Science Ninjas: Valence – Examining Learning Gains in a General Chemistry Classroom with Card Games

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ABSTRACT
Using games in the classroom can be an engaging and fun way to promote student learning. To enhance learning in General Chemistry, 79 undergraduate students were introduced to a game called Science Ninjas: Valence. This commercially available chemistry card game focuses on combining elements to make molecules, which can then react with each other via common chemical reactions. It was found that this card game could contribute to chemistry knowledge gains and be used to teach certain concepts within a single class period.

KEYWORDS
First-Year Undergraduates, Humor/Puzzles/Games, Reactions

INTRODUCTION
Educational games provide engaging learning opportunities outside of lectures, homework, and exams.[1-3] Within the field of chemistry and chemical education, several recent papers have reported on the use of games to enhance learning in the classroom setting. Many of these learning activities are adaptations of common games such as Jeopardy, Taboo or even Go Fish used to review course material.[4-7] Games can be designed to teach specific chemical concepts. For example, ChemKarta focuses specifically on learning functional groups in organic chemistry while ChemMend works on concepts about the periodic table often covered in a general chemistry course.[6,7] These games can be fun and interesting ways to promote student learning, giving students will have an opportunity to learn course material in a fun and enjoyable way.

Typically, papers published on games are instructional: they present how the games can be played and incorporated into the classroom but do not examine the impact of the games on student learning or engagement. However, a handful of recent studies have started to investigate student perceptions on the usefulness of games or have directly measured learning gains associated with game play. These studies have, not surprisingly, shown that students believe the games had a positive influence on their learning and that student are learning during the gaming process.[7-11]

In this study, we introduced undergraduate science majors to a game called Science Ninjas: Valence. This commercially available chemistry card game focuses on combining elements to make molecules, which can then react with each other via common chemical reactions. The objective was to determine if the game play could contribute to chemistry knowledge gains and be used to teach certain concepts within a single class period.

THE GAME

Science Ninjas: Valence is a card game for 2-4 players. The goal of game is to combine Element cards to make Molecule cards, which are worth points. Certain molecule cards (i.e. acids) can react with an opponent's molecule cards (i.e. bases) to reduce the opponent's total points. The first player that reaches 10 points wins the game.

Game Set-up

The deck consists of 41 Element cards (9 unique cards) and 45 Molecule cards (8 unique cards). Each Element card includes its Atomic number, Element name, Color (group), Valence number (positive or negative charge with atomic diagram), and Science Ninja. Before play, the molecule bank is assembled, and each player is dealt 6 Element cards. The player with the highest atomic number in their hand begins the game.

Game Play

Players start their turn by drawing an element card from the Element deck. During their turn, a player can make molecules, by identifying element cards (with given oxidation states) that sum to zero. The type of molecule that is formed can be identified by the colors on the combined elements (see Figure 2). Once a molecule is made, the player places that card face up in front of them, earning the point value on that card. On their turn, a player can also use their molecular cards to attack their opponent's molecule cards. For instance, a player can use their acid (worth zero points) to attack another player's base card (worth 4 points), leaving the player with a salt (worth 1 point) and water (worth one point). Details of which cards can react are listed on the individual molecule cards.

Learning Objectives

The game was developed to teach or reinforce secondary school chemistry learning objectives; including basic chemistry vocabulary, the conservation of atoms in chemical reactions, identifying the location of an element on the periodic table from atomic diagrams, predicting common compounds from periodic table location, and predicting the outcome of chemical reactions. A full list of associated Next Generation Science Standard objectives (relevant to secondary school education) and more information on the game can be found at: www.scienceninjas.com.

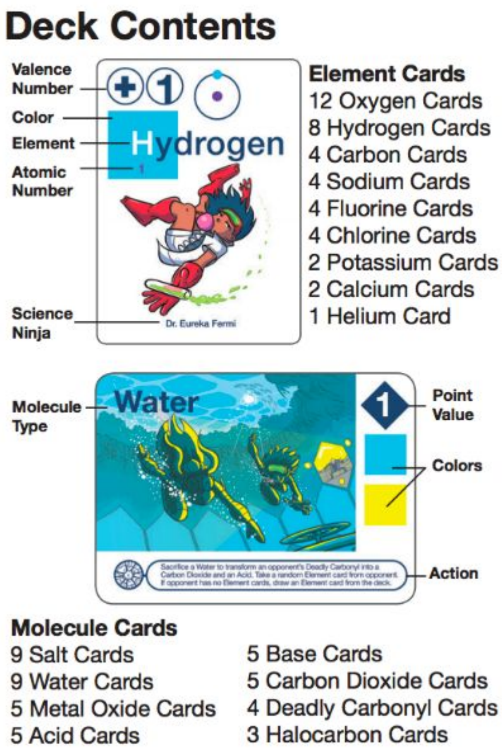

Figure 1: Image from Instruction booklet of Science Ninjas: Valence detailing deck contents, and information located on Element and Molecule cards. Image courtesy of Science Ninjas.

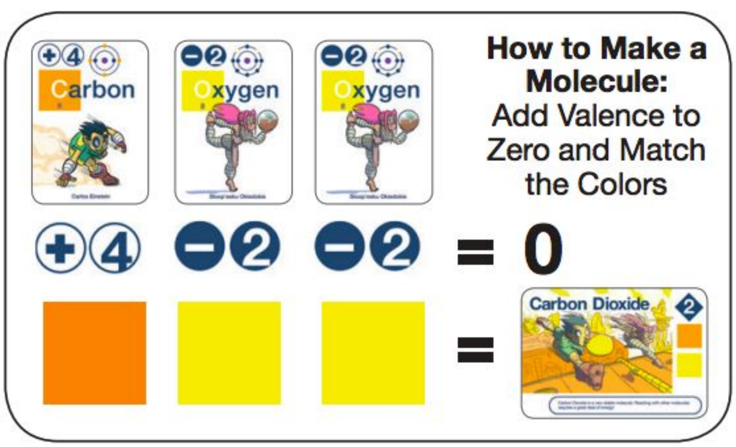

Figure 2: Image from Instruction booklet on how elements cards are combined to form molecule cards, worth points needed to win the game (CO2, pictured, is worth 2 points). Players must match elements cards that add to zero to identify possible molecules, colors are used to identify what type of molecule has been made. Image courtesy of Science Ninjas.

METHODOLOGY

This study used a quasi-experimental design with a focus on 79 undergraduate first semester science majors that had been identified as academically underprepared at a private 4-year institution. Classification as academically underprepared was determined based on the students' math placement scores when entering their first year where Pre-Calculus math placement was determined to be college-ready for science majors. Each student participating in this study was enrolled in College Algebra and General Chemistry 1. This student group was required to dedicate additional time to learning and therefore participated in weekly supplemental instruction sessions in groups of 20 or less students. These sessions were overseen by a Graduate Assistant with the help of undergraduate Teaching Assistants, but materials were developed by a faculty member. During the week, these students were enrolled in varying lectures of General Chemistry 1 with different faculty members at the university.

The game was incorporated as a lesson in one of the hour and fifteen-minute sessions. The game was administered approximately 10 weeks into the semester, when most students had covered atomic structure and bonding, naming, chemical reactions and basic stoichiometry using an atoms-first approach. A week prior to the supplemental instruction session, the Teaching Assistants spent an hour learning and playing the game.

Pre and post surveys were given to assess the learning gains obtained by game play. At the beginning of the class period, students were administered a 12 question, multiple-choice pretest that included basic questions on subatomic particles, chemical reaction products, identification of bonds and acids and bases. The students were then instructed by Teaching Assistants on how to play the game and were separated into groups of 4 and allowed to play for approximately 45 minutes. After play, students were given a post-test, identical to the pre-test, but that included additional questions that gauged their interest in chemistry, asked their self-reported GPA and allowed for open-ended responses to the game. There was no grade incentive associated with the pre-test, post- test or the game. During the course period, students had no exposure to outside chemistry concepts and Teaching Assistants were instructed only to help with gaming instructions. Pre-test and post-test results as well as open-ended responses were anonymous; students assigned themselves a number for the pre-test and identified themselves with the same number when taking the post-test.

RESULTS

To determine if the game contributed to basic chemistry knowledge, pre-test and post-test scores were analyzed and a paired t-test was used to determine if there was a statistically significant difference between the two tests.

Significant increases were seen for student performance on the quiz after playing the game: the average class score increased from a 5.85 out of 12 on the pre-test ($SD = 1.78$) to a 7.37 out of 12 on the post-test ($SD = 2.37$). The t-test for paired samples showed a significant difference between the means, $t(79)=-7.67$, $p<.001$. The effect size as measure by Cohen-d was 0.868, a value corresponding to a large effect on the difference in the tests, indicating the game had a large reliable effect on basic chemistry knowledge when looking at the questions and overall Topics.

Performance on individual questions were also examined to determine if the game contributed to an increased knowledge for specific content. As seen in Table 1, the greatest increases in student understanding of chemical concepts (>10) was seen on questions directly associated with game content, with two of the highest increases focusing on product anticipation in chemical reactions, which we would consider the more difficult of the questions presented to Students.

Table 1: Pre-test and post-test questions and results	Pretest Average Percent Correct	Posttest Average Percent Correct	Difference
The atom is made of 3 subatomic particles. Which particle is most responsible for bonding:	58%	67%	+9
Which of the following is the smallest?	82%	85%	+3
When sodium is bonded to fluorine, what type of bond occurs?	59%	58%	-1
A metal oxide occurs when an oxygen reacts with a metal. These compounds are typically vulnerable to:	25%	58%	+33
How many fluorine's would be required to create a neutral compound with carbon to form a halocarbon?	48%	46%	+8
The reaction of an acid and base should form:	20%	62%	+42
Which of the following is an example of an Acid	13%	39%	+27
The reaction between mustard gas (phosgene) COCl2 and a water molecule H2O should form CO2 and...	76%	67%	-9
Calcium chloride has ratio of ___ Calcium to____ Chloride	52%	63%	+11
Gold is an example of a	82%	81%	-1
Sodium chloride would be considered a(n):	51%	63%	+12
Potassium hydroxide would be considered a(n):	23%	41%	+18

In addition to measuring chemistry knowledge, in the post-quiz students were asked to provide open-ended responses to four questions:

1. What did you like most about the game?
2. How helpful was the game in solidifying your understanding of basic chemistry concepts? And
3. Would you recommend using this game as a teaching tool in future classes?
4. Are their concepts you have learned so far in this class that you think could have been included in the game that were not?

The most common responses to question 1 (*What did you like most about the game?*), was that it was “easy” or “simple” to learn or to play (17% of responses) or that it was “fun” or “engaging” (17% of responses). Students also remarked on the “colors” or “color matching” to create molecules (16%) or on the “art” (11%). One student remarked ““It helped me to see the bonding” and another remarked that it was “good for visual learners.” Several students also enjoyed the aspect of competition noting either “competition” or “attacking” or “attack” in their responses (9%).

For the second of the open-ended response questions (*How helpful was the game in solidifying your understanding of chemistry?*), there were 56 students (71%) that indicated the game was helpful and 54 students (68%) that said they would recommend the game as a future teaching tool in the course. Student enjoyed the simplicity of the game, as well as the design and art on the cards and felt “(i)t was interesting, made you pay attention, and instigated competition”. Students that recommended the game had a higher self-reported average class grade (3.0 on 4.0 scale) compared to students that would not recommend the game (2.7 on 4.0 scale).

A majority of the students did not identify additional concepts that could be added to the game (74%), however, four students recommended adding types of bonding as a learning objective for the game. Identifying types of bonding was a concept included in the quiz, that was not addressed by the game, and that students did not show gains on during the post-quiz (Table 1).

DISCUSSION

The goal of the study was to determine if learning gains could be achieved for undergraduate science majors by playing a game designed to reinforce basic chemistry vocabulary, the conservation of atoms in chemical reactions, identification of elements on the periodic table from atomic diagrams, prediction of common compounds from periodic table location the outcome of common chemical reactions. Based on the statistically significant improvement in student averages on the post-test, it learning gains are possible while playing Science Ninjas: Valence. Student had large gains in testing on topics directly associated with game play and students reported that it helped to solidify their learning. While learning gains were seen in the one period, future studies should be done to determine if these learning gains are retained one to two weeks following game play versus learning gains made through more traditional teaching methods.

AUTHOR INFORMATION

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