

GAME ON! Addressing the Nuclear Skills Shortage Through an Interactive Radioactivity Card Game for School Pupils – 24307

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ABSTRACT

The global challenge of addressing the current and future nuclear skills shortage necessitates comprehensive investment in multifaceted training pathways, spanning apprenticeships, undergraduate programs, and doctoral training. Therefore, collaboration between educational institutions, industrial sectors, and schools is vital to galvanize student interest and nurture future talent pipelines. Our work has assessed the efficacy of gamification as an educational instrument through an interactive card game (RAD Ratings), a curriculum-enriching activity that can be employed by teachers and industrial STEM ambassadors for engaging 13 to 18-year-old school students in nuclear science.

INTRODUCTION

Many areas within the nuclear sector including new build, decommissioning, healthcare, and radiopharmaceuticals will require workforce expansion over the next two decades. As such, addressing the current and future shortage of nuclear skills requires a multifaceted approach, encompassing apprenticeships, undergraduate programs, and doctoral training [1]. Collaboration between schools, academic institutions, and industry is essential to engage students at a young age and foster an interest in these career pathways [2],[3].

This project addresses the limited exposure to nuclear science in the UK curriculum, as well as the need for increased school engagement. Nuclear science holds diverse applications in sustainable energy, nuclear waste management, decommissioning, and environmental remediation, making it a topic of significant importance in both the present and future. While nuclear science plays a crucial role, it receives relatively limited curriculum time and could benefit from more dedicated outreach initiatives. Additionally, there is room for improvement in emphasizing its real-world applications and potential career prospects to students [3,4]. Negative public perceptions, stemming from incidents like Fukushima and dramatized media portrayals, have perpetuated misconceptions about the safety of nuclear power and waste management, further hindering recruitment and innovation in the sector [5].

To combat this, the ‘RAD Ratings’ card game was developed (Figure 1) to attract and retain students interested in nuclear science, establishing a robust education-to-career pipeline. Through funding received from the TRANSCEND Consortium (TRANSformative SCience and Engineering for Nuclear Decommissioning), the RSC (Royal Society of Chemistry) and NNUF-EXACT (National Nuclear Users Facility – nEXt generation Accelerated Characterisation Technologies), > 400 card packs, complete with lesson plans and supporting classroom materials, have been distributed nationally to schools and industry-linked STEM Ambassadors – reaching over 1,000 students in the first year. For STEM Ambassadors conducting in-person visits, pre-prepared card games have streamlined preparation and reduced barriers to previous school engagement.



Figure 1. Example classroom set of RAD Ratings.

This paper will detail the development, distribution, and reception of the interactive card game. By reinforcing key concepts of radioactivity and radiochemistry in the curriculum, RAD Ratings highlights the role of radioactivity in everyday life, potential career paths, and fosters general interest in nuclear science. This effort aims to sustain critical skills in the long term and enhance workforce diversity. Additionally, the success of digitising RAD Ratings will be discussed.

METHODS

Gamification has previously been assessed as an effective outreach tool for increasing student understanding of nuclear chemistry [4]. Additionally, educational card games have been successfully developed and utilized in classroom settings to enhance and supplement topics covering chemical elements and the periodic table [6]–[8]. To assess the effectiveness of gamification in engaging Key Stage 4 (KS4 –

ages 14 to 16) students with the subjects of radioactivity and radiochemistry, we developed an interactive card game and accompanying PowerPoint presentation for use in a school lesson or an extra-curricular STEM activity. The goal was to augment and reinforce key concepts in the KS4 syllabus while emphasising the practical applications of radioactivity in everyday life, potential career paths, and general interest in nuclear science. Evaluating the impact of the project involved collecting feedback from teachers, administering questionnaires to students, and conducting classroom observations.

Game Description and Educational Objectives:

RAD Ratings is a multiplayer interactive card game, collaboratively developed by researchers at the University of Southampton, Royal Society of Chemistry, and TRANSCEND Consortium. Tailored as a supplementary teaching tool for students aged 13 and above, the game comprises 30 distinct radionuclide cards that illustrate wide-ranging applications within the nuclear industry. Each card covers a radionuclide's proton and neutron number, half-life, cost (relative to other isotopes), "danger" rating, radioactive decay emission, occurrence, uses and potential environmental impact (Figure 2). Each RAD Ratings pack can be used to play 2 games, designed to accommodate a diverse range of ages and learning abilities. Each card also included a short description with some example uses for each radionuclide.

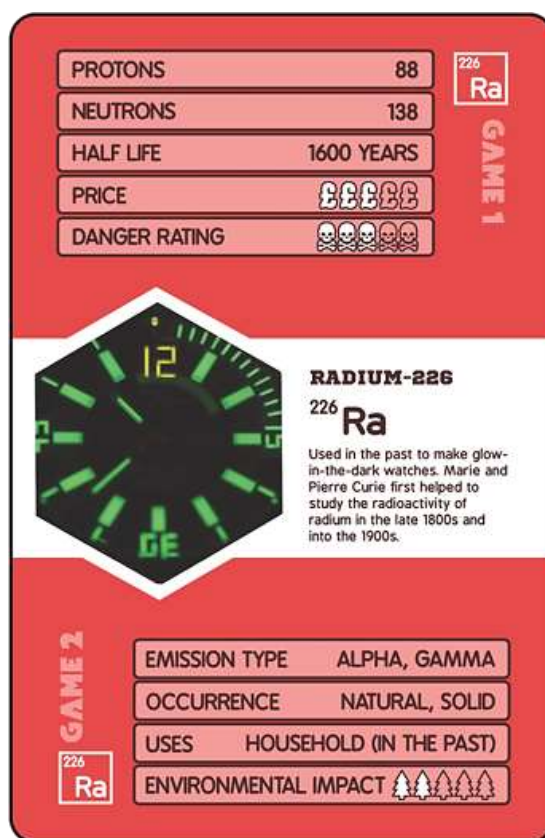


Figure 2. Example radionuclide card (radium-226).

Game 1 adopts a top-trump style format, allowing students to compete against each other using factors including cost, half-life, proton/neutron numbers, and environmental impact relevant to the nuclear industry. This game can be completed in under 20 minutes depending on group size, making it suitable for

both introducing the fundamental concepts of radioactivity to younger students and acting as a warm-up activity before starting the second game with older students.

Game 2 aims to raise awareness about the practical applications of radioactivity and nuclear science in daily life. Discussion points were crafted to encourage open-ended conversations, such as "Which isotope would you use to power a satellite and why?" (Figure 3). While Game 2 is primarily discussion-based, the content has been adapted into a teacher-led quiz-style game, incorporating PowerPoint slides to facilitate whole-class participation and guided discussion (Figure 4).

Game Rules:

Game 1 requires 2 to 5 players. First, the radionuclide cards are shuffled and dealt face down equally between all players, with everyone examining only the top card in their pile. Player 1 selects a category on the card and announces their chosen rating. Other players then call out the same category rating on their card. The player with the highest rating wins all the top cards used in that round, adding them to the back of their hand. In the case of ties, cards are placed in a separate pile and the winner of the next round also adds these to their hand. The winner of each round selects the stat for the subsequent round. The first player to collect all the cards emerges as the winner.

Game 2 is best suited for 3 to 6 players. Each player collects 3 radionuclide cards from the central pile but doesn't look at them until player 1 has also chosen a scenario card. Once the scenario has been selected and read aloud, each player looks at their own radionuclide cards and picks the most suitable isotope for the job. This is done by considering environmental impact, emission type, occurrence, danger rating, cost, and half life. Each player then takes turns to justify why their radionuclide is the best for the scenario. The group then votes on the most suitable card, and the winning one goes into that player's victory deck. The player with the most cards in their victory deck at the end of the game is declared the winner.

The image shows two presentation slides side-by-side. The left slide is white with a black border and features the University of Southampton logo at the top. It is titled "THE SCIENCE OF RAD RATINGS GAME 2" and contains a paragraph of introductory text and an 8-step numbered list of game rules. The right slide has a pink background and a white rounded rectangle containing the text "NUCLEAR POWER QUESTION" in bold, followed by a paragraph about Advanced Gas-cooled Reactors (AGRs) and a question: "Which is the best radionuclide to use as a fuel for an AGR and why?"

THE SCIENCE OF RAD RATINGS
GAME 2

Game 2 is best played with 3 to 6 students. Win the game by presenting the best radionuclide for the job! You need to consider environmental impact, emission type, occurrence, danger rating and price to justify your choice. You can also incorporate the stats from game 1 into your answer! You might be surprised to see what you can use the radionuclides for!

1. Shuffle the radionuclide cards and place the deck face down. Each player takes 3 cards but doesn't look at them yet.
2. Player 1 chooses a scenario card and reads it aloud.
3. Everyone looks at their own isotope cards and picks the radionuclide that they think is best suited for the job.
4. Each player presents their chosen card to the group and explains why they think it is the most appropriate radionuclide.
5. The group votes on which card they think is best for the scenario - you cannot vote for yourself!
6. The card with the most votes gets put in that player's victory deck and all other cards are shuffled and returned to the bottom of the main deck. If there is a tie, both cards are put in their respective players' victory decks.
7. Player 2 picks the scenario for round 2, and so on.
8. The first player to have 4 cards in their victory deck wins!

NUCLEAR POWER QUESTION

Advanced Gas-cooled Reactors (AGRs) are the second generation of British gas-cooled reactors.

These reactors, like other nuclear technology, use the energy released by splitting atoms of certain elements.

Which is the best radionuclide to use as a fuel for an AGR and why?

Figure 3. Game 2 instruction card and example of scenario card

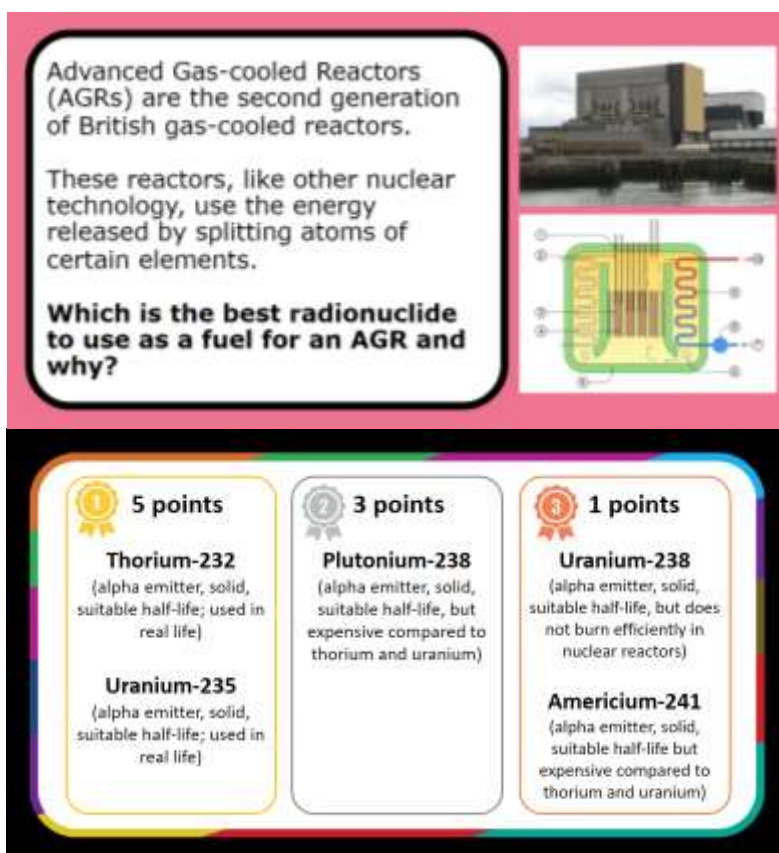


Figure 4. Example of Game 2 scenario PowerPoint question and answer.

Creation of the cards

Conceptualisation and Planning: The initial phase included brainstorming and defining the game's purpose, objectives, and educational goals. Multiple GCSE and A-level exam-board syllabi were examined to identify the extent of radioactivity and radiochemistry taught at schools, as well as the ages at which students encounter the material. This analysis guided the development process to ensure the game effectively supplemented the existing curriculum, with a specific focus on engaging KS4 (age 14-16) students.

Educational Content Design: With the educational objectives in mind, the game's primary content was designed. This involved the creation of 30 unique radionuclide cards to demonstrate the wide array of applications within nuclear and various STEM industries, as well as sectors including nuclear medicine. The content covers essential curriculum topics such as physical properties of nuclear structure, half-life, radiation, products of radioactive decay, risk assessment, and applications.

Game Mechanics and Rules: Gameplay mechanics and rules were then developed to ensure the game was both educational and enjoyable. This included determining how players would interact with the cards and other players, establishing win conditions, and structuring progression in the game.

Playtesting and Iteration: To refine the game, the team conducted extensive playtesting sessions. This involved observing how players interacted with the game, identifying any potential issues or areas for improvement, and gathering feedback from participants. This iterative process was crucial in fine-tuning the game's mechanics and ensuring its effectiveness as a fun and educational tool.

Integration with Educational Objectives: The game was designed to align and complement educational objectives of the KS4 curricula. It aimed to reinforce key concepts in radioactivity and radiochemistry while emphasising the practical applications of these subjects in real-world scenarios to highlight potential career paths.

Collaborative Partnerships: The development process benefitted from collaborative partnerships with the teachers, outreach and engagement specialists, accessibility practitioners as well as the Royal Society of Chemistry, the TRANSCEND Consortium. These partnerships provided additional expertise, resources, and perspectives throughout the project, contributing to the game's overall quality, accessibility, and effectiveness.

Creation of Supporting Materials: In addition to the physical cards, supporting materials such as a PowerPoint presentation to enhance the educational experience were developed in conjunction with teacher feedback. These materials were designed to complement and reinforce the lessons taught through gameplay.

Overall, the development of the RAD Ratings card game was a comprehensive and collaborative effort, leveraging the expertise and resources of the University of Southampton, along with its partners, to create an engaging and educational tool for teaching radioactivity and radiochemistry to KS4 students. Through careful planning, iterative design, and alignment with educational objectives, the team successfully produced a valuable resource for both teachers and students.

TEACHER AND STUDENT FEEDBACK

Surveys

RAD Ratings was played in schools located in both rural and urban areas across England. Anonymous feedback was then collected through Microsoft Forms from students and teachers that had participated in the activity to determine the success of the game. Pre- and post-activity surveys for students were created to assess the level of enjoyment and establish the extent to which they found the activity beneficial in comprehending the concepts of radioactivity. Further, the surveys aimed to gauge the understanding of how radioactivity is employed in various applications and whether it stimulated student interest in learning more about their diverse uses. Teacher surveys obtained a general overview of how a group engaged and benefitted from the game.

In total, 98 students aged 14-16, across 4 schools, provided feedback (Figure 5). Most students reported they had heard of the term radioactivity prior to playing RAD Ratings but the game served to strengthen the positive majority by a further 20.3 % (60.2 % agreed or strongly agreed before playing; 80.5 % after playing).

Teacher feedback (Figure 6) on whether they felt students had heard of the term radioactivity supported these findings, with a decrease of 28.6 % in negative majority (42.9 % disagreed or strongly disagreed before playing; 14.3 % after playing), increased neutrality of 28.6 %, and strong agreement remained constant at 42.9 %. This demonstrates that students may have a positive bias of their understanding of radioactivity.

Through playing RAD Ratings, the proportion of students that reported they understood how radioactivity could be used for different applications increased by 20.5 % (41.1 % agree or strongly agree before playing; 61.6 % after playing). Whilst this improvement was not tested by a diagnostic quiz, teacher feedback corroborated an improved student understanding; the initial 28.6 % proportion that selected 'agree' before engaging with RAD Ratings selected 'strongly agree' after playing (0 % strongly agreed before playing; 28.6 % after playing) whilst strong disagreement was eliminated (28.6 % before playing; 0 % after playing).

Student interest in learning about radioactivity and its uses improved after playing RAD Ratings, with strong agreement improving by 5.4 % (9.1 % before playing; 14.5 % after playing) and strong disagreement decreasing by 2.6 % (15.9 % before playing; 13.3 % after playing). This was also reflected in teacher feedback where the positive majority improved overall by 14.3 % (28.6 % agreed and strongly agreed before playing; 42.9% after playing) and the negative majority decreased by 14.3 % (28.6% disagreed or strongly disagreed before playing; 14.3% after playing).

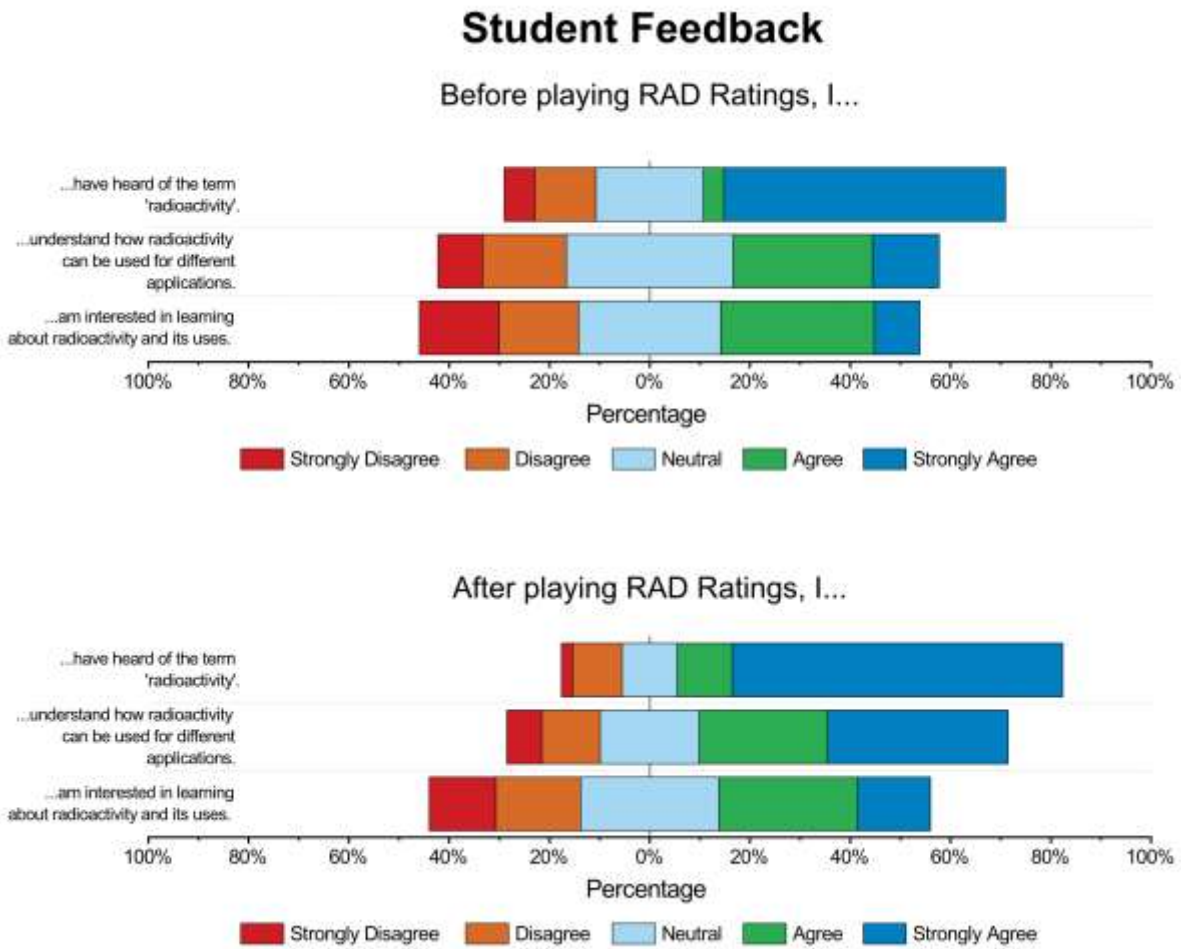


Figure 5. Student feedback before and after playing RAD Ratings.

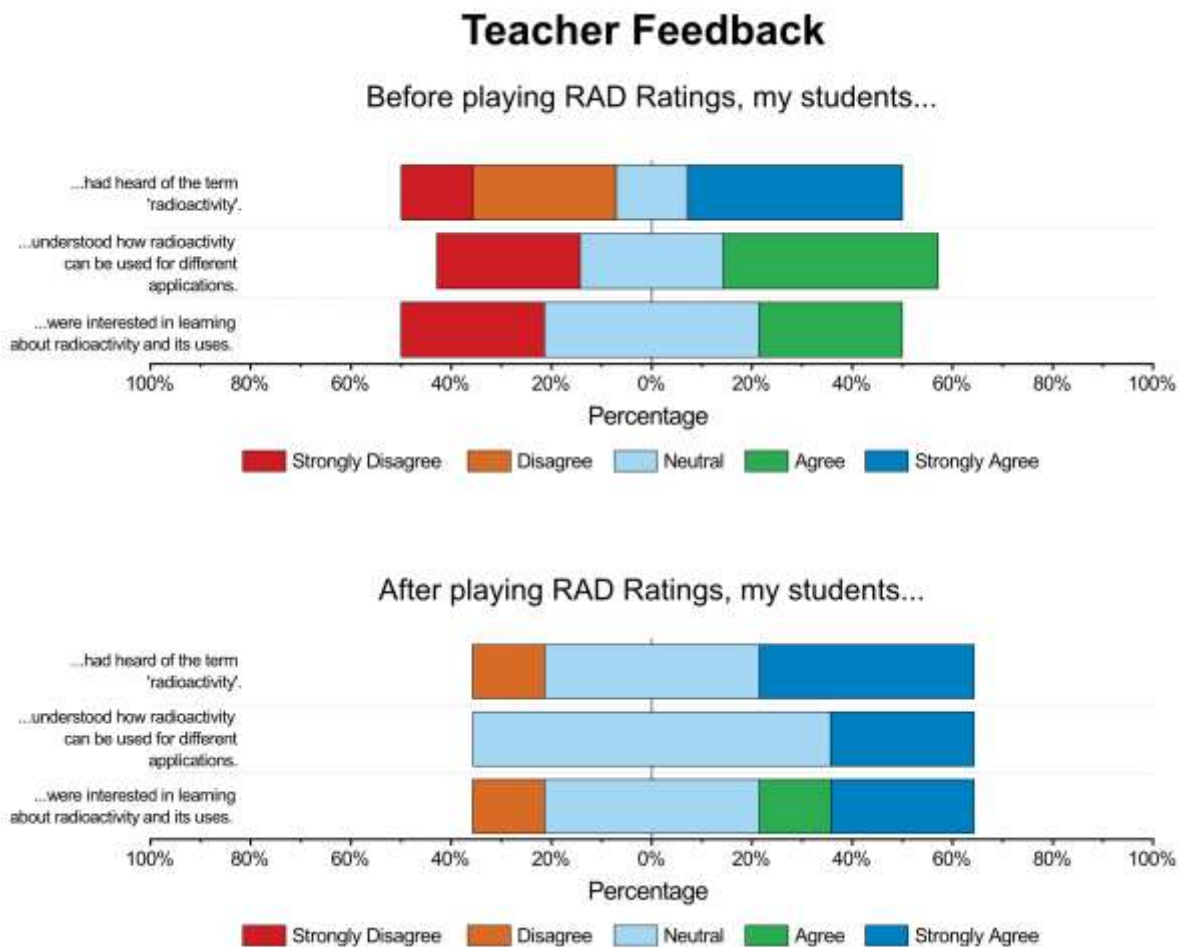


Figure 6. Teacher feedback before and after playing RAD Ratings.

Classroom observations and post-activity interviews

After completing a session of RAD Ratings, interviews with teachers and groups of students were conducted to further understand the strengths and limitations of the game. The results from these, as well as from observations made throughout the sessions, are summarised below:

Increased interest in radioactivity: Student feedback clearly indicated heightened enthusiasm for learning about radioactivity and its practical applications after participating in RAD Ratings. This positive shift in interest was further confirmed by teachers, demonstrating the game's capacity to capture and sustain student engagement.

Easy implementation of Game 1: The simplicity and effectiveness of Game 1 made it a valuable addition to the classroom setting. Teachers noted that it supported and integrated with both KS3 and KS4 curricula, supporting existing lesson plans and providing educators with a practical tool to reinforce key concepts related to radioactivity.

Game 1's suitability for novices: Game 1, characterised by its simplicity, proved to be well-suited for students with limited prior knowledge of radioactivity. However, it was noted that this format had limitations in terms of expanding on critical curriculum concepts, as it primarily focused on surface-level comparisons.

The incorporation of a PowerPoint presentation for Game 2: following teacher feedback that “Game 2 should be teacher led” a PowerPoint presentation was developed to accompany Game 2, transforming it into a whole-class activity and fostering heightened student engagement. This collaborative format allowed for the rapid identification and addressing of areas where students lacked understanding or knowledge. Furthermore, teachers were able to embed cross-curricular learning and revision, noting that direct parallels with additional science subjects were achievable. Despite the increased complexity, classroom observations and teacher feedback consistently highlighted that Game 2 was significantly more engaging and beneficial compared to Game 1. The emphasis on applications and discussions of radioactivity concepts proved to be a valuable tool for reinforcing students' understanding across various science curriculum subjects.

Competitive aspects of PowerPoint presentation: teacher feedback and classroom observations confirmed that the incorporation of a scoring system within the PowerPoint presentation for Game 2 introduced a competitive element that further heightened student engagement. This competitive aspect added an extra layer of motivation, encouraging students to actively participate and strive for improved performance. Additionally, teachers observed and reported that typically difficult to engage students participated well in the PowerPoint version of Game 2.

In summary, RAD Ratings displayed its effectiveness in igniting student interest in radioactivity and radiochemistry. The game's adaptability for both novices and those with a deeper understanding of the topic, in combination with the competitive elements of Game 2, made it a valuable tool for reinforcing curriculum concepts and enhancing classroom engagement. This assessment underscores the game's potential to bolster the educational experience in the context of nuclear science. Student feedback demonstrated increased interest in learning about radioactivity and its uses after playing RAD Ratings. This was supported by teacher feedback.

TEACHER AND STUDENT EXPERIENCE

To assess the reception of RAD Ratings from students the post-activity survey included questions (Figure 7) asking whether they whether they enjoyed playing RAD Ratings (64.4 % agreed or strongly agreed), whether they understood the instructions for playing the game (59.4 % agreed or strongly agreed) and would want to play the game again (58.4 % positive majority).

Teacher experiences and perspectives of RAD Ratings were evaluated in post-activity interviews and surveys which included asking whether RAD Ratings was easy to implement in the classroom (83.3 % agreed or strongly agreed), whether they thought that RAD Ratings improved the student's interest in the topic (100% agreed or strongly agreed) and whether they understood the instruction for playing the game (83.4% agreed or strongly agreed). To address comments in post-activity interviews which included clearer visual instructions for both Game 1 and Game 2, the PowerPoint presentation with sequential instructions and information diagrams was created and distributed to all recipients of RAD Ratings.

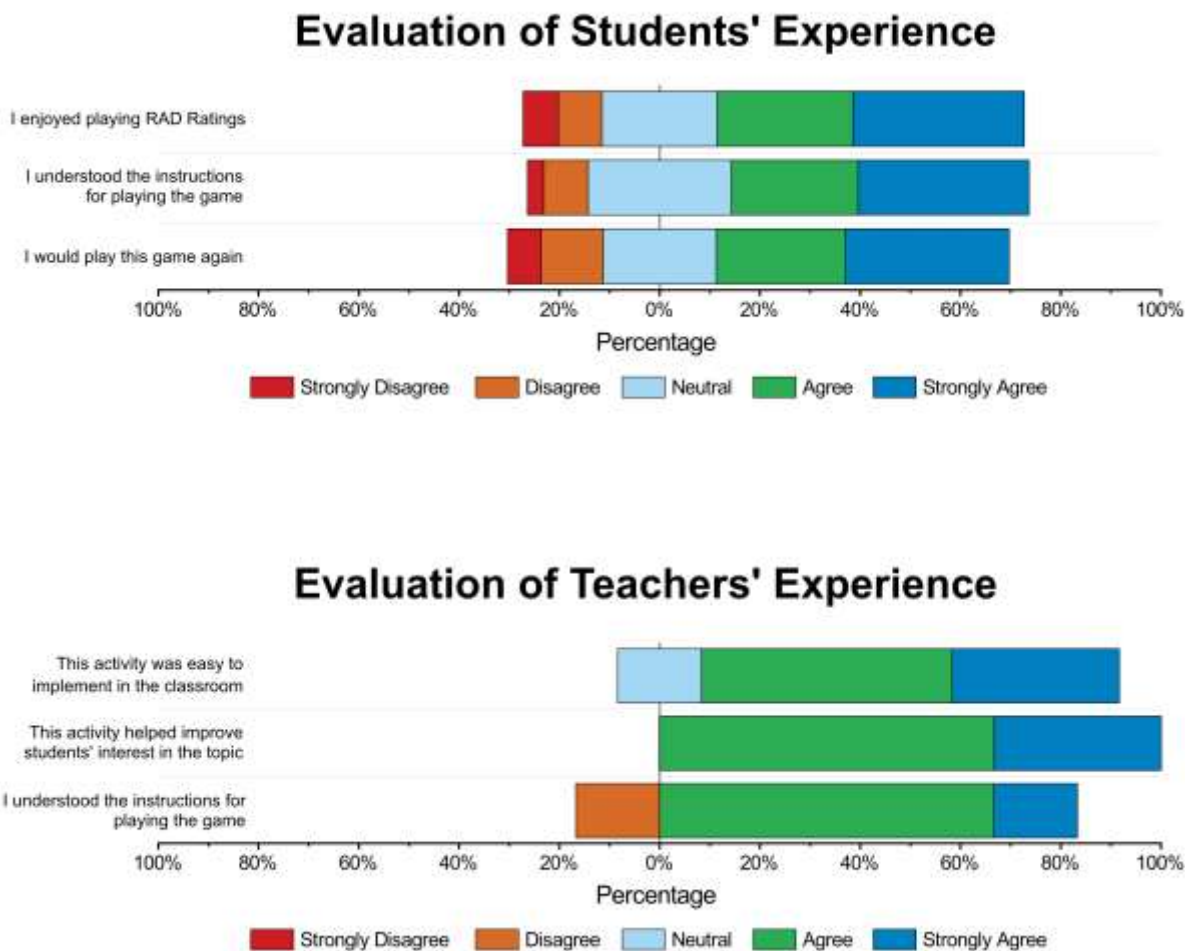


Figure 7. Evaluation of student and teacher experiences after playing RAD Ratings.

GAME DISTRIBUTION

Upon completion of the pilot stage, RAD Ratings was made available to request without cost for schools, universities, and industrial STEM ambassadors. The distribution between these groups is shown in Table 1. This was achieved by a Microsoft form where the requestor would enter the sector that best described their workplace. The popularity of RAD Ratings and feedback from STEM organisers involved in school engagement activities highlights the significant positive impact of utilising pre-prepared card games. Specifically, it was noted that this approach substantially streamlined the preparation process, resulting in a notable reduction in time commitments for engagements. Moreover, feedback highlighted that pre-prepared materials effectively lowered participation barriers, allowing for more engagement interactions with schools. This observation highlights the practical advantages of incorporating gamified educational tools in outreach initiatives, ultimately enhancing the effectiveness and efficiency of these valuable educational endeavors.

Workplace/Sector	Cards Distributed
Universities/ Academia	16%
Government/ Public Sector	8%
Private Sector	26%
Schools	50%

Table 1. Percentage of cards distributed to different sectors.

FURTHER WORK AND DIGITISATION

The future of RAD Ratings holds exciting possibilities for expansion and accessibility. One avenue of exploration involves the digitisation of the card game to enable broader distribution and easier integration into various educational settings. By creating a digital version, we can leverage technology to reach an even wider audience of students, educators, and STEM Ambassadors. Furthermore, ongoing collaboration with educational institutions, industry partners, and outreach programs will be essential in ensuring its continued alignment with evolving curriculum standards. This collaborative effort will play a crucial role in maximising the educational impact of RAD Ratings and solidifying its place as a valuable resource in the realm of nuclear science education.

CONCLUSIONS

We have developed the card game RAD Ratings, which has been distributed to 13 schools across England and reached over 400 students in the first year. Additionally, the provision of 160 packs to industry-linked STEM Ambassadors in both public and private sectors underline the broader reach and potential for impact beyond the classroom. Student feedback reveals enhanced interest in radioactivity and its applications following participation in RAD Ratings, corroborated by positive teacher feedback and classroom observations. Teacher comments emphasise the ease of implementation and the activity's effectiveness as a learning resource. The overwhelmingly positive feedback from both students and educators serves as a testament to the value and impact of this educational resource.

A key observation has been the enhanced effectiveness of Game 2, particularly when teacher led. This strategic approach not only facilitates better comprehension among students but also offers a structured framework for testing and improving their understanding of radioactivity and radionuclides, and how these concepts are applied in everyday life. Furthermore, the streamlined preparation process for STEM ambassadors, facilitated using pre-prepared card games, highlights the practical benefits of gamified educational tools in outreach initiatives. This not only saves time but also lowers participation barriers, ensuring a smoother and more engaging experience for both Ambassadors and students. Ultimately, RAD Ratings stands as a testament to the potential of innovative and interactive educational tools in shaping the next generation of scientific minds.

REFERENCES

- [1] “The skills gap for long term nuclear future.” Accessed: Nov. 08, 2023. Available: <https://blog.policy.manchester.ac.uk/posts/2022/07/the-skills-gap-for-long-term-nuclear-future/>
- [2] “The nuclear renaissance: Taking on the skills shortage and net zero | New Civil Engineer.” Accessed: Nov. 08, 2023. Available: <https://www.newcivilengineer.com/latest/the-nuclear-renaissance-taking-on-the-skills-shortage-and-net-zero-25-11-2021/>
- [3] Chris Hutson, James Barker, Robbie Mackenzie, Sebastian Oakes, Jarred Minards, Antonios, Banos, Sam White, Dimitris Samaras, Erin Holland, Sarah Lu Jacob Moorman, Grace, Sercombe Olivia Douglas, Hannah McCombs, Phoebe Lynch, Marianne Morris, K. Hutson, and Deanna Gillespie****, Iona Murdock, Calum Cunningham, Elen William, “I’m a Nuclear Scientist! Online Stem Enrichment Inspiring the Next Generation of Nuclear Advocates,” in *I’m a Nuclear Scientist! Online Stem Enrichment Inspiring the Next Generation of Nuclear Advocates*, Phoenix, Arizona, USA, Mar. 2022. Accessed: Nov. 08, 2023. Available: https://s3.amazonaws.com/amz.xcdsystem.com/A464D2CF-E476-F46B-841E415B85C431CC_abstract_File754/FinalPaper_22245_0228110757.pdf
- [4] S. C. Marker, C. C. Konkankit, M. C. Walsh, D. R. I. Lorey, and J. J. Wilson, “Radioactive World: An Outreach Activity for Nuclear Chemistry,” *J. Chem. Educ.*, vol. 96, no. 10, pp. 2238–2246, Oct. 2019, doi: 10.1021/acs.jchemed.9b00242.
- [5] “Public Perceptions: Nuclear Power,” Institution of Mechanical Engineers, Mar. 2020. Accessed: Jan. 15, 2023. Available: <https://www.imeche.org/policy-and-press/reports/detail/public-perceptions-nuclear-power>
- [6] A. J. Franco Mariscal, J. M. Oliva Martínez, and S. Bernal Márquez, “An Educational Card Game for Learning Families of Chemical Elements,” *J. Chem. Educ.*, vol. 89, no. 8, pp. 1044–1046, Jul. 2012, doi: 10.1021/ed200542x.
- [7] V. Martí-Centelles and J. Rubio-Magnieto, “‘ChemMend’: A Card Game to Introduce and Explore the Periodic Table While Engaging Students’ Interest,” *Journal of Chemical Education*, vol. 91, no. 6, pp. 868–871, Jun. 2014, doi: 10.1021/ed300733w.
- [8] E. Bayir, “Developing and Playing Chemistry Games To Learn about Elements, Compounds, and the Periodic Table: Elemental Periodica, Compoundica, and Groupica,” *J. Chem. Educ.*, vol. 91, no. 4, pp. 531–535, Apr. 2014, doi: 10.1021/ed4002249.

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