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Diamond: The Game – a board game for secondary school students promoting scientific careers and experiences

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Abstract

Diamond: The Game is a board game designed for secondary school students (aged 11–18) to enable them to explore a broad variety of science, technology, engineering and mathematics (STEM) careers, STEM subjects and life as a scientist. Board games are a reusable and entertaining way to directly engage students in STEM, but careful consideration of mechanics, messages and accessibility is required to successfully deliver on this goal. Diamond: The Game was designed and evaluated against these considerations. The inclusive approach to design resulted in a better and more accessible game for all. Its success is further evident in the rise in the number of players who would consider a career as a scientist or an engineer after playing. The opportunities to explore collaboration, failure and

the interdisciplinary nature of science in the game were particularly highlighted in discussions with students, teachers and careers advisers.

Key messages

- Board games can be powerful tools for engaging the public with scientific research. Conveying cutting-edge science through play is not trivial, and the power of games to stimulate independent curiosity and conversation should not be underestimated.

- Challenges, such as pandemics, make public engagement very difficult. However, creativity and a quick response can provide new opportunities and routes for engagement.

- We should talk more about the reality of being a scientist. The game normalises failure as a key process in science, but this was unexpected for the players. Additionally, many players were surprised to find collaboration to be an important element in the game. Teamwork underpins 99 per cent of modern science, so this misunderstanding about the skills involved in scientific careers in these age groups is very concerning.

Introduction

Tabletop games have become increasingly popular as a tool to deliver educational content and experiences over the past decade. Whether they are professionally produced by commercial publishers, or developed and released by academics, it is clear that they represent a unique mode of addressing students and the public about a wide range of technical topics (Gee, 2003; Barab et al., 2012; Whitton, 2012; Lean et al., 2018; Wake and Illingworth, 2019). Board games cast participants as active learners within a positive learning environment, forming new understanding through their actions and interactions with other players and the game system, and allow experimentation and exploration of an educational topic. This is especially important when tackling educational outcomes which deal with changing participants' views of themselves in the world, such as engaging students with the breadth of careers in science, technology, engineering and mathematics (STEM) that are available to them.

Game design as a discipline has advanced greatly in the past decades, especially in tabletop games, and these advances can be applied to educational games. Foundational works, such as *Rules of Play* by Katie Salen and Eric Zimmerman (2003) and *The Art of Game Design* by Jesse Schell (2008), have sought to codify different approaches to game design and the use of the different viewpoints through which to consider a participant's interaction with game systems. These various lenses give educators new tools with which to merge educational content with play experience, where both aspects reinforce and support each other. Games are a unique form of media which directly place participants in the topic presented by the game, and ask them to make decisions based on their observations, experiences and knowledge. Players ultimately determine how they learn, creating their own learning experience through the freedom of play within the defined game structure (Klopfer et al., 2009). Considering games to be just a method of information delivery is therefore to miss their much more powerful ability to create emotions and experiences which lead to reflection, recall and change in their participants. However, they must also naturally support the content they are based upon, in order to generate the best response.

Just as the people behind the games lie on a continuum from commercial to academic, so do the games themselves fall on a different spectrum, from purely pedagogical, with little or no focus on game mechanisms or play experience, to fully realised games that use themes and concepts as window-dressing, rather than seeking to deliver any educational experience. There are pitfalls at either end: the

former approach misses the advantage that a well-designed game has in engaging its audience and placing them into a visceral experience, whereas the latter ignores the rich details of its content matter and fails to communicate any lasting educational message. The options and opportunities within the building blocks of board games are by no means limited (Engelstein and Shalev, 2022). Balancing the content and information density is therefore critical in developing an interesting and effective board game (Treher, 2011). Indeed, other work in this field questions whether games focusing on pedagogical outcomes provide better learning outcomes than those focusing on play experience (Coil et al., 2017).

There are several excellent recent examples of games which balance design and educational content, and which can serve as inspiration for future work. Carbon City Zero, released in 2019, casts players as mayors of modern English cities, tasked with the job of reducing their carbon emissions to net zero (Possible, 2020). Evolution, released in 2014, by Dominic Crapuchettes, Dmitry Knorre and Sergey Machin, has players improving different species to cope with changing environmental conditions and potential predators, exploring an enormous combinatorial space of possible adaptations (NorthStar, 2022). Periodic: A Game of the Elements, 2019, by John J. Coveyou and Paul Salomon, asks players to strategise by directly using the fundamental chemical principles underlying the periodic table to score different element goals (Genius Games, 2017). The astronomy board game developed by Adriana Cardinot and Jessamyn Fairfield has players learning the astronomy topics recently introduced as part of the new Irish Science Syllabus, as well as presenting a diverse range of astronomers (Cardinot and Fairfield, 2019). These games all utilise approaches in game design to use mechanisms which directly evoke and support the educational message they seek to deliver.

There is clearly space for both approaches, but there are currently very few board games which facilitate broader conversations about the type and nature of careers in STEM. Diamond Light Source ('Diamond') is the UK's national synchrotron, funded through the government agency UK Research and Innovation (UKRI), and health sciences charity the Wellcome Trust. The interdisciplinary nature of science at Diamond underpins work on everything from, for example, fragments of Rembrandt's *Homer* (Price et al., 2019) and COVID-19 drug screening (Douangamath et al., 2020), to the degradation of the Tudor warship *Mary Rose* (Aluri et al., 2020), and much more. There is evidence that children can make career-limiting decisions as early as 7 years old (Padwick et al., 2016; Van Tuijl and Van der Molen, 2016). However, this board game was developed in line with the current comprehensive public engagement programme at Diamond, which actively promotes careers in STEM to secondary level students who are able to visit the facility and see their scientific curricula in action. The target for the game was therefore to create an engagement option for schools that are not able to visit the facility.

Our aim was to design a board game to explore the science carried out at Diamond, scientific careers and the experiences of being a scientist. Key points to address in the design process were that the board game could be learnt and played in class, and that inclusive design should be actively considered. The emphasis on scientific careers was particularly important, following discussions with careers advisers, who were interested in the opportunity to explore a breadth of scientific careers, in line with the Gatsby Good Career Guidance benchmarks (Holman, 2013). The report by Holman (2013) also highlighted the value of empowering students to imagine themselves as scientists by sharing the many ways in which one can be a scientist. This is difficult to achieve via a narrow understanding of potential careers, which will naturally result in a limited uptake of science subjects in secondary school. In turn, this will further reduce science capital – a conceptual tool to measure an individual's exposure and knowledge of science – for future generations (Archer et al., 2013, 2020). One method to address this is by linking curriculum and classroom learning directly to real-life careers and applications of science, which has been shown to increase student engagement and attainment (Woolley et al., 2013). An additional problem is that the perception of (the lack of) scientific success, failure and collaboration contributes towards the belief that science is for the elite few (Zaringhalam, 2016; Dreyfuss, 2019; Parkes, 2019). By introducing students to these concepts early, we hoped to destigmatise failure and collaboration, which are both essential elements of every scientist's career.

Methods

The initial stages involved brainstorming which ideas and aspects of being a scientist and working on experiments at Diamond were to be included. These included: the collaborative nature of experimental work at a large facility, involving staff and the more than three thousand academic and industrial scientists who use the facility annually; the uncertainty and pressure of performing complex experiments with a set time limit, which can suffer any number of setbacks both within and outside the control of users; the wide range of experiments that can be performed at Diamond across a plethora of different scientific and humanities disciplines; and the process surrounding applying for, and successfully receiving, experimental time at one of Diamond's 34 laboratories, known as 'beamlines'.

Initial prototypes were designed in Adobe Illustrator, and then assembled with paper and cardstock. A rough version of the game was ideal for initial playtests among the design team, to assess basic mechanisms, so that more graphically developed prototypes could be forgone in order to enable rapid playtesting and redesign iteration cycles. This 'fail faster' approach has been widely adopted in tabletop game design, and it is a good approach for newer designers making educational games, to ensure that ideas are not stuck at the prototype stage. Four subsequent iterations of the game were then playtested with over fifty individuals to acquire feedback on the game mechanics and design, including specific playtesting to check if the game was compatible for players who have colour vision deficiency and/or had sight impairments. Further to this, to test that the design and content were fit for purpose, an early version of the game (after ironing out initial issues) was playtested with three classes of thirty secondary school students and their teachers, where one of the schools was for deaf and hard of hearing students. This feedback was critical to incorporate at the start of the design process, to ensure that our game was accessible, appropriate and relevant to our target audience. All of the input from the playtesters and the schools was collated and filtered to factor in that some of our playtesters were scientists and/or experienced gamers (which would affect their expectations of the game), to optimise game design and content.

It was clear that having players taking the roles of scientists themselves necessitated a game based at Diamond, with players moving from beamline to beamline to perform experiments. The final design of the board, created by a graphic designer, is therefore based on the engineering floor plan at Diamond (Figure 1), where the zones around the synchrotron ring, like the colours around the board,

Figure 1. Diamond: The Game board (left), and an aerial image of the facility (right) (Source: Authors, 2022; left: Diamond Light Source, 2021)

are coloured to reflect the electromagnetic spectrum of visible light. The six core science fields were selected (science icons in Figure 2), in combination with the 12 scientists, to try to cover the broadest range of scientific careers, and the work being carried out at Diamond. This was further reinforced using a simple goal-based system where players are assigned specific projects, chosen from actual experiments previously performed at Diamond, which require a set number of experimental successes representing work in specific scientific fields. These successes come from different beamlines, which highlights the interdisciplinary nature of science, requiring players to move around the board to collect the necessary successes for their given project. When a player completes all the requirements for a project, they gain a set amount of fame, as shown on the card, and the player with the most fame from completed projects at the end of the game is the winner.

It will be helpful to outline how the game worked in classroom environments during playtesting. Initial contact and preparation for the session was minimal, mainly requiring contact with the teacher to introduce the class plan, and to discuss the optimum location for the class. An important starting consideration for the demonstrator was that secondary school classes in the UK generally have thirty students. Coordination of the students into groups of five, sitting around six tables, was mainly managed by the class teacher. Each table was given one of the questionnaire sheets (Figure 8) and a blue pen. The class was asked to fill in the questionnaire sections using either ticks or crosses, and to put one word into the middle section. After completing this, all groups collected a game box (usually five minutes into the lesson), and the demonstrator took ten minutes to explain how to play the game. The students then played the game for 25 minutes, with the demonstrator and available teaching staff moving between the tables to answer questions and to clarify rules. Occasionally, teachers played the game with the students. Questions often involved explaining unfamiliar vocabulary, or how to use some of the cards. At the end of the 25-minute session, one or two groups had usually finished the game. The rest were told to finish the current round, and then score the game – a significant benefit of the game's scoring strategy is that the game can be ended early, and a winner is still possible. The students were then asked to pack the

Figure 2. The main science icons, clockwise from top left: Physics, Earth science, Energy, Chemistry, Biology and Cultural heritage (Source: Authors, 2022; Diamond Light Source, 2021)

game away (five minutes). Each table was then given a red pen, and asked to fill in the questionnaire one last time. The full questionnaire results are available online (Basham and Murray 2022). At the end, the demonstrator built on discussion points overheard at the tables, frequently including topics such as STEM career options, interesting science research, and how failure feels. Teachers were excellent at co-facilitating this section, which could last as long as there was time remaining in the lesson. It was possible to run this several lessons in a row back-to-back, as set-up and clean-up were completed during the lesson time.

The first impression of the game is usually acquired from looking at the front cover of the box, and this would therefore impact the likelihood of our target audience (students aged 11–18, who may not play games at home) reaching for the game to play from the classroom store. Several designs of box were investigated, but this raised the question of what colour box would be less intimidating to players who may not regularly play games, which led to an experiment. Over four of the sessions, an equal number of the white box and the navy box (Figure 3) were left on the table, and the colour preference of the participants in selecting a box was noted. We also built a piece of software in Python (Basham, 2020) to look at the top 1,000 games of the last five years, according to BoardGameGeek (the most popular website for board game enthusiasts, https://boardgamegeek.com/browse/boardgame), and to analyse the brightness of the front box cover from the art provided on the website. The BoardGameGeek database was used due to the consistent provision of a clear image of the box cover, rather than those images provided elsewhere, where boxes were positioned at arbitrary angles (thereby introducing shadowing). In addition to this, BoardGameGeek has entries for several key statistics for each game, such as play time and player age, and a weighting which is related to the complexity of the game. From this wealth of metrics, the average play time was considered to be an appropriate proxy for low player intimidation, as shorter games are more likely to be played by people new to board games.

The software script, created as a Jupyter Notebook in the Python language, uses web-scraping libraries to extract the required information from the BoardGameGeek website, and analyses and displays the data. Usage of the code is documented in the code, and this worked at submission time, but it should be noted that any changes to the BoardGameGeek web pages are likely to cause this code to need to be adapted to accommodate the changes (Basham, 2020).

From all the playtests, it was evident that the game functioned, but the question of whether the game worked as a tool for science communication remained. This was tested by working with 222 secondary school students and their teachers. Some of these visited Diamond Light Source as part of the annual

Figure 3. The initial light and dark box designs (Source: Authors, 2022; Diamond Light Source, 2021)
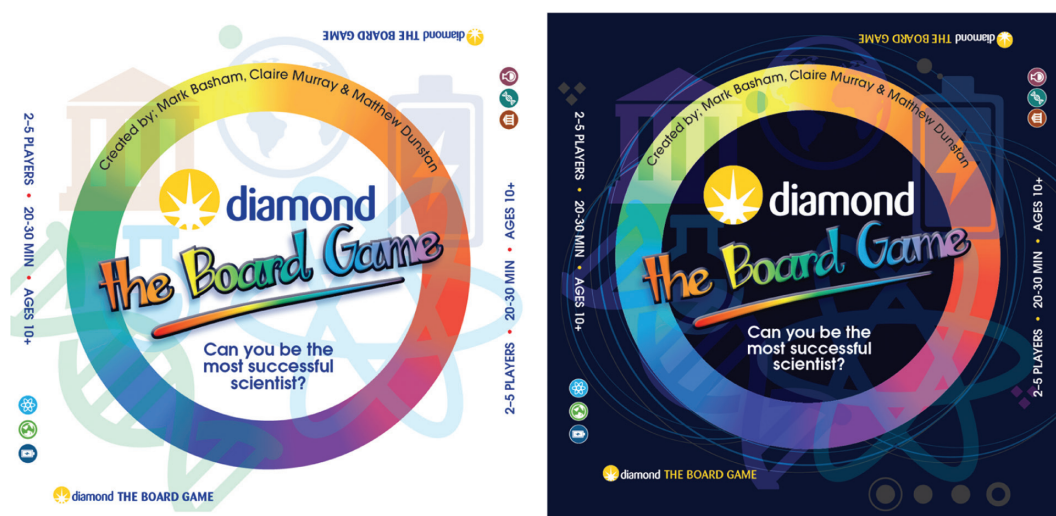
Table 1. List and format of questions answered before and after playing Diamond: The Game in the pilot sessions (Source: Authors, 2022)

Question	Format of answer	Pre-game answers? (blue pen)	Post-game answers? (red pen)
Would you be a scientist or engineer?	Yes/No	✓	✓
I like science	Yes/No	✓	✓
I see science in my daily life	Yes/No	✓	✓
Being a scientist means…	One-word free choice	✓	✓
Did you have fun?	Yes/No	✗	✓

outreach tour programme for schools (where ages range from 11 to 18 years), and some carried out the tests in a classroom setting. These sessions were facilitated by a member of the team, who first briefly introduced Diamond and the science at Diamond, before explaining how to play the game. In every session, each of the participants was given a blue pen and a red pen, and asked to use the blue pen to answer Questions 1–4 before playing, and to use the red pen to answer Questions 1–5 after playing the game (see Table 1). The questions were selected to provide insight into their experiences during the game, and how their impressions of science evolved through playing the game. The participants were also asked 'Did you have fun?', as a means of testing whether the game functioned as a game, and therefore if it was enjoyable for players to play. In total, eight sessions were run with students and teachers. After each session, discussions with each group were guided by a team member to collect feedback. After the initial few rounds of these sessions, the feedback was reviewed to address minor game issues, and to identify key trends that would be useful to discuss during the remaining sessions.

Game design and concept

A critical element to consider in the game design was the timescale of delivery for the game in the classroom environment. The game needed to be simple enough for teachers and students to learn how to play, and to actually play the game, in a one-hour class, with some additional time factored in for discussing the science and STEM careers at Diamond, as well as for evaluation. This placed important limitations on game length and complexity, meaning that many initial concepts were quickly set aside due to being inappropriate for the game objectives, such as peer reviewing applications, while others proceeded to be used for the initial prototype stage.

The final game consists of four card decks, one board, 12 scientist pieces, 50 success tokens and a rule book. The four decks are: Scientist, Experiment, Project and Action. The Scientist deck consists of 12 scientist types, each corresponding to one of the scientist pieces used to mark players' locations on the board. The Experiment cards are predominantly grouped into success and failure cards. The Project cards contain 36 discrete multidisciplinary scientific research topics, where successes achieved with the Experiment or the Action deck are indicated through the use of the success tokens. The Action cards have eight different actions, which can be played throughout the game by players, affecting all elements of the game. The rule book was designed to be concise, to enable people to start the game quickly, and to consult easily throughout.

Players prepare for the game by selecting between two random scientists from the Scientist deck, where each scientist has expertise in two science specialties. The 12 Scientist cards were intentionally chosen to cover a broad range of science, and they are a true reflection of some of the many types of scientists who carry out experiments at Diamond. Each Scientist will investigate two Projects, representing the scientific research that they will carry out at the start of the game (see Figure 4). These projects present 36 different research topics, all of which are research programmes previously carried out or currently

Figure 4. A Paleontologist Scientist card (left), with two Project cards related to their specialties in cultural heritage (middle and right top cards) and biology (middle and right bottom cards). The varying number of science icons needed for the successful completion of the Project are reflected in the number of stars (or 'fame') awarded (Source: Authors, 2022; Diamond Light Source, 2021)

under way at Diamond. The topics were chosen to bridge the gap between science topics about which players might be aware, and cutting-edge research. The language used to describe the research topics was therefore optimised through various design iterations with schools to strike a balance between familiar and new science vocabulary for the students. The Project cards also highlight, via the 3–9 science icons required for completion of the card, how each research programme relies on a variety of science specialties to succeed. Players place their corresponding Scientist piece on a space of their choice, and the game is ready to start.

There are two key mechanical choices, decided on early in the development process, which progress the game and introduce game options for players. First, movement is based on a direct choice: on their turn, a player can simply choose to move their Scientist piece to a beamline between one and four spaces ahead of where they currently are on the board, and which is unoccupied. This mechanism allows players a sense of control, allowing a meaningful choice towards completing their goals, rather than using a more random element, such as rolling a die. However, it remains simple in terms of rules. Furthermore, it introduces a simple way for players to interact with each other in terms of blocking a beamline from use, without being directly confrontational (which would be against the spirit of working at Diamond). Interactions between players are encouraged via the use of Action cards, which are described below.

The second mechanism relates to how players actually perform experiments in the game. Clearly, it was necessary to abstract the actual nature of experiments performed at Diamond, but it also needed to engage the players, as this is the key action fusing game experience with real-world experience. A push-your-luck approach was used, as this both accurately reflects the real risks and sense of uncertainty associated with experimentation, which we wanted to include, and creates excitement for all players, whether they are actually performing the experiment or not. A player performing an experiment flips cards from the Experiment deck one by one, each card displaying a number of either success or failure symbols. After each card is revealed, the player may choose to stop and gain all of the successes they have accumulated, or they can push on and keep flipping Experiment cards. If a player ever reveals two failure symbols during an experiment, they must stop, and forgo some number of the successes gained previously.

The success/failure mechanism was thoroughly tested throughout the playtests, as successful completion of a Project (leading to drawing new Projects) is the key to winning the game. Early iterations had players lose all successes, but playtesting revealed that this was too harsh, so this was changed to losing half of their successes. This mechanism was engaging from very early on in the playtesting process, and again allowed players a clear choice about how to proceed towards their goals. It also injected an amount of uncertainty and luck into the game, ensuring that the game does not lean too far into a heavier strategic genre, which would be unsuitable for the target audience. This was a surprisingly accurate representation of the emotions experienced during real experiments!

Including failure in the game as something that players directly experience as scientists was intended to initiate conversations between players about the results of scientific work, and the emotional aspect of being a scientist. STEM outreach rarely focuses on normalising failure as a necessary part of scientific discovery (Dreyfuss, 2019), but Diamond: The Game does this, with players' actions in the game delivering immediate feedback and prompting reflection. Another important reality of modern science is that problems are rarely single-field problems, but instead these problems require more than one science subject to answer them, and so this was a key consideration in the game design. This is conveyed through the interdisciplinary nature of Project cards, which require success in multiple science areas, and also in the Breakthrough cards in the Experiment deck. The latter highlight how scientific breakthroughs in one specific research area can benefit all.

The Action deck is the only secret part of the game for players, as they do not reveal these cards until they play them. This deck introduces events which affect everyone's chance of winning by interacting with all other elements of the game. Action cards also introduce some of the humanity of being a scientist through, for example, regular requirements for sleep, coffee and human interaction. An important example is the Collaboration card, as this highlights how modern science relies on scientists working together cooperatively (Figure 5), rather than perpetuating the problematic stereotype of a scientist as a lone genius, with which students cannot identify (Steinhardt, 2019). Exploring the interactions between scientists through the board game dynamics is intended to help players to realise the social nature of science, and aims to break the damaging perspectives of scientists always working alone, which is completely incommensurate with students' self-image, and with their desires for their career (Heering, 2010).

Game accessibility

A critical question for this work was how to target inclusive design, which is an important discussion ongoing in the science communication and board game community (Ryan, 2016; Pobuda, 2018; Dawson, 2019; Lewenstein, 2019). The nuances of accessibility, and of board games, mean that it is difficult to design a perfectly accessible game, but there are certainly many small design tweaks and adaptations that can easily be made in the design phase to open up board games to even more players (Heron et al., 2018; da Rocha Tomé Filho et al., 2019). We aimed to minimise barriers for players, and started by considering the experiences of players with sight impairments. One of the key issues for these players

Figure 5. Examples of cards which highlight under-represented themes in STEM, such as failure and collaboration (Source: Authors, 2022; Diamond Light Source, 2021)

is how information is encoded and conveyed during the game. We used a high-contrast design, using large icons and large text in the sans serif font ITC Avant Garde Gothic, and the largest standard card size available (Poker size: 63.5 mm x 88.8 mm) (see Figure 6). We also used a dual colour and icon encoding for the science icons to facilitate card decoding by colour and icons for players with colour vision deficiency, who might struggle to differentiate the icons by colour alone.

The true success of a design relies entirely on it working for the target audience, so feedback on the accessibility of the game was actively sought throughout the design and development process. The eventual design has benefited enormously overall from this valuable input, and the game has been tested both with members of the sight impaired community and with members of the deaf and hard of hearing community. Feedback on the text used in the card decks specifically highlighted the importance

Figure 6. Examples of cards from the Experiments deck and the Projects deck (Source: Authors, 2022; Diamond Light Source, 2021)

of conveying instructive rather than descriptive information, with distinct icons to represent each card. Focusing on the core actions that the player is required to execute means that players can engage faster in the game, rather than spending time filtering descriptive information that is unnecessary for understanding game play. Discussions with teachers also highlighted opportunities to support learners with reduced vocabularies through the use of simple text. The game offers a clear and concise opportunity for this target group to improve their vocabulary, and furthermore leads to an easier learning experience for all participants. These benefits have contributed to a final game design that allows a wider range of participants to engage with STEM. Our experiences in teaching the game to new players highlighted that the text, the mixture of colour and icon cues, and the clean design of the cards and the board, made the game easier to teach and play – and also made it less intimidating for first-time players.

The selection of Scientist pieces for the game was widely discussed by the authors in the context of representation. Diversity in board games is a serious issue, with under-representation in box art, where you are more likely to see an animal or an alien than a woman (Pobuda, 2018). This is also apparent in the game design community, where 93.5 per cent of the designers of the top 200 ranked games on the BoardGameGeek website are White males. Beyond the box art, there is the important question of whether women or BAME are represented with agency and respect within the game (Hargrave, 2020). Representation of LGBTQ+ and people with disabilities is also extremely poor (Pappas, 2017). The design choices mentioned previously for sight impaired players focus players' attention on the symbols which differentiate the scientists and engineers, rather than the scientist icons, and also provide gender-neutral icons, so that players can project their identities onto their selected scientist. However, the authors acknowledge that this is only one approach, and that a lot of work needs to be done to improve diversity and representation in board games, and in the game design community, and they welcome feedback on this matter.

Box colour experiments

The experiments on the box cover colours originate from our hypothesis that darker game boxes often contain more adult, and therefore more complex, games, whereas lighter boxes often contain more light-hearted and simple games (for example, see the top-selling family board games on most websites). This could be a key factor in influencing players' expectations about the game, and their desire to play the game. Our first experiment for this was observational, where we recorded which box participants chose over four sessions. However, participants chose the dark and light boxes equally over four sessions. There were limitations in this experiment, given that participants may also have been selecting boxes to ensure symmetry of the boxes left on the table, and that for most classes, there were only four boxes of each colour from which to choose six.

The colour distribution of the top-selling family games was explored through our software, as we aimed to position our game in this area to ensure that it was welcoming for those players who do not regularly play games. We felt that the BoardGameGeek 'average play time' rating was the best available metric to explore any potential connections between the colour palettes of the usually shorter play time of family-oriented games and longer play time of more intense games, particularly given the restrictions of lesson lengths in schools. Our code is available open source for others to explore this and other metrics (Basham, 2020). The relationship between the BoardGameGeek 'average play time' and the brightness of the box art images is plotted in Figure 7. The brightness of the box covers in Figure 3 is shown via a black star for the dark box and a white star for the light box. Although the spread of colours over the different play times for the top 1,000 games is broad, there is a downward trend line that demonstrates that games with shorter play times generally have a higher box art brightness. The lighter end of the brightness scale is particularly revealing, as very few games had a higher average play time. The lower number of counts at both extremes of the brightness scale is representative of the fact that few boxes are entirely black or white, which is unsurprising, given the presence of contrasting text or pictures on the box art. These data led us to select the brighter box design for the final version of the game.

Figure 7. A 2D histogram of the average play time of the top 1,000 games from BoardGameGeek against the overall brightness of the box. The dark box is represented by a black star, and the light box is represented by a white star (Source: Authors, 2022)
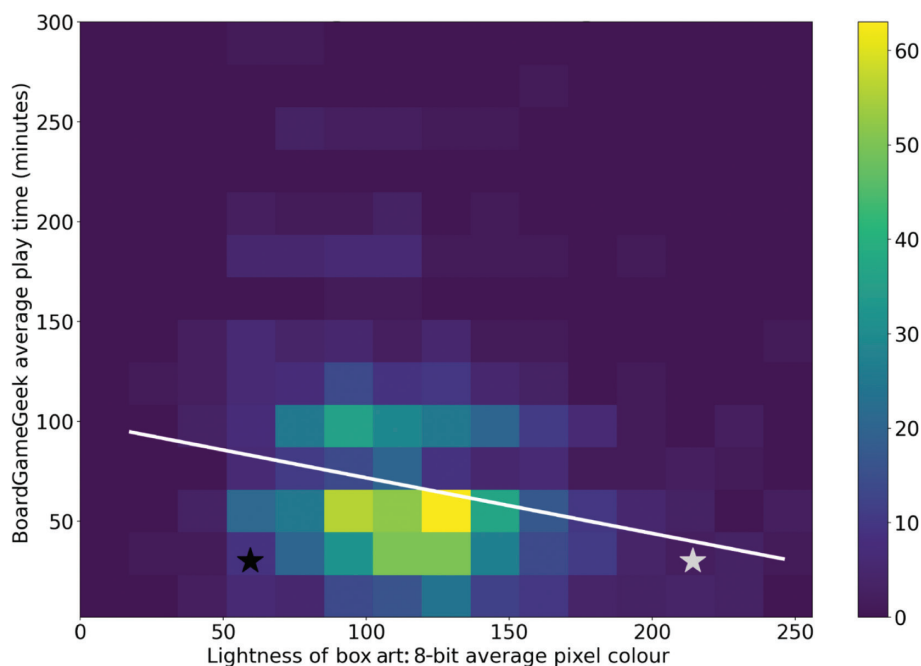
Game evaluation

The results from the sessions with the 222 participants provided important feedback on the role and success of the game as a science communication tool (see Figure 8 and Table 2). First, playing a board game for half an hour does not significantly change the participants' like or dislike of science. This is understandable, as opinions are often difficult to change in a short period of time. However, this does give more credence to the significant increases we see in the answers to the other questions. The 85 per cent positive response to the question 'Did you have fun?' was important to gauge whether the experience of playing the game was pleasurable, as this obviously will affect the players' experience of the game. Players' positivity or negativity will also encourage or deter recommendations and/or inclinations to replay, which are clear determinants of the game's success.

The biggest uplift is for the 'Would you be a scientist or engineer?' question. As the general liking of science did not increase, this must be made up of participants who liked science, but who did not consider it as a career option. The process of playing the game improved their understanding of various STEM careers, and might have directed them towards one they had not considered. Of the 82 students who specified that they would not like to be a scientist or engineer, 22 changed their response positively, with only 5 changing their response negatively. The increase in 'I see science in my daily life' is an excellent outcome, as it shows that the students have an increased recognition of science in their daily lives, which we think is closely connected to the visibility of real science experiments and scientific careers in the game. Of the 30 students who did not see science in their daily lives, 16 positively changed their answer, which is an effect of 53 per cent, and there was only one associated negative answer change. Assuming the counts are independent and fall as a Poisson distribution, the standard error of positive answers to 'Would you be a scientist or engineer?' is 11 per cent. For 'I see science in my daily life', it is 18 per cent. Therefore, both results show significant signal above the noise.

Figure 8. An example of a completed questionnaire received from the participants (Source: Authors, 2022)

Table 2. Responses to the questionnaire where change was possible (Source: Authors, 2022)

Question	Number of students where a positive/negative change is possible	Proportional change positive/ negative	Change positive/ negative (confidence) (%)
Would you be a scientist or engineer?	82/140	22+/5−	+27 (SE 11)/−4 (SE 8)
I like science	30/192	6+/7−	+20 (SE 18)/−4 (SE 7)
I see science in my daily life	30/192	16+/1−	+53 (SE 18)/−1 (SE 7)

The preliminary analysis conducted on the questionnaire output of the free-entry text answers to 'Being a scientist means?' (Figure 8, centre section) was explored using 'before' and 'after' word clouds (Figure 9). The provision of words before playing the game will obviously influence the words selected after the game (for example, participants may feel that there is little point repeating the word they selected beforehand); however, it is a helpful route to acquiring feedback on participants' experience of the game. The most popular words in the (pre-survey) were 'smart', 'experiments' and 'research'. These words reflect the scientific process, and the stereotypical expected characteristics of scientists. The most popular words in the post-survey were 'collaboration', 'success' and 'failure'. These words are implicitly more grounded in the reality of the daily lives of scientists. This move reflects the importance of how people start thinking and talking about science in a way that scientists think and talk about science, as a result of their experiences in playing the game (Wake and Illingworth, 2019). This was further verified by comments from teachers, who specifically highlighted how students were acquiring scientific vocabulary by playing the game.

Figure 9. Word clouds from the 'Being a scientist means' question before (left) and after (right) playing Diamond: The Game (Source: Authors, 2022)

The fact that a scientist could fail, or that they might require some help in the lab, is often under-represented when communicating science, but conversations about this help humanise scientists and make a potential career more appealing. The cards in the Experiment and Action decks, such as 'Success', 'Failure' and 'Effective Collaboration', are the most popular word choices after playing the game, and they are particularly powerful, as they help players realise that the reality of a STEM career is not so different to that of other careers. To confirm this was true, discussions with participants were held after each session – in the second half of the sessions, the data collected in the first half of the sessions were reviewed and used to guide discussions. The recurrence of 'failure' as an 'after' answer was identified as an important topic for further discussion, due to the concern that participants might be forming a negative association with science. Players reported that the first time they saw the 'Failure' card they did feel confused, but as the game proceeded, and they saw how other players also failed, it became less intimidating and less scary to have these cards. Players also reported feeling encouraged to try again when they played the Failure cards, as well as enjoying the risk introduced into the game. Multiple groups expressed a desire to replay the game, which is a positive sign, both in the context of playability and of their feelings about winning or losing the game. This demonstrates that the game experience, and the associated emotions, did not hinge on success alone. An interesting additional point was the recurring surprise of players at the range of scientific careers that they had not previously considered.

Verbal feedback from teachers after seeing their students play the game (or, indeed, playing the game themselves) also provided important insights into the power of play in the classroom environment. It highlighted the exposure to scientific careers, and to a breadth of scientific research, as a positive for them, as the curriculum (by design) must focus on narrow topics within each subject. They were also very positive about how engaged the students were, and noted that students were having 'on topic' conversations among themselves during the lesson. Feedback was also given requesting that lesson plans be provided to accompany the game when it is used independently by teachers in the classroom, and this is under development.

Takeaways

The potential for a resource such as this to function in both formal and informal settings makes it a valuable tool in multiple learning environments, which is an important consideration during a global pandemic,

when it might have to function simultaneously at home and at school. Although the game will have a very different life in these settings, conversations about scientific careers, the life of a scientist and the role of failure in science can be incredibly powerful and, indeed, are necessary to improve science literacy at home, at school and beyond. Evaluation plays an important role in exploring this. While the lack of follow-up surveys and limited evaluation in this work only allow for a partial understanding of the impact of these conversations, the feedback from the 222 participants highlights the promising engagement potential for board games in STEM and more.

Games such as Diamond: The Game represent an opportunity to improve diverse representations of people within STEM careers, and they can be used to showcase positive role models for students with various backgrounds. The design of resources such as this also creates important discussions around accessibility of communities to science and science communication. Diamond: The Game has tried to build an inclusive design, but a limitation is that this design is not accessible for everyone. This game should therefore be part of a package of resources, so that other resources can engage other groups. Future work in this field should find ways to include a more diverse range of voices on the design and evaluation side, to improve the quality of games made for educational purposes. This would surely lead to a better range of methods for engaging audiences with scientific concepts.

The concept of winning and success, and how it applies to the scientific method and STEM careers, is another concept that should be considered in design. For example, cooperative or semi-cooperative games, such as Pandemic (Z-Man Games, 2022), are a relatively new phenomenon to change the wider tabletop gaming landscape in recent decades, and this different mode of playing could align well with the collaborative teamwork nature of doing science in the real world; indeed, it questions the necessity of designing games that require one or more players to win. Not only can this emphasise the need to work with other scientists across many different disciplines, which is increasingly required to solve complex global problems, but also it can question the dominant ways of recognising what makes a successful scientist at a professional level. Challenging the perception of a lone genius sacrificing everything for science is greatly needed to properly recognise the much wider set of skills that are valuable for those in STEM (Heering, 2010; Steinhardt, 2019).

The work presented here showcases a gaming approach which could be adapted by educators, educational professionals or subject enthusiasts to cover any desired topic of study. This is obviously not limited to STEM subjects, and could indeed be transferred to the broader curriculum. Critically, we found that the natural elements of creating a fun and inclusive game, capable of being played in the classroom, necessitated a clear focus on key messages. This can run counter to the instinct to share a breadth of knowledge in the classroom or in engagement activities, so it is an important takeaway to consider in future similar projects. It is essential to note, however, that these considerations greatly enhanced the experience for students, teachers and the board game activity deliverer.

Conclusions

The development of Diamond: The Game has shown the value in using games for educational purposes, highlighting their ability to place participants as active agents within the chosen setting and content matter. In this case, students were directly faced with the emotional highs and lows of conducting scientific experiments at a large-scale national facility, which in turn directly questions their perceptions of their own aptitude for STEM careers and what being a scientist really entails. Through playing the game, participants were led to consider the full breadth of different scientific disciplines that utilise Diamond, the interdisciplinarity of global scientific problems, the nature of failure and success in experiments, and the broader range of people who work at a facility such as Diamond to ensure its smooth operation. These changing perceptions are evident in the survey data, where there is an uplift in the number of students who would consider a science or engineering career after playing the game, as well as an increase in the number of students who see science in their daily life.

Along the way, we sought to intentionally use inclusive design (both in a game sense and graphically) in order to improve the experience for a wider range of potential participants, from considering the visual representation of scientists and science in the game, to the choice of colour, font size and overall cognitive load that players encounter. These considerations only serve to improve the overall game and educational experience, as highlighted by teachers' feedback. We hope our work can inspire others to realise that inclusivity need not come at the expense of educational outcomes, but rather enhances them. However, we also recognise that further work is needed to improve diversity, especially within the design team, and that including a wider range of inputs also serves to improve the end result.

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Declarations and conflicts of interest

Research ethics statement

Not applicable to this article.

Consent for publication statement

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Conflicts of interest statement

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