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Activity

Radioactivity and U-235: An Educational Card Game to Introduce Nuclear Decay and the Benefits, Risks, and Safe Handling Strategies for Radionuclides

Kirsten E. Martin, Angus J. Koller, and Eszter Boros*

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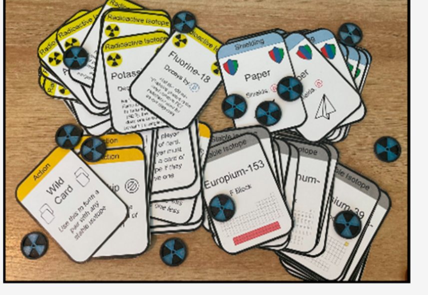
ABSTRACT: Radioactive isotopes are an essential part of everyday life and an expanding area of research in the fields of medicine, catalysis, and energy. Here, we describe an educational activity that introduces the concept of radioactive decay and the corresponding benefits, risks, and safe handling strategies. Specifically, we have developed an interactive card game, *Radioactivity and ^{235}U*, as an activity which can be implemented in a fully remote setting without the need for a trained instructor or specific, previously acquired expertise. The card game consists of 72 playing cards and 50 tokens and contains links to two remotely accessible introductory videos on (1) fundamental concepts of radioactive decay and (2) instructions on gameplay. The goal of this activity is to familiarize students with the concepts of radioactive decay, shielding, and applications of radioactive isotopes. Gameplay incentivizes students to prevent, reduce, or limit exposure to a radioactive dose by collecting and using shielding cards, while also learning facts about radioactive isotopes and their stable congeners. The game was tested with undergraduate college students. Pre- and postactivity questionnaires measured the students' familiarity and opinion on the use and harm of radioactivity. The results indicate that the activity is suitable to introduce basic concepts surrounding radionuclides, radioactive decay, and shielding. We additionally observed a shift in students' opinions of nuclear chemistry and its role in the world from neutral to slightly positive after the workshop.

Radioactivity and ^{235}U



KEYWORDS: *Radioactivity Decay, Radiation, Shielding, Nuclear/Radiochemistry, Card Game*

INTRODUCTION

The decline of radiochemistry research programs in chemistry departments, paired with decreased coverage of nuclear chemistry in undergraduate and graduate coursework in chemistry,[1] have contributed to a shortage in the radiochemistry and nuclear chemistry workforce; these workers are imperative for the fields of nuclear medicine, power, and waste management.[2−4] Outreach and workshop activities by national laboratories and academic institutions to provide this education to students cannot effectively compensate and provide means to disseminate knowledge evenly to a large student body.[5,6] Additionally, safety concerns associated with radioactivity use in the classroom limit the hands-on activities available to convey the concepts of nuclear chemistry to students. Most recently, the COVID-19 pandemic has further limited such outreach activities, precluding student engagement.

The American public is evenly divided regarding whether nuclear energy should be a source of electricity in the United States according to a 2022 survey by Gallup (51% in favor and 47% opposed).[7] However, this opinion is largely based on impressions, as according to a 2022 survey by Bisconti, only 16% of respondents felt well informed about nuclear energy. In this same survey, it was found that of those who felt well informed, 73% favored nuclear energy, and those who felt least informed favored nuclear energy the least.[8] Additionally, the general public perceives radioactivity and radiation risks very differently, depending on the context and applications of radioactivity. Surveys of the public in the United States, Sweden, Canada, and Belgium have shown that nuclear power and waste are viewed as extremely high in risk and low in benefit to society.[9] In a 2004 study of the Belgian population, nuclear waste was considered to be high or very high risk by about two-thirds of sampled persons, while medical radiography was considered to be highly risky by less than 20 percent of participants.[9] This perception often differs significantly from that of risk assessment experts. In all cases, it has been indicated that there is a need for increased education of the public on the basics of radioactivity and nuclear chemistry.

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Educational games to help facilitate student learning have been introduced in many areas of chemistry with a particular focus on general chemistry and organic chemistry. Students' understanding of the material and their motivation to learn have been shown to be enhanced when educational games have been included in the curriculum.[10−15] An educational board game recently developed and evaluated, aimed at teaching students about radioisotopes and their uses, called Isotope Rummy, was found to be very effective at teaching high school students the basic concepts of nuclear chemistry.[16]

Herein, we describe our efforts in developing and testing the educational card game, *Radioactivity and ^{235}U*. As a research group active in the field of radiochemistry, we sought means to improve and inform student populations about our field.

During the COVID-19 pandemic, our group was limited in its ability to conduct in-person outreach and therefore sought ways to introduce engaging content in a remote setting. *Radioactivity and ^{235}U* is highly portable and can be easily dispersed to remote locations or alternatively implemented and adapted by printing of the required playing cards and using coins of any currency as make-shift tokens. The game provides links to remote and freely accessible instructional videos which provide (1) a primer on the scientific basis of radioactive decay and (2) provides a brief demonstration of active gameplay. Together, *Radioactivity and ^{235}U* is intended to communicate key concepts of radioactivity, radioactive decay, and shielding to better educate the general public and students on underrepresented topics in nuclear chemistry. We also posit that a more positive and informed attitude to these concepts can motivate students to consider a career in nuclear and radiochemistry related fields.

■ CONCEPT AND EDUCATIONAL OBJECTIVES

Radioactivity and ^{235}U seeks to explore the following concepts: atomic structure and the origins of radioactive decay, modes of radioactive decay, and methods of shielding necessary for each type, minimizing radioactive dose received, and examples of radioactive isotopes and their many applications. This activity can be used on its own in a workshop setting or as a supplement to classroom lectures. Two short introductory videos are employed to introduce key scientific concepts and provide all information necessary to initiate gameplay ("Introduction to Radioactivity" and "Gameplay", for links see Supporting Information).

The card game then seeks to reinforce these concepts. As students learn about the different types of shielding, they can then use each type of shielding to prevent them from receiving a radioactive dose in the card game.

■ THE GAME

Description of Card Decks and Tokens

The game includes a total of 72 cards and 48 plastic tokens. There are four different types of cards in *Radioactivity and ^{235}U* including stable isotopes, radioactive isotopes, action cards, and shielding (Figure 1, Table 1).

1. Action cards allow players to impact gameplay. "Steal" allows player A to request a card from player B, which is given to player A if such card is in player B's hand—this should motivate players to accumulate cards that protect themselves most effectively against radioactivity. Similarly, "Time" and "Distance" action cards allow players to receive one less dose token when receiving dose from drawing a radioactive isotope card. This reinforces the concept that by decreasing time near a radioisotope and by increasing distance from the source, a lower radioactive dose can be achieved, in accordance with the as low as reasonably achievable (ALARA) rule.
2. Shielding cards are used to decrease or eliminate the radioactive dose one would receive from drawing a radioactive isotope card. Each type of shielding card (lead, plexiglass, and paper) shields a corresponding type of radioactive decay. Paper shields from alpha decay, plexiglass shields from beta decay and lead shields from gamma decay.
3. Stable isotope cards contain the name and location within the periodic table of a given stable isotope, with 8 elements from each block (s, p, d, and f). This is intended to familiarize students with stable isotopes of elements that also have radioactive nuclides of significance. For instance, Carbon-12 is a stable isotope, but radioactive isotopes Carbon-11 and Carbon-14 (part of this deck) are important isotopes for nuclear medicine and dating of archeological remains, respectively.
4. Radioactive isotope cards contain information about a given isotope including its decay mode, half-life, and a fun fact about its use or application in the world. The 15 radioactive isotope cards encompass nuclides with different decay modes (alpha, beta, mixed beta/gamma, and gamma), and from different sections of the periodic table. Applications for these isotopes include diagnostics and therapeutics in nuclear medicine, archeological dating, self-illumination of signage, and diagnostic radioactive fallout from nuclear accidents, among others.
5. Dose tokens are used to indicate when a player receives a radioactive dose. Players may receive a dose after drawing a radioactive isotope card and not supplying the

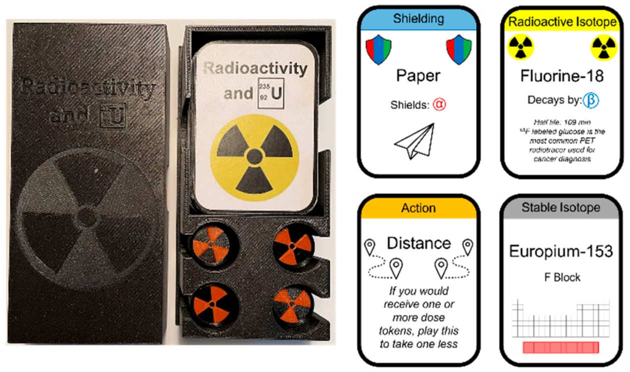

Figure 1. Components of *Radioactivity and ^{235}U* including tokens to keep track of doses received, four types of cards, and a convenient storage container. Examples of each card type are provided.

Table 1. Card Deck Components and Card Types

card	number per deck	iterations
Action card	14	skip (3), steal (3), wild card (3), sneak peek (3), time (1), distance (1)
Shielding	12	paper (6), plexiglass (3), lead (3)
Stable Isotope	32	f-block (8), p-block (8), d-block (8), s-block (8)
Radioactive Isotope	15	alpha (6), beta (5), mixed beta/gamma (3), gamma (1) decay

Table 2. Pre- and Postactivity Questionnaire Summary Results[a]

question	strongly disagree (1)	disagree (2)	neutral (3)	agree (4)	strongly agree (5)	avg ± st dev
1: I am familiar with the concepts of radioactivity, radioisotopes, and shielding.	3/0	10/1	16/6	5/19	1/8	2.7 ± 0.5/ 3.8 ± 0.88
2: I can name an example of a radioisotope.	7/0	7/1	6/7	5/12	10/15	3.0 ± 0.46/ 4.1 ± 0.89
3: I can name three different modes of radioactive decay.	5/0	10/1	1/0	6/8	13/25	3.3 ± 0.69/ 4.4 ± 1.5
4: I can give examples of how radioactivity is used in the world around us.	5/0	7/0	11/8	7/13	5/14	2.9 ± 0.32/ 4.1 ± 0.89
5: I know the types of shielding necessary to shield different types of radioactivity.	12/0	11/2	7/1	4/17	1/15	2.1 ± 0.19/ 4.2 ± 1.1
6: I know how to decrease the dosage received from radioactivity.	14/1	11/0	7/8	1/14	1/11	1.8 ± 0.24/ 3.1 ± 0.64
7: The game was a clear way of understanding the concepts of shielding and learning about different types of radioactivity.	−/0	−/0	−/8	−/12	−/15	4.1 ± 0.90
question	very negative (1)	negative (2)	neutral (3)	positive (4)	very positive (5)	avg ± st dev
8: In your opinion, what type of role do radioactivity and nuclear chemistry play in the world?	0/0	7/1	13/7	10/16	5/9	3.3 ± 0.47/ 3.7 ± 0.77

[a]Results from before activity are denoted first, and results from after the activity are denoted second.

correct or any shielding card. The fully assembled game contains 3D printed tokens in the shape of the radioactive warning symbol, but alternatively coins of any currency can be used. Players want to avoid accumulating these tokens and decrease their dose.

The game additionally contains a 3D printed box to hold the playing cards and tokens. The templates for printing the tokens and game box are provided in the Supporting Information. The playing cards, full game rules, links to instructional videos, and questionnaires used are also provided in the Supporting Information.

Game Rules

The rules of the game are described below, and a gameplay video is linked within the Supporting Information to illustrate how the game should be played.

- The objective of *Radioactivity and* ^{235}U is to be the last remaining scientist that has not received 7 or more radioactive doses. The game can be played with 3−7 players.
- The action and stable isotope cards are shuffled together. Each player is given 5 of these cards and 1 shielding card at random to start the game. The remaining shielding and stable isotope cards are then shuffled with the radioactive isotope cards and placed in the center of the playing surface.
- On each turn, a player may play a pair of stable isotopes from the same block of the periodic table to steal a card at random from another player, play an action card, or play nothing.
- To end each turn, a player draws a card from the deck.
- If the player draws a radioactive isotope card, they must either play a shielding, time, or distance action card that will shield or decrease part or all the radioactive dose or obtain the corresponding amount of dose tokens. The number of dose tokens a player must take for each type of unshielded radioactive decay is relative to the severity of the dose each decay mode can cause.
- Play then continues until all players except one have received 7 or more doses and the remaining player is deemed the winner. A player who has received 7 or more doses is considered to have reached their ALARA limit, and thus can no longer “work with radiation” for a time.

By the end of the game, players will have improved their understanding of the types of shielding required for different types of radioactivity and methods of decreasing the dosage received. Stable isotope cards will further familiarize students with nonradioactive nuclides. Radioactive isotope cards will introduce students to fun facts and applications of radioisotopes in everyday life.

RESULTS AND DISCUSSION

This workshop was evaluated with a group of first year graduate and undergraduate chemistry students (35 total students). Consent forms and questionnaires were provided in accordance with IRB 2023−00189 approved by Stony Brook University. Students were shown the introduction to radioactivity video and the gameplay video and then allowed to break into groups of 6−7 to play the card game. In the pre- and postquestionnaire, questions to assess the students' familiarity with radioactive decay and shielding as well as their opinion on the roles radioactivity and nuclear chemistry play in the world were posed. For each question, students were asked to rank on a scale from 1 (*strongly disagree*) to 5 (*strongly agree*), with the exception of Q8 (“In your opinion, what type of roles do radioactivity and nuclear chemistry play in the world?”) which was ranked from 1 (*very negative*) to 5 (*very positive*) (Table 2). In questions intended to assess students' knowledge base, the responses to questions and the resulting shifts in answers from the pre- to postassessment fell into three distinct categories. Q1 and Q4 were questions aimed at assessing the general knowledge base of the students surveyed. Q5 and Q6 demonstrated the most significant increase in student knowledge. These questions assessed more specialized knowledge including the shielding necessary for various types of radioactivity and other methods to decrease the dosage received. Students generally felt that the game was a clear way to understand the concepts of shielding and learning about different types of radioactivity (Q7: 4.20 ± 0.79), and overall feedback was positive, including many students leaving comments that the game was fun and well put together. Future questionnaires will explicitly ask students to rate their

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enjoyment of the game as well as its ruleset to further provide feedback on the development of the exercise.

Q2 and Q3 produced pre- and postresponses that did not contain a clear distribution. This is a result of the ambiguous phrasing of the questions rather than indicative of the student knowledge base. These questions should be modified for future workshops either to provide a binary (yes/no) answer choice or to provide ranges (i.e., "I can name 0, 1−2, or 3−5 isotopes") or other more readily quantifiable responses.

■ CONCLUSIONS

We developed an educational card game, *Radioactivity and ^{235}U*, which aims to provide a safe and enjoyable manner for students to learn about radioactivity, decay, and shielding. The game and educational videos are designed as highly portable and can be easily disseminated to students across the globe. The evaluation of the game within the course workshop indicated a shift in perception toward a more positive opinion of radioactivity and nuclear chemistry can be achieved. Given the shortage in the radiochemistry and nuclear chemistry workforce facing much of the world, it is imperative that students receive adequate education about nuclear chemistry and radioactivity and their interest is fostered. Ultimately, as a radiochemistry group, we aim for a better-informed public with a more positive attitude toward radioactive isotopes and the scientific discoveries and advances they enable.

Feedback from students demonstrates that *Radioactivity and ^{235}U* is a fun and effective tool to increase the base and more specialized knowledge of undergraduate students. This activity additionally aligns with New York State specific learning objectives in Science Curricula (Standard 4, Key Ideas 3−5)[17] for high school students, and evaluation by high school students is ongoing.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.3c00478.

Game cards (PDF) (DOCX)

Game rules, evaluations used with students, survey results, links to "Introduction to Radioactivity" and "Gameplay" videos (PDF) (DOCX)

3D printing files for tokens and game box (ZIP)

■ AUTHOR INFORMATION

Corresponding Author

Eszter Boros − *Department of Chemistry, Stony Brook University, Stony Brook, New York 11794, United States;* orcid.org/0000-0002-4186-6586; Email: eboros@wisc.edu

Authors

Kirsten E. Martin − *Department of Chemistry, Stony Brook University, Stony Brook, New York 11794, United States*

Angus J. Koller − *Department of Chemistry, Stony Brook University, Stony Brook, New York 11794, United States*

Complete contact information is available at: https://pubs.acs.org/10.1021/acs.jchemed.3c00478

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Notes

The authors declare no competing financial interest.

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