in order to understand the logic of organic synthesis. A method that allows students to systematically solve organic synthesis problems without memorizing dozens of reactions would be beneficial. Two new card games, Synthesis and Synthetic Dominos, have been developed using a variation of traditional flash cards. Both of these games allow players to develop the logical skills needed to solve organic synthesis problems, review organic functional groups, and review reaction reagents. The first game, Synthesis, is a solitaire game that uses reaction cards to link up a starting material and target by connecting functional group conversions. The game play mimics the process used to solve synthesis problems. The second game, Synthetic Dominos, is a single-player or multiplayer game that has a gameplay similar to that of Dominos. An initial functional group card is dealt, and then players play their cards to build off this initial card. Strings of functional group conversions develop as the game progresses. These games are an excellent method of developing the logic for solving synthesis problems and reviewing organic reactions. These games are especially effective in lower-division organic chemistry courses, upper-division organic synthesis courses, and preparing for placement exams, such as the MCAT and ACS.

KEYWORDS: *Second-Year Undergraduate, Upper-Division Undergraduate, Organic Chemistry, Humor/Puzzles/Games, Synthesis, Student-Centered Learning*

Undergraduate students in organic chemistry courses utilize fundamental organic chemical reactions to plan organic synthesis pathways. In order for students to do this, they must be able to recall the numerous functional groups and reactions discussed in the course from memory. Because of the large amount of knowledge required, students often struggle with the planning of synthesis pathways. One solution to this problem is to provide students with a challenging, yet enjoyable, game which allows them to quickly consider large numbers of reactions without memorizing them. In addition, when learning takes the form of a game, students can engage a subject in new ways.[1,2] Moreover, games take advantage of the finding that learning is an inherently social process.[3−5] Games can develop the critical-thinking and collaborative skills in ways that traditional flashcards cannot. In particular, card games have been used to teach concepts of general[6−12] and organic chemistry, including functional groups, stereochemistry, nomenclature, functional group interconversion, reactions of aliphatic compounds, and the regiochemistry of aromatic ring reaction.[13−20]

Recently, journaling and the use of web-based tools have been used to teach organic sythesis.[21−23] Being able to see functional groups and different reactions allows for a systematic solution to some synthesis problems. Thus, the organic synthesis card games described herein have been developed to increase learning and improve the retention of the material. Also, the games have been designed so that someone with almost no chemistry knowledge can play, and the games are simple enough to explain in a few minutes. These games are different from all other chemistry card games in that the game process can be used to solve synthetic problems with variable starting and target molecules. Lastly, these games allow students to learn chemistry in a stress-free, interactive way.

■ CARD DESIGN

The games are played with two types of game cards: functional group and reagent.

Reagent cards list the given reagent and the functional group conversions (Figure 1, left).

Functional group game cards list a specific organic functional group name and its Lewis structure (Figure 1, right). These cards are displayed in red to make their identification easier during gameplay.

Received: August 7, 2015
Revised: January 11, 2016

DOI: 10.1021/acs.jchemed.5b00646
J. Chem. Educ. XXXX, XXX, XXX−XXX

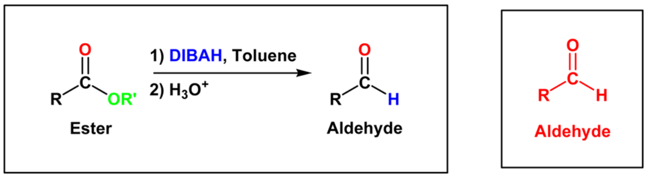


Figure 1. (Left) Example of a reagent game card. (Right) Example of a functional group game card.

The cards (Supporting Information) follow the reactions presented by McMurry.[24] Some functional groups and reactions have been excluded for the sake of brevity. The deck consists of 76 reagent cards and 13 functional group cards. Cards can be added to the deck using the template or removed from the deck, depending on the content of the chemistry course.

SYNTHESIS GAMEPLAY

Gameplay starts by dealing two of the given functional group cards: the starting functional group and the target. The object of the game is to connect the two functional groups cards by using the reagent cards. All of the reagent cards are made available to the player to utilize. Functional groups are connected by similarity, much as the game of Dominos is played. The initial reagent card's reactant functional group must match the designated starting functional group card. Reagent cards can be connected by matching the product functional group from one card with the reactant functional group of another card. The product functional group of the last reagent card played must match the target functional group card. This produces a string of functional group conversions (Figure 2).

This game can also be played using synthesis problems that use actual molecules instead of representative functional groups. In this case, after the reagents cards are used to form a possible synthesis pathway, the viability of the suggested syntheses can be considered and structures of the actual intermediates can be drawn (Figure 3).

SYNTHETIC DOMINOS GAMEPLAY

Gameplay starts by dealing out one functional group card. Reagents cards can be played off any functional group or reagent card in play. In order to be played, the reactant functional group of the reagent card must match a functional group card in play or the product functional group of a reagent card already in play. Functional group cards can be played on a reagent card that has the same functional group as its product. Once played, functional group cards act as spinners, i.e., reagent cards can be played on all four sides of the functional group card, causing the line of play to branch. A sample Synthetic Dominos scenario is shown in Figure 4. The objective of the game is to play as many cards as possible while making the fewest number of draws from the boneyard.

EVALUATION

The game card sheets and rules were originally given out as additional study material for an undergraduate organic chemistry course (~75 students). The lecture hall did not have movable seats, which made gameplay during lecture times almost impossible. In this course, the playing cards and instructions were e-mailed to the class. Also, a brief explanation of gameplay was covering during lecture. After the initial introduction, students were encouraged to form study groups and play the games or come by the instructor's office hours to play against whoever was in attendance. New card sheets were sent out prior to each exam, and by the time of the final exam the student had a complete collection of the cards for the course. The large number of students which attended office hours allowed multiple games to be played in small groups. Based on these experiences, these games would optimally be played during a lecture of smaller classes (<30) or during a laboratory period devoted to discussing synthesis. These games would be of most value in traditional organic chemistry courses or in an upper-division organic synthesis course. Because gameplay would help students learn functional groups and reactions, these games would still have some benefit in chemistry courses where synthesis is barely covered, such as a General, Organic, and Biological chemistry course.

The Synthesis game was optimally played either by single players or in small groups of two or three people. With the gameplay cards, simple synthesis questions could be solved in less than 5 min. The best classroom use of the Synthesis game would be to hand a sheet with multiple sample synthesis problems, have the students break into groups, and have the students use the gameplay cards to solve them. A sample problem set is included in the Supporting Information.

Synthetic Dominos was optimally played with 3−4 people, but games with 2−5 people are possible. Each round of Synthetic Dominos would take roughly 5 min, and to complete a game typically takes about 20 min. However, the total end game points can be varied so the length of a game can be altered to fit any need. Students appeared universally pleased with the idea of receiving additional study material and having a way of systematically solving synthesis questions. Students would come to office hours claiming to have difficulty solving a synthesis problem, and after being shown a sample solution using the game cards they would be able to solve a subsequent synthesis problem on their own. Although formal evaluation of these games has yet to be conducted, informal student responses were universally favorable. Students said they enjoyed the game's simplicity and their competitive nature. Also, many students commented on the utility of being able to systematically solve synthesis problems while studying on their own. Lastly, I was delighted to find out that many of the students used the provided cards as flashcards to enhance their learning beyond just playing the games. Offering up my office hours for gaming session seemed to strike a chord with

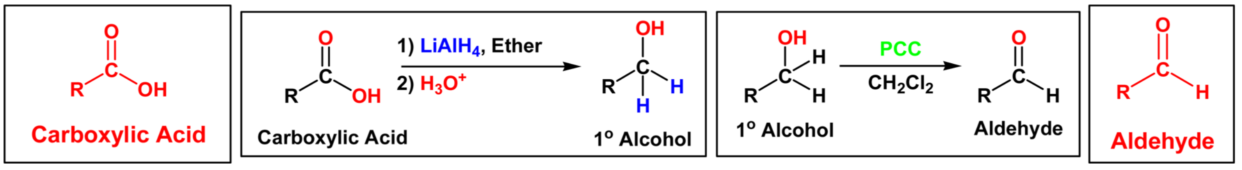


Figure 2. An example of a complete solution to a Synthesis problem.

DOI: 10.1021/acs.jchemed.5b00646
J. Chem. Educ. XXXX, XXX, XXX−XXX

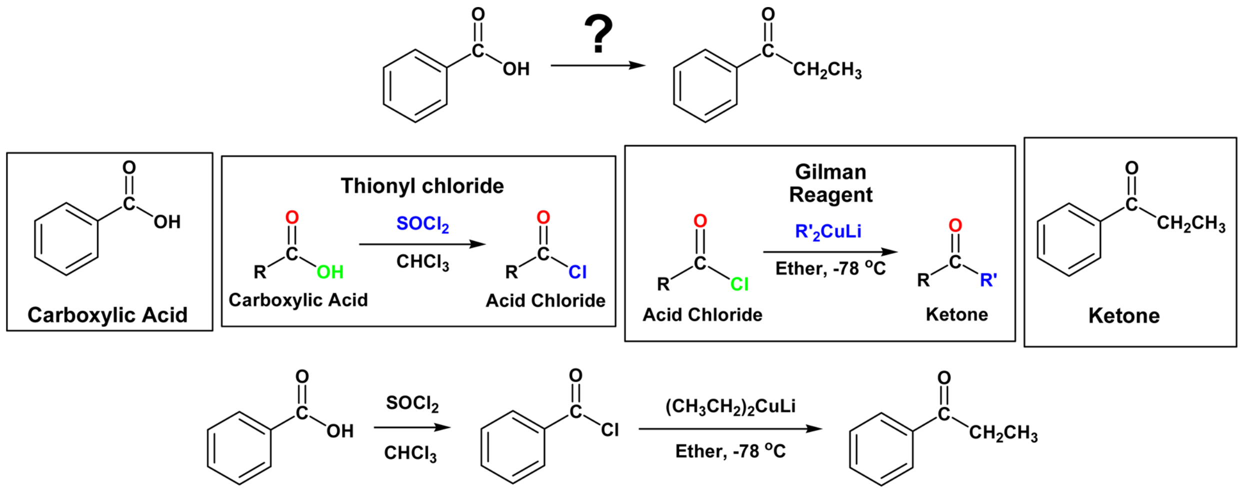


Figure 3. Example using Synthesis cards to solve an organic synthesis problem.

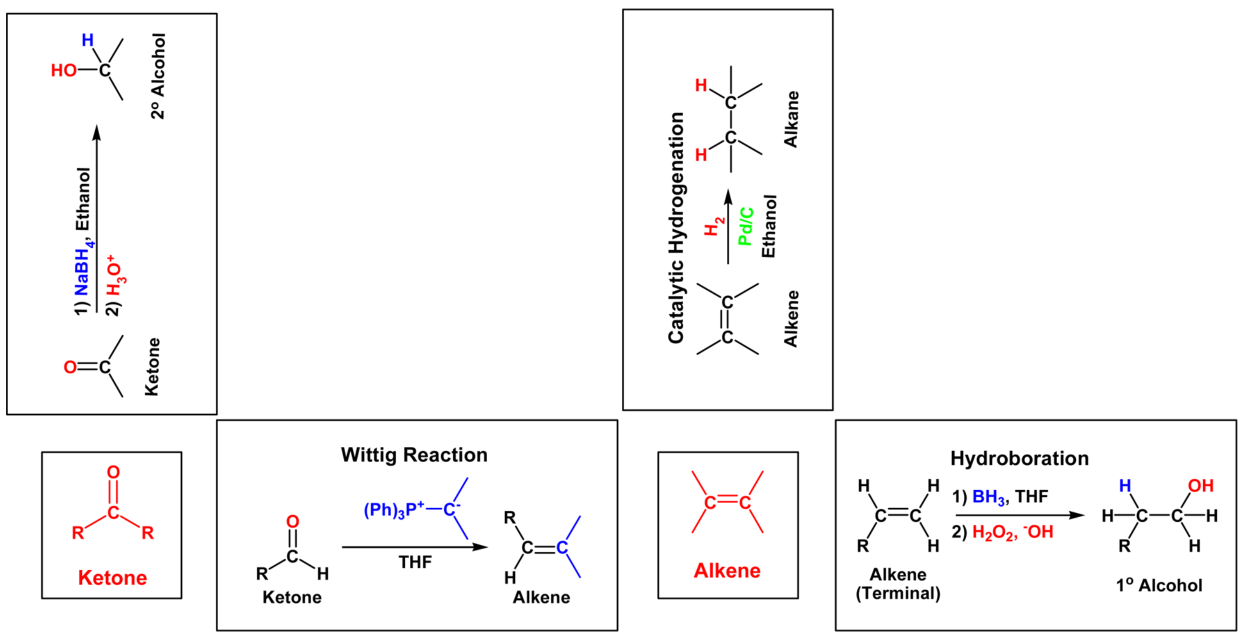


Figure 4. Example of gameplay for Synthetic Dominos.

students. Gaming is quite common with modern students, and they seemed accustomed to meeting in groups to play. Also, the students seemed quite interested to see if they could beat the instructor at his own game.

■ DISCUSSION

Although a large number of these cards may be necessary to represent all of the reactions required for an entire course, only a select few would be required to introduce the subject. Once the idea has been shared, the students can generate their own cards. These games seemed to make it enjoyable to review functional groups and reagents in a way that traditional flashcards do not. More importantly, playing the game can allow students to develop the logic required to solve organic synthesis problems. The social nature of the games allowed students to learn in a cooperative environment. Because these games can be played by one to five players and for variable times, they should be ideal for use in a classroom. Students seemed eager to play these games and use a new method to solve synthesis problems.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.5b00646.

Sample cards, game rules, strategy, and sample problems (PDF, DOCX)

■ AUTHOR INFORMATION

Corresponding Author

*E-mail: farmers@sonoma.edu.

Notes

The authors declare no competing financial interest.

DOI: 10.1021/acs.jchemed.5b00646
J. Chem. Educ. XXXX, XXX, XXX−XXX

REFERENCES

(1) Samide, M. J.; Wilson, A. M. Games, Games, Games; Playing to Engage with Chemistry Concepts. *Chem. Educ.* **2014**, *19*, 167−170.
(2) Stringfield, T. W.; Kramer, E. F. Benefits of a Game-Based Review Module in Chemistry Courses for Nonmajors. *J. Chem. Educ.* **2014**, *91* (1), 56−58.
(3) Bruffee, K. A. *Collaborative Learning*; Johns Hopkins University Press: Baltimore, MD, 1993.
(4) Johnson, D. W.; Johnson, R. T.; Smith, K. A. *Active Learning: Cooperation in the College Classroom*; Interaction Book Company: Edina, MN, 1991.
(5) Lawson, A. E. What Should Students Learn About the Nature of Science and How Should We Teach It? *J. Coll. Sci. Teach.* **1999**, *28* (6), 401−411.
(6) Granath, P. L.; Russell, J. V. Using Games to Teach Chemistry. 1. The Old Prof Card Game. *J. Chem. Educ.* **1999**, *76* (4), 485−486.
(7) Sevcik, R. S.; Hicks, O.; Schultz, L. D.; Alexander, S. V. Elements−A Card Game of Chemical Names and Symbols. *J. Chem. Educ.* **2008**, *85* (4), 514−515.
(8) Morris, T. A. Go Chemistry: A Card Game to Help Students Learn Chemical Formulas. *J. Chem. Educ.* **2011**, *88* (10), 1397−1399.
(9) Franco-Mariscal, A. J.; Cano-Iglesias, M. J. Elemental B-O-Ne-S. *J. Chem. Educ.* **2011**, *88* (11), 1551−1552.
(10) Kavak, N. ChemPoker. *J. Chem. Educ.* **2012**, *89* (4), 522−523.
(11) Russell, J. V. Using Games to Teach Chemistry: An Annotated Bibliography. *J. Chem. Educ.* **1999**, *76* (4), 481−484.
(12) Martí-Centelles, V.; Rubio-Magnieto, J. ChemMend: A Card Game To Introduce and Explore the Periodic Table while Engaging Students' Interest. *J. Chem. Educ.* **2014**, *91* (6), 868−871.
(13) Welsh, M. J. Organic Functional Group Playing Card Deck. *J. Chem. Educ.* **2003**, *80* (4), 426−427.
(14) Costa, M. J. Carbohydeck: A Card Game To Teach the Stereochemistry of Carbohydrates. *J. Chem. Educ.* **2007**, *84* (6), 977−978.
(15) Angelin, M.; Ramström, O. Where's Ester? A Game that Seeks the Structures Hiding Behind Trivial Names. *J. Chem. Educ.* **2010**, *87* (4), 406−407.
(16) Eglinton, G.; Maxwell, J. R. Chemsyn−Chemical Card Game 1. *Educ. Chem.* **1971**, *8*, 142−144.
(17) Kristol, D.; Perlmutter, H. D. Organocards−Chemical Card Game 2. *Educ. Chem.* **1971**, *8*, 145.
(18) Kristol, D.; Perlmutter, H. D. Organocards−Chemical Card Game 3. *Educ. Chem.* **1971**, *8*, 176−177.
(19) Knudtson, C. A. ChemKarta: A Card Game for Teaching Functional Groups in Undergraduate Organic Chemistry. *J. Chem. Educ.* **2015**, *92* (9), 1514−1517.
(20) Carney, J. M. Retrosynthetic Rummy: A Synthetic Organic Chemistry Card Game. *J. Chem. Educ.* **2015**, *92* (2), 328−331.
(21) Teixeira, J.; Holman, R. W. A Simple Assignment That Enhances Students' Ability to Solve Organic Chemistry Synthesis Problems and Understand Mechanisms. *J. Chem. Educ.* **2008**, *85* (1), 88−89.
(22) Chen, J. H.; Baldi, P. Synthesis Explorer: A Chemical Reaction Tutorial System for Organic Synthesis Design and Mechanism Prediction. *J. Chem. Educ.* **2008**, *85* (12), 1699−1703.
(23) Draghici, C.; Njardarson, J. T. Chemistry By Design: A Web-Based Educational Flashcard for Exploring Synthetic Organic Chemistry. *J. Chem. Educ.* **2012**, *89* (8), 1080−1082.
(24) McMurry, J. E. *Organic Chemistry*, 7th ed.; Brooks Cole: Pacific Grove, CA, 2008.

DOI: 10.1021/acs.jchemed.5b00646
J. Chem. Educ. XXXX, XXX, XXX−XXX