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SPECIAL ISSUE
Science communication in unexpected places

ARTICLE

Back for the future: public engagement with climate science through a multimodal STEM escape room

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Abstract

Research has explored escape rooms for their education potential but there is a notable lack of literature in the public engagement context. This paper illustrates findings from three editions of Back for the Future, a climate-themed STEM escape room delivered both online and in person, with and without COVID-19 restrictions. We demonstrate that escape rooms can engage those who normally do not seek out science in an enjoyable experience that may foster future engagement. Players become immersed in the game environment, losing track of time and can succeed in the activity regardless of their science background. We also propose that self-determination theory, science capital and flow are beneficial concepts for designing games that enhance engagement for a variety of audience groups. Finally, we hope to provide useful and generalisable recommendations for delivering impactful STEM escape rooms in unexpected places (and perhaps with unexpected limitations).

Keywords

Environmental communication; Informal learning; Public engagement with science and technology

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1 ▪ Introduction

Escape rooms have exploded in popularity since the 2010s as a versatile form of entertainment suitable for various audiences [Lama & Martín, 2021]. Players are placed in a narrative-based predicament, and they must solve puzzles within a time limit to resolve it. This lends itself well to science communication, as scientific content can be provided within the room that players must seek out and leverage to solve puzzles [Wilkinson & Little, 2021]. The escape room format is highly adaptable, allowing it to be leveraged to a variety of contexts [Nicholson, 2015]. Additionally, the narrative chosen can allow players to explore important socio-scientific issues such as climate change in an immersive, self-directed manner [Ouariachi & Wim, 2020]. This has generated significant interest in the use of escape rooms in formal education, and several systematic literature reviews have explored their efficacy [Fotaris & Mastoras, 2019; Veldkamp, van de Grint et al., 2020; Kim et al., 2025]. However, there has been much less academic exploration of escape rooms in informal learning settings, despite their potential compatibility. Informal learning settings rely on an intrinsic desire to engage [Stocklmayer & Rennie, 2017], as participation is optional. Playful activities such as escape rooms could ignite this intrinsic desire and therefore may be an ideal format to encourage continued curiosity about science outside of the formal classroom and with broader audiences. In this paper, we aim to explore this possibility by assessing the informal engagement potential of a climate-change themed escape room with broad audiences. We also explore its design elements, how they were changed to suit differing contexts across three separate editions and how they might enhance players' engagement with the game across three foundational categories of engagement. Ultimately, we wish to provide insights for other science communicators about whether escape rooms are suitable for inclusive engagement with science and if so, what design elements are recommended.

2 ▪ Background

The origin of escape rooms is often credited to Takao Kato, who delivered the first live escape room in Japan in 2007 [Cheng, 2014]. Inspired by digital games with similar goals [Rad, 2015], he crafted an event where players had to solve puzzles to escape a locked room [Corkill, 2009]. By 2011, the first European escape room began operating in Budapest [Walker, 2016] and by 2015, escape rooms had developed into a global entertainment format [Cheng, 2014]. Interestingly, an early analysis of 175 recreational escape rooms showed that, while a wide variety of topics were featured, science and technology were common themes, with 12% of rooms set in a laboratory and 7% in an advanced technological future [Nicholson, 2015]. This adaptability to different educational content and the potential to foster learning is perhaps what sparked a growing interest in escape rooms as a formal education tool. Game-based learning was already a developing area of pedagogy [Plass et al., 2015], particularly for learning outcomes not suited to traditional teaching methods [Qian & Clark, 2016]. It provided a suitable foundation to explore escape rooms in educational contexts and numerous empirical studies have been conducted over the past 10 years. Systematic literature reviews of these studies conclude that escape rooms are engaging for students, allow for teamwork, complex problem solving and promote persistence [Fotaris & Mastoras, 2019; Kim et al., 2025]. While perceived learning may often be greater than actual learning, escape room experiences can still be impactful when combined with pre-game learning and post-game reflection [Veldkamp, van de Grint et al., 2020]. However, it is notable from these reviews that there has been little academic exploration of escape rooms in informal, science communication settings. For example, in the review by Veldkamp et al., only 3 of 39 studies were situated in an informal context [2020]. This seems counter-intuitive, when considering the adaptability and entertainment factor of escape rooms, which aligns very well to informal encounters with science. As science education and science communication often have different goals, there is a need to explore how escape rooms can contribute specifically to those of informal contexts.

2.1 ▪ *From scientific literacy to engagement*

In the late 20th century, many Western societies held the belief that increased understanding of science would lead to greater appreciation of it [Gregory & Miller, 1998]. This roused a 'public understanding of science' movement within science communication [Bauer, 2009]. It was proposed that a deficit in knowledge was the main barrier to positive attitudes towards science [Pitrelli, 2003; Bauer et al., 2007]. Later evidence demonstrated that this approach did little to foster appreciation of science and could in fact polarise disapproving groups further [Evans & Durant, 1995; Kahan et al., 2012; Drummond & Fischhoff, 2017]. In response to this, practitioners began to explore new approaches to science communication, with the aim of developing better relationships between science and society [Trench, 2008; Weingart et al., 2021]. Though a full transition is yet to be seen, a more democratised Public Engagement with Science and Technology (PEST) model has been pushed, where building trust, centring enjoyment and encouraging inclusive dialogues with diverse publics takes precedence [Trench, 2008; Davies, 2013]. Therefore, while increased scientific literacy remains an important goal of science education [Osborne, 2023], science communication now strives for a stronger focus on engagement. This approach is logical, when considering the informal context of science communication and the diverse audiences it must reach [Stocklmayer & Rennie, 2017]. While formal educators benefit from the compulsory attendance of their students, informal communicators must draw in and retain willing audiences, even where they are non-enthusiasts of science. Engagement becomes the crucial foundation from which communication or relationship building can occur, therefore there is a critical need for innovative methods to support broader engagement with science [Bucchi, 2013; Gillian-Daniel & Grandell, 2024].

Yet, while engagement is an essential concept in science communication, this does not mean it is unexplored, or without its value in science education. Though students must attend classes, their level of participation and commitment can vary [Fredricks et al., 2004]. Greater engagement with school is linked with positive academic performance and attitudes, making it an important consideration for educators [Lee, 2014; Grabau & Ma, 2017]. For this reason, some argue that engagement is a 'threshold concept' for both fields of science communication and education and must be understood before either can truly progress [McKinnon & Vos, 2015]. It is for this reason we seek to build on prior research examining the educative potential of escape rooms, focusing instead on their ability to engage audiences. We hope that our exploration of these mechanisms we may provide insights for designing such activities, not only for informal contexts, but for all settings that encourage interactions with science.

2.2 ▪ *Understanding engagement*

An accepted model of engagement defines three types; behavioural, cognitive and emotional [Fredricks et al., 2004]. Behavioural engagement relates to physical participation, while cognitive relates to mental focus. This is then contextualised by emotional engagement; the ways participants experience their engagement and the values and perspectives it may generate [Lawson & Lawson, 2013]. In this way, engagement is a multi-faceted construct that needs to be analysed comprehensively [McKinnon & Vos, 2015]. It is not enough to see physical participation and call this 'engagement', as this would neglect or assume the internal experience. Similarly, we cannot examine engagement through a binary lens of 'engaged' or 'not engaged', as it will naturally vary in its intensity over time [McKinnon & Vos, 2015]. Individuals may disengage at any point of an activity and, particularly in informal settings, this may result in the audience being lost [Stocklmayer & Rennie, 2017]. Ideal engagement methods will therefore keep an audience engaged at the desired level, or have the capacity to re-engage with some regularity. It is important that we are able to design such methods by understanding what sparks engagement in the first place.

Engagement is preceded by 'interest' [Lawson & Lawson, 2013], which can be extrinsically or intrinsically motivated [Deci & Ryan, 2000]. In a formal classroom setting, an intrinsic motivator to engage may be a genuine enjoyment of science, while an extrinsic motivator may be the pursuit of good grades [Fredricks et al., 2004]. These are only two examples and in reality, a diversity of motivators will appeal differently to different individuals, making engagement highly context-dependent [McKinnon & Vos, 2015]. Therefore, in our pursuit of methods that might engage, we must consider the context and how it relates to our audience [Gillian-Daniel & Grandell, 2024]. Zooming out to informal contexts, we know that there are fewer extrinsic motivators. Science communicators rely on a willingness to participate and therefore intrinsic motivation is vital [Stocklmayer & Rennie, 2017]. It is no surprise then, that informal science communication activities are often frequented by avid science enthusiasts [Evia & Peterman, 2020]. However, if a major goal of the field is to reach broad audiences, this raises questions about the non-science enthusiasts. What can be offered to motivate them?

In recent decades, science communication practitioners have explored numerous ways to draw in new audiences. Many have leveraged STEAM methodologies, incorporating the arts with science to broaden its appeal [Mejias et al., 2021]. For example, one may set up a futuristically themed diner at a festival to spark conversations about eating insects for environmental sustainability [Bevan et al., 2021]. Our own interest in escape rooms began through an EU project exploring STEAM approaches for broader engagement [Mathieson & Duca, 2021; Roche, Bell, Martin et al., 2021]. This combination of art and science creates novelty to spark what is referred to as 'situational interest' [Hong et al., 2019]. An individual becomes engaged with a topic they are normally not interested in, simply due to the way it is presented [Fredricks et al., 2004]. While this engagement may appear superficial, it is thought that repeated interactions that leverage situational interest may foster genuine interest in a topic over time [Palmer et al., 2017; Hong et al., 2019]. Additionally, combining science with other forms of culture may bridge the gap between science and broader society, fostering greater connections with scientific identity [Davies & Horst, 2016]. In light of this, escape rooms are ideally suited for engagement in informal contexts as they are enjoyable enough to be commercialised [Dixon et al., 2021]. Though learning can occur, it is not the primary focus, and games can be designed to fit any location, whether you are hosting them in a garden, a portacabin or even inside a single rucksack [Bättig-Frey et al., 2023; Rawling, 2018]. This flexibility is no doubt attractive to creative practitioners with limited resources, allowing for many science museums, centres and libraries to use escape rooms to engage audiences they don't normally cater to [Wilkinson & Little, 2021]. It is likely that a lack of studies of STEM escape rooms in informal spaces has less to do with their suitability and more to do with public engagement practitioners not being in the habit of publishing their work [Volk & Schäfer, 2024]. Either way, if we wish to take advantage of this versatile format, we must understand the fundamentals. What intrinsic motivators, situational cues or other design elements can be leveraged to make any escape room engaging?

2.3 ▪ *Fostering engagement*

Self-determination theory (SDT) is a well-evidenced and accepted framework for understanding intrinsic motivation. It suggests that for individuals to feel intrinsically motivated towards an activity, three psychological needs must be met. These are the needs of autonomy, relatedness and competence [Deci & Ryan, 2000]. Autonomy represents a need for control over one's actions. Competence, the need to apply ourselves to challenges and demonstrate that we are capable. Meanwhile relatedness refers to our need for social connection. This theory has been evidenced empirically through a review of 60 meta-analyses. Findings demonstrate positive influences over intrinsic motivation where these needs are satisfied [Ryan et al., 2022], making this an important concept for fostering engagement. We can expand on this by drawing in other theories that overlap with SDT and the above-described model of engagement. One example is science capital; a theoretical framework developed from Bourdieusian concepts of cultural capital. Succinctly, cultural capital is the 'cultural currency' an individual has that enables them to participate in various societal contexts (fields) with reduced friction [Bourdieu, 1973]. It can include an individual's characteristics, background, knowledge, skills, contacts, mannerisms and more. Science capital applies this theoretical lens to science, to understand how individuals might engage with it, particularly in a formal education context [Archer et al., 2015]. It is theorised that if a student's science capital is low, they are less likely to engage, as they do not have the type of currency that will be most rewarded in class [DeWitt et al., 2016]. This has led researchers to develop the approach of 'broadening the field', devising scenarios that allow students to leverage other, 'non-science' forms of capital towards their science lessons [Godec et al., 2018]. For example, students might apply their knowledge of playing musical instruments towards lessons about soundwaves [Godec et al., 2017] and this may allow more students to engage with the topic. This concept not only provides more insight into why engagement is context-dependent but is also linked with psychological needs for relatedness and competence. Broadening the field (through STEAM for example) might stimulate situational interest [Hong et al., 2019] as well as reassure an individual they possess the right capital to engage [Godec et al., 2018]. This in turn may foster a sense of belonging and comfort participating [Dawson, 2018]. Similarly, allowing individuals to leverage their existing capital towards a challenge may help it seem more achievable, satisfying the need for competence. For example, a scientific equation might seem daunting to someone with low self-efficacy in STEM. Yet, if similar material is presented as a poem or riddle (providing this is strength of theirs), it might inspire confidence. Such approaches may improve the context of our engagement, but we should also be concerned with its depth, i.e. cognitive engagement.

In our first escape room, Escape Malta: Space Station, we applied the theory of cognitive load, which is concerned with reducing the level of mental effort needed to complete tasks [Mathieson & Duca, 2021; Sweller, 1988]. This involves techniques such as dosing information, engaging different senses and providing informational cues [Mayer & Moreno, 2003]. However, we were keen to enhance our players' ability to focus further. The creator of ParaPark, Europe's first commercial escape room, was inspired by the concept of flow in his designs [Walker, 2016]. Flow is an autotelic experience where individuals become intensely focused on an activity, losing their awareness of self and time [Csikszentmihalyi, 1990]. In essence, it is a deep form of cognitive engagement. Encouraging players into a flow state may therefore enhance the experience for players and its impact. Suggested antecedents to flow include creating an ideal balance between difficulty and skill, clear goals and immediate feedback, which aligns with the psychological need to demonstrate competence. Autonomy is also said to enhance flow, further aligning with SDT. Finally, to sustain flow, reduced distraction and capacity to distance from the self [Michailidis et al., 2018] are considered important. From the opposite perspective, experiences that might make one more self-conscious, (drawing one back to the self), may interrupt flow. This would be the case if contextual cues signal to individuals they have insufficient science capital, leading to feelings of being 'othered' and ultimately disengagement [Dawson, 2018]. Therefore, while these theoretical concepts all provide distinct insights into how engagement can be fostered, it is likely there is significant overlap and interplay between them. To summarise, we have aggregated them into Table 1, offering a list of recommendations for enhancing engagement in escape rooms.

Table 1. A framework for designing an engaging escape room.

Antecedent	**Code**	**Recommendation**
Autonomy	A	Giving players control over the game
Competence	C	Delivering the right level of challenge
Relatedness	R	Providing opportunity for social interaction / bonding
Broadening the Field	B	Providing opportunity to leverage other (non-science) forms of capital
Clear Goals	G	Giving players clear goals
Feedback	F	Ensuring actions receive immediate feedback
Concentration	D	Creating an environment free from external distraction
Immersion	I	Encouraging players to step out of their reality

2.4 ▪ *Further theoretical concepts of engagement*

It is important to note that while the above theories have been selected for inclusion in this study, there are many more exploring how to foster engagement. Some were excluded as they are applicable to contexts other than public engagement with science. For example, concepts such as the Job Demands-Resources (JD-R) Model [Demerouti & Bakker, 2011], Goal-Setting Theory [Lunenburg, 2011] or Transformational Leadership Theory [Bass, 2015] are more relevant to the engagement of employees in a workplace setting. Meanwhile, Fogg's Behaviour Model [Fogg, 2009] or Eyar's Hook Model [Lukyanchikova et al., 2023] are relevant to habitual engagement with digital products such as apps or social media. Some theories were relevant to the context of public engagement with science but were less applicable to the escape room format. Dialogue methodology is an important PEST approach, but it is more appropriate for open-ended discussions between scientists and public groups [Escobar, 2011]. STEAM relevant concepts such as Narrative Transportation Theory [Thomas & Grigsby, 2024] would require a larger focus on story elements, with less time for active puzzle-solving. Other theories overlap with those we have chosen. Gamification Theory is already grounded in SDT for example [Lamprinou & Paraskeva, 2015]. Social Identity Theory and Social Capital Theory overlap with Science Capital, though the latter is more targeted to our niche. Social Identity Theory can be used to explore if an individual's association with specific groups will impact their engagement in a context (i.e. within school) [Kelly, 2009]. Meanwhile Social Capital Theory frames social connections as assets that may hinder or foster engagement. For example, high social capital within a population is thought to be crucial for civic engagement [Putnam, 2000]. While these concepts are all rooted in Bourdieusian notions of cultural capital, Science Capital allows us to narrow our scope to an individual's experience of a short-term science engagement intervention.

2.5 ▪ *Escape room design*

As with our previous escape room [Mathieson & Duca, 2021], our aim was to leverage theory related to motivation and engagement to design an experience that would appeal to players (Table 1). Some features of escape rooms already align with these concepts, with the potential to broaden the field, cater to psychological needs and encourage a state of flow. For example, escape rooms are played in groups allowing for social interaction (R) and you must complete all puzzles within a time limit to 'beat' the room (C). Players are locked in a room (D) that is often themed with set dressing and a backstory that creates an immersive environment, taking players out of their day-to-day reality (I). Players have some level of free reign to explore the room as they desire (A) and puzzles are normally diverse in type and solvable without the need for prior knowledge (B). Escape rooms are hands-on, with players interacting with objects and receiving immediate feedback (F) and if the escape room is well designed, the difficulty level will be tailored to the target audience (C).

According to Veldkamp, there are three basic escape room structures as shown in Figure 1 [2020], though these structures can be combined into something more complex. A sequential escape room requires puzzles to be solved in order, allowing players to enjoy a sense of progression and accomplishment (C). Meanwhile an open structure gives them more control over their own path (A) and allows them to abandon puzzles as needed, finding others that suit their skills better (B). In our experience, a path-based structure is a good compromise, with both sequential and open elements. Providing three optional pathways with one standard puzzle and one more complex STEM puzzle is an ideal number for a game of 40–60 minutes. Standard escape room puzzles can be solved through pattern recognition, lateral thinking or other innate means, and are solvable regardless of background. The aim of these puzzles is to broaden the field (B) and give players a boost of confidence that they are up to the task (C), before they unlock a more complex STEM puzzle relating to the scientific content. Having STEM puzzles locked away not only doses information but also aims to increase players' investment in solving the puzzle once opened. Finally, a meta-puzzle placed at the very end, will require multiple elements from previous puzzles to be solved. This may encourage even further investment and satisfaction of progress made (C). Another key element in our escape room design is the actor, as they take the role a facilitator might in other public engagement settings [Chilvers, 2013]. The actors' theatrical performance adds

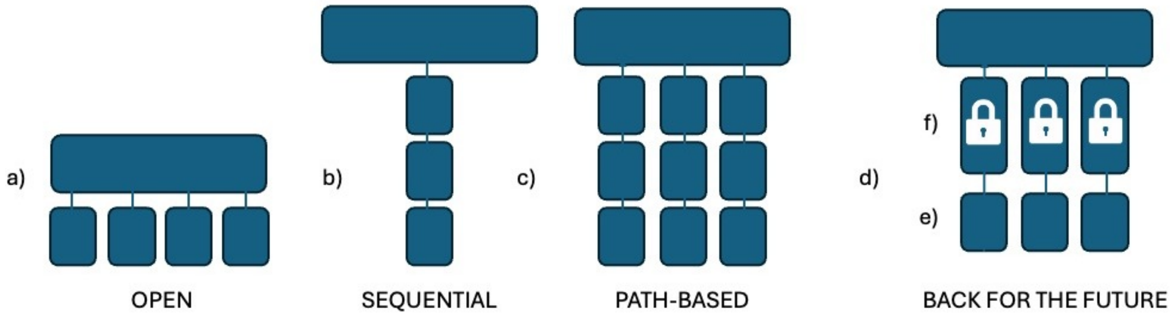

Figure 1. Showing an open (a), sequential (b) and path-based escape room structure (c). Back for the Future's structure is also shown (d), which includes standard puzzles (e) and STEM puzzles (f). Horizontal rectangles denote meta-puzzles. [Veldkamp, Daemen et al., 2020, Adapted from].

to player immersion (I) and provides further opportunity for social interaction (R). Actors can guide players away from anything that might break the immersion (such as design limitations) and can encourage players through difficult moments or reinvigorate them, keeping them focused (D). The actor can act as a buffer, providing hints to players' who are finding the room too difficult or even throwing in curveballs to players' who are performing too well. This means the room will always be set at the right level of difficulty (C). The actor also allows the room to be more flexible to different player needs (B), relating puzzle information to what players already understand, or even making the room more accessible. For example, in one game we catered to a player who couldn't read by having the actor read information out to them.

2.6 ▪ *Scientific content*

Our escape room aimed to build awareness of current research projects working towards environmental sustainability. Titled Back for the Future, the game was themed as an escape room where players must solve puzzles to prevent the climate crisis. In the game, players come from a dystopian future where the climate crisis is not solved, and humanity is in danger. As chrononauts, their only option is to go back in time to the early 2020's and speed up vital research that will help Ireland transition to a sustainable path. Along with a team captain, played by an actor, they travel to a fictional Professor's office and complete three major research projects to increase biodiversity, reduce farming emissions and find circular solutions for bio-based waste. The escape room aims to communicate current research, as well as impress upon players the importance of acting against climate change now, while it is still possible.

We chose three major themes: biodiversity regeneration, waste valorisation and emissions reduction as broadly representative of environmental research. Both our biodiversity regeneration and carbon emissions puzzles were inspired by the Farm Zero C project; where researchers, farmers and industry are working together to establish the world's first carbon-neutral dairy farm in Ireland [Rubhara et al., 2024]. The biodiversity puzzle involves players making decisions for farm operations that will have neutral to positive impacts on nature. This aims to highlight the consequences of human activity, both positive and negative. Meanwhile, for the carbon emissions puzzle, they must compare different carbon reducing strategies in various categories, finding a combination that hits an emissions reduction target, whilst also staying within budget. This puzzle aims to convey the fine balance between environmental protection and financial stability for farmers. For the third puzzle, the 2020 edition tasked players with figuring out which sample of bioplastic would meet industrial requirements via a logic puzzle. However, most players found this tricky, so in 2021 it was replaced with a fish waste puzzle. In this puzzle, players are presented with various waste side streams from fishing and must find out what useful products can be made from them. They extract this from the Professor's Dictaphone, connecting information across various audio notes about conferences and meetings. This puzzle aims to convey the importance and benefits of circular design within our economy.

2.7 ▪ *Adapting to different contexts: online, restricted and standard*

The first edition of Back for the Future was delivered in 2020 during the height of the COVID-19 pandemic and, like many public engagement events, had to be conducted entirely online [Roche, Bell, Hurley et al., 2021; Jensen et al., 2022]. This presented several logistical challenges as to how players would be able to interact with the room, solve puzzles and still have control over the game. Similarly, we were concerned with how immersive the experience would be through a screen, with technological limitations and difficulty for players to interact with each other. However, we were able to address most of these concerns by leveraging technology and creative storytelling. For this edition, we had players join via

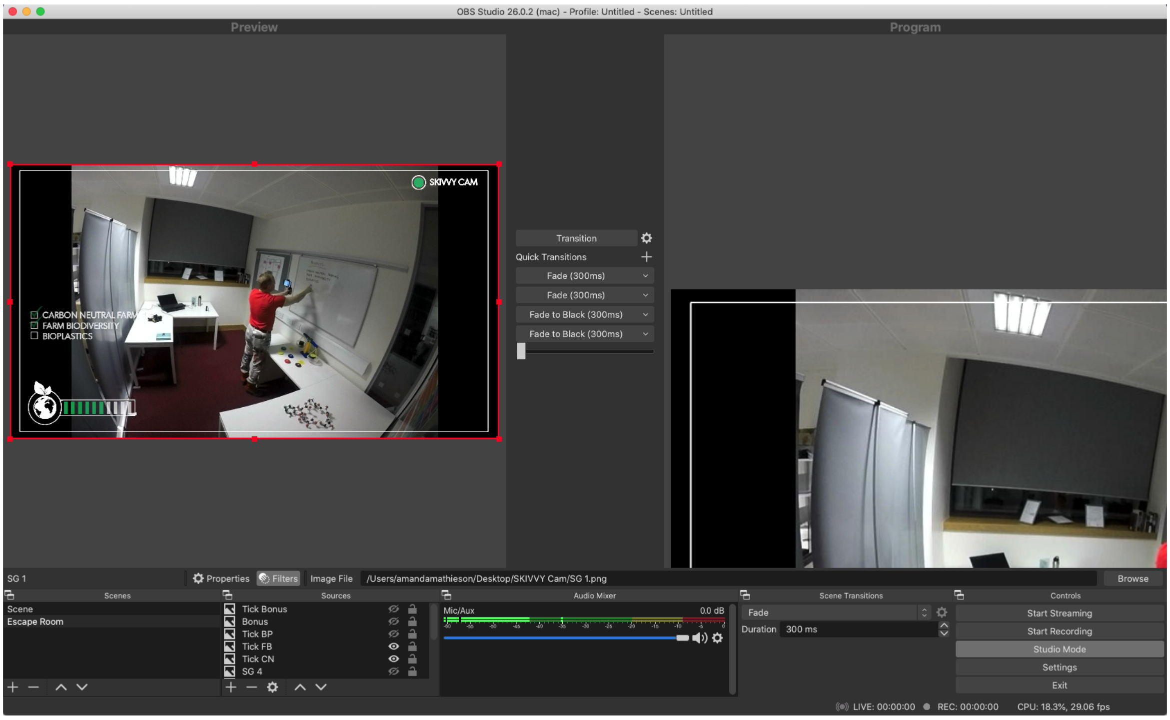

Figure 2. A view from within the OBS software used to overlay graphics to the SKIVVY-bot camera stream. In this instance, two puzzles have been solved, and the sustainability gauge is almost full.

Zoom and view the room through two cameras. One was controlled by the actor to show close ups of objects, and one was mounted to give a CCTV style view of the room (see Figure 2). Players were told the actor was the only team member who had time-travelled to the past and (due to severe jet lag impacting their cognitive abilities), they needed to be guided by other members of the team. Players therefore explored the room by controlling the actor, asking them to show objects or interact with them in specific ways. When information was discovered, players were provided with links to puzzle documents stored online. They were told that an AI character called 'SKIVVY-Bot' had 'scanned' the information and recreated it in their online portal. The AI character was played by a technician who was connected to the CCTV style video stream and communicated with players in the chat. When puzzles were solved, SKIVVY-Bot would announce that 'sustainability had increased' and a sustainability gauge projected onto the CCTV stream would fill up. This was achieved through a streaming software called OBS, where graphics can be overlaid onto webcam streams and altered as needed. During the 2021 edition, we were able to conduct the rooms in person but

Figure 3. Pictures from different Back for the Future editions. The online version in 2020 (top left), the restricted version in 2021 (top right) and the standard version in 2022 (bottom).

with various restrictions. In some venues players needed to be two metres apart and many hosts were uncomfortable with the idea of the actor being present. Therefore, for this version we swapped both the narrative and setup of the room. Now the players were the ones who would time travel and would engage with the room in person, while their team captain (the actor) would guide them from the future on a large screen. The actor would inform players when sustainability had increased and would change their virtual background from a dystopian future to a more positive one as puzzles were solved. Costume and prop changes included donning a wig to show that the actors' hair had 'grown back' due to positive impacts on the future (Figure 3) or replacing a dead plant with a live one.

In the room itself, we crafted a design where puzzle objects were located at up to six different stations, each placed more than two metres apart. Players were allocated a station and could only interact with the objects placed there. We distributed the materials to ensure that players would need to talk to each other and share information to solve puzzles (R). Players were informed that they were restricted to their positions to reduce unnecessary 'impacts on the past' (I). After each game it was necessary to allow time to wipe everything down with rubbing alcohol.

For the 2022 edition, all restrictions had been lifted, and it was now possible to return to a normal format, with all the players and the actor in the room. Our only concern to address was how players would be informed when puzzles were solved. We brought back the AI character, using a Bluetooth speaker and a text-to-speech app to communicate. A technician sitting outside the room would occasionally talk to the players and inform them when 'sustainability had increased'. Similarly, a set of coloured strip lights moved from red, to orange, to yellow, and finally to green as puzzles were solved.

It is worth noting that during the two tours of Back for the Future, it was necessary to adapt the escape room to the various limitations of our venues. Where a suitable room was not possible, we provided our own with a collapsible marquee tent. Occasionally this needed to be erected outside due to lack of space and it was important to provide a heater. For some locations it was easy to find a place for the technician to hide, though in others we needed to be creative, manoeuvring bookshelves. Several venues had poor Wi-Fi which required us to rely on cellular data. Some venues were chaotic and noisy, affecting immersion. In all cases, it was necessary to have good communication with the venues to learn as much as possible about the environment and be adequately prepared.

3 ▪ Methodology

Back for the Future was a STEM escape room designed to engage the public with the work of BiOrbic, the Research Ireland Centre for Bioeconomy. The centre focuses on the development of a sustainable, circular bioeconomy through research on biodiversity regeneration, sustainable farming, waste valorisation and more. The puzzles for Back for the Future were inspired by these research projects and were developed with funding from START, the European Researcher's Night operated by Trinity College Dublin [Jensen et al., 2022]. The first edition conducted 16 games across four nights completely online in 2020, catering to approximately 70 players. The following year, some COVID-19 restrictions had been lifted, allowing us to tour the escape room across Ireland and deliver them in person (within certain limitations). The room toured 4 locations and catered to 129 players across Ireland's national Science Week, funded by Research Ireland. Finally in 2021, the tour went to a total of 6 locations, catering to 252 players and running without any COVID-19 restrictions. This was also funded by Research Ireland for Science Week.

Throughout these editions, we conducted surveys with players, systematic non-participant observations of the rooms [Hardman & Hardman, 2017] and staff debriefs to explore the following questions:

1. Can STEM escape rooms engage those who don't normally seek out science activities?
2. What features of a STEM escape room motivate players to engage?
3. What design elements make a STEM escape room more engaging?
4. How might players react to a STEM escape room?
5. How can the challenges of different contexts and informal learning environments be overcome in STEM escape room design?

While the first four questions drove our exploration of escape rooms, the final question came out of our experience of running three versions of the same escape room, each catering to very different requirements.

3.1 ▪ *Analytical tools*

The escape rooms were analysed in three different ways. Through post-game surveys with players, systematic observations and team debriefs. Close to 100% of players completed the surveys as it was part of the activity, therefore this was our method for counting the number of players. In the online edition, players completed surveys through an online form before being given their game time. For the in-person editions, paper surveys were completed immediately after the game. A number of survey questions were reused from our previous escape room study [Mathieson & Duca, 2021]. We were interested in who would play our escape room and so surveys covered player demographics such as gender, age and ethnicity. We also wanted to explore whether the games would engage those who normally won't seek out science. While it would have been interesting to analyse the level of science capital of our players, as our intervention was short, we decided this type of measurement would be burdensome and we needed a simpler metric. Therefore, players were asked how often they accessed science media such as documentaries, popular science books or science fiction content (Q4) and how often they spoke about science with others (Q5). Responses were recorded and scored as daily (5 points), weekly (4), monthly (3), rarely (2) and never (1). Players' scores from both questions were combined and if this total score was 5 or less, they were categorised as a 'non-enthusiast'. We also asked players what factors had motivated them to play the game the most, to explore how much of a draw the science content would be in comparison to other factors. We recorded their first and secondary reasons for playing and gave each reason an overall score using the equation: *(no. of 1st rankings × 2) + no. of 2nd rankings = overall score*. In terms of intrinsic motivation, we explored how important each of the three psychological needs of SDT were to players, and how the escape room scored in these categories. From 2021 onwards, we asked players about their experience of time passing as this can indicate if participants might be in a flow state [Hancock et al., 2019]. Finally, we were interested in players' motivations after the game, including whether they would talk about the escape room with others and whether they would seek out a similar experience again. These questions might identify if we had achieved our goals of creating a positive experience with science that could encourage further engagement.

Ideally, our escape rooms would have been recorded and researchers trained in observation methods could have explored the games in detail. However, requesting recordings might have impacted who was comfortable participating and interfere with our goal of reaching broad audiences. Funding limitations also meant we could not bring on board additional researchers and therefore, any observational data would need to be collected by our technicians in real time. For this reason, we chose systematic observation as a method that would allow player behaviour to be categorised and quickly tallied, along with other brief notes, [Hardman & Hardman, 2017]. We created a simple rubric for technicians to complete as the game continued and trained them on its use for as much consistency and validity as possible within the constraints. These rubrics were completed for all games and a total of four technicians contributed to the data collection across all three editions. The completion of these rubrics proved challenging, as technicians also had tasks during the game that often diverted their attention. We would have preferred there to have been a separate individual completing the rubric, however we were limited by the number of team members and therefore some data may have been missed. All team members were trained on how to use the rubric and conformity was checked. Our rubric explored the number of players per game, the time taken, the number of puzzles solved, how often players were guided by the actor and how often they abandoned a puzzle and later returned to it. The type and number of player reactions were recorded to explore players' emotional engagement. These reactions included joy, laughter, curiosity, encouragement, boredom, frustration, dislike and sabotage and were developed from observations of previous escape rooms [Mathieson & Duca, 2021]. We had specific descriptors for each reaction category. For example, a joyful reaction might involve a spirited 'yes!' or a 'we did it!', while boredom might be indicated by players disengaging with puzzle content and looking for other ways to be entertained. We balanced the number of positive and negative categories to avoid bias towards one or the other. We also leveraged our previous experiences to devise categories for the atmosphere of the room. This included whether it was chaotic or organised, fun or stressful, noisy or quiet, engaged or disengaged, social or anti-social and positive or negative. Technicians were instructed to only record the categories that stood out to them the most, therefore they did not always make a record in each category. Player strategy was recorded as either group work (all players focusing on the same tasks), delegation (different players focusing on different tasks) or a mixed approach. There was also room for technicians to add their own qualitative notes.

Finally, staff debriefs were conducted as an evaluative exercise. Insights from these conversations contributed to our understanding of how the logistical challenges of each edition were best overcome.

4 ▪ Results: player surveys

4.1 ▪ *Player demographics*

In the online edition, geographic location was collected as players could join from anywhere in the world. While most (73%) were based in Ireland, 27% came from other countries including Malta (14%), the U.S. (4%), Germany (4%), the U.K. (2%), Norway (2%), France (2%) and Hong Kong (2%). Gender was roughly even across the three editions, and we were able to cater to a wide range of ages. When the escape room moved offline, the ages skewed younger as we were able to reach school groups, as well as families and adults.

Table 2. Outlining player demographics across three editions of Back for the Future.

	2020 (Online)	2021 (Restricted)	2022 (Standard)
Responses	59	67	137
Gender	Non-binary 0% Female 61% Male 39%	Non-binary 3% Female 36% Male 58%	Non-binary 3% Female 56% Male 40%
Age Range	9 to 66	12 to 47	6 to 53
Median Age	39	16	15
Ethnicity	White (Irish) 86%	White (Irish) 76%	Not collected

4.2 ▪ *Enthusiasm for science*

Figures 4 and 5 show that our 2020 edition attracted players who already consumed science media or talked about science regularly, with 86% being categorised as science enthusiasts according to our metric. However, our 2021 and 2022 editions, which leveraged the networks of libraries and schools managed to reach broader audiences. In 2021 over half of players were classified as non-enthusiasts at 54%, though this dropped to just over a third (34%) in 2022.

Table 3. Percentage of non-enthusiasts of science calculated as having a score of 5 or less from their combined answers to Q4 and Q5.

	2020	2021	2022
Non-enthusiasts	14%	54%	34%

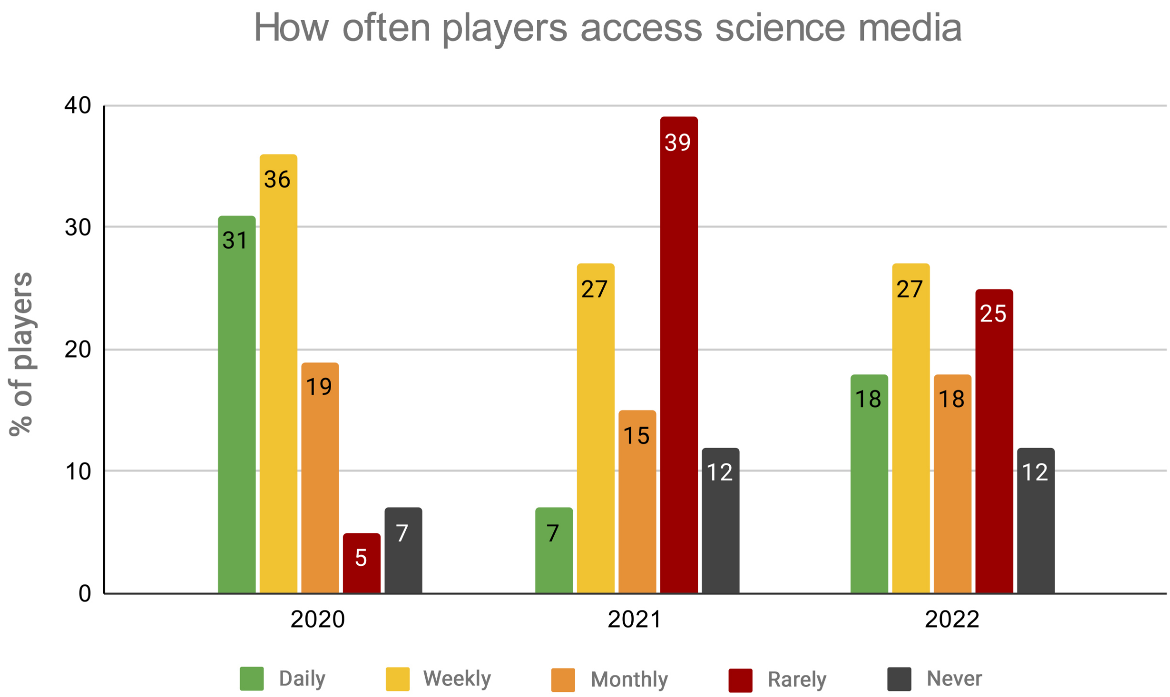

Figure 4. How often players access science media. Survey responses to Q4 from 2020, 2021 and 2022.

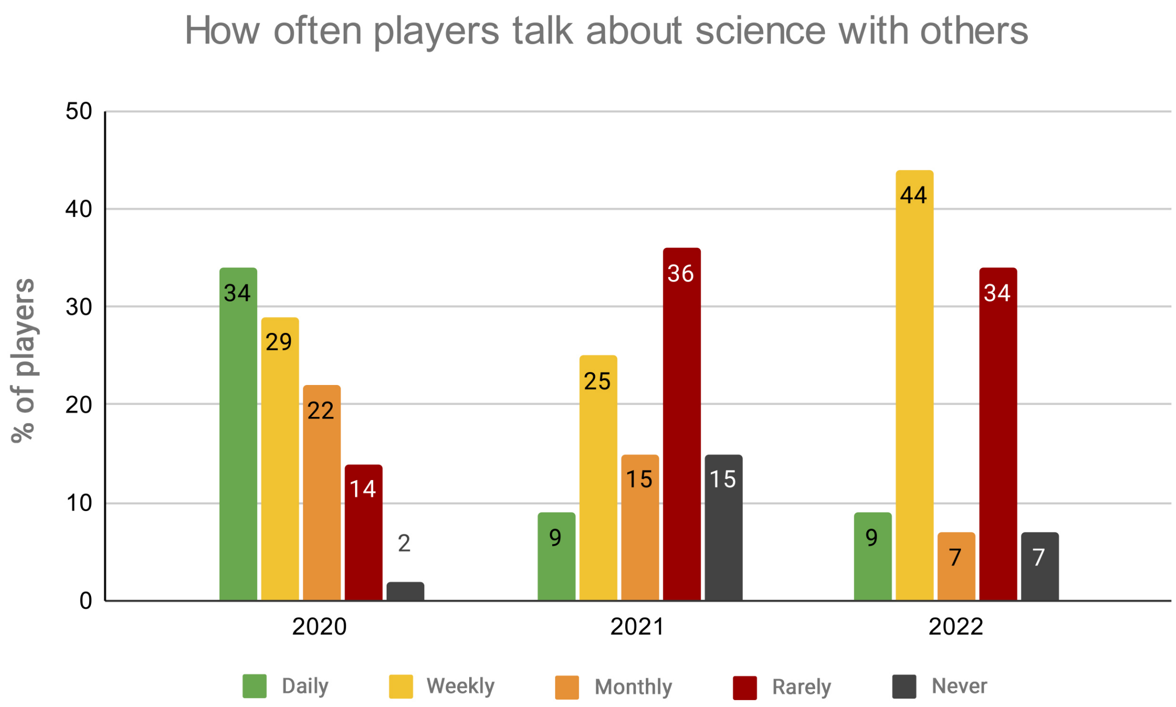

Figure 5. How often players talk about science with others. Survey responses to Q5 from 2020, 2021 and 2022.

4.3 ▪ *Motivation to play back for the future*

Players were asked to rank which factor had motivated them to participate in the escape room the most, as well as which factor was second. This was important to explore if situational interest might be a factor in why audiences were drawn to our escape room. Table 4 shows that in 2020, teamplay was ranked significantly higher (1st) than it was in subsequent years (5th and 6th). Overall, the puzzles and the fact it was a game were popular motivators at 1st and 3rd respectively. Science was never ranked particularly high and came 5th out of 6 options overall, suggesting this should not be a focus for engaging broad audiences.

Table 4. Annual and overall rankings of players' motivations for playing the escape room.

Rank	2020	2021	2022	Overall
1st	Teamplay	Game	Puzzles	Puzzles
2nd	Puzzles	Challenge	Entertainment	Teamplay
3rd	Game	Puzzles	Challenge	Game
4th	Science	Entertainment	Game	Entertainment
5th	Other	Teamplay	Science	Science
6th	Entertainment	Science	Teamplay	Challenge
7th	Challenge	Other	Other	Other

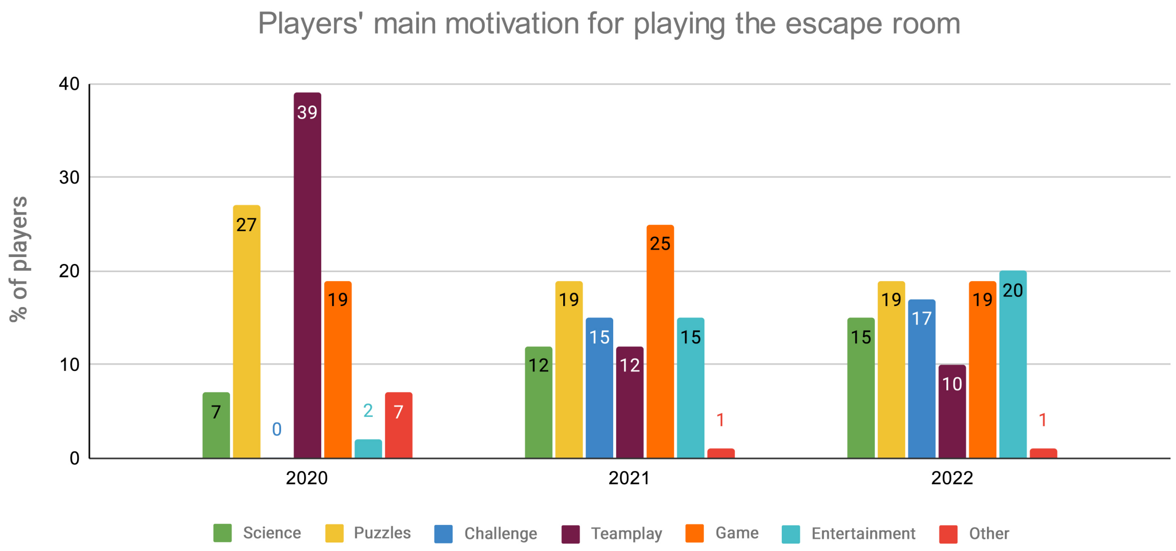

Figure 6. Players' main motivation for playing the escape room across three editions.

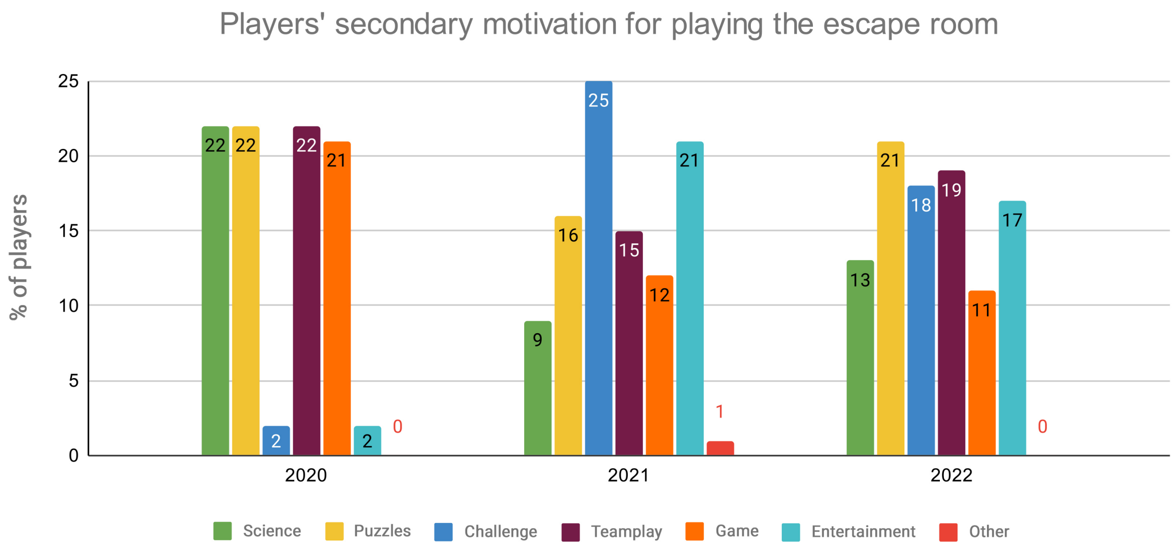

Figure 7. Players' secondary motivation for playing the escape room across three editions.

4.4 ▪ *Back for the future quality and engagement*

To test SDT in the context of escape rooms and our ability to adhere to its principles, we asked players to rate the importance of social interaction, being challenged and having control over the game in their enjoyment of the experience. We also asked them to rank Back for the Future on these factors. Figure 8 shows that all three factors are ranked as important and that our escape room scored well in each category. Importance ratings were mostly consistent, with relatedness showing a downward trend from 2020 to 2022 and autonomy decreasing after 2020. The scores for the escape room itself were also relatively consistent, with Relatedness improving in 2022 after restrictions were lifted. Scores for Autonomy and Competence seem to align with the number of non-science enthusiasts in the sample, starting high when there were few non-enthusiasts, dropping lower when half were non-enthusiasts, and raising slightly when non-enthusiasts made up a third of players.

Despite these fluctuations, scores always remained close to a 4 out of 5 on average. Figure 9 shows that most players felt the time passed quickly indicating immersion, with a slight improvement in 2022 when restrictions were lifted and the actor could be in the room with them. This may indicate the importance of the actor for creating an environment that encourages immersion.

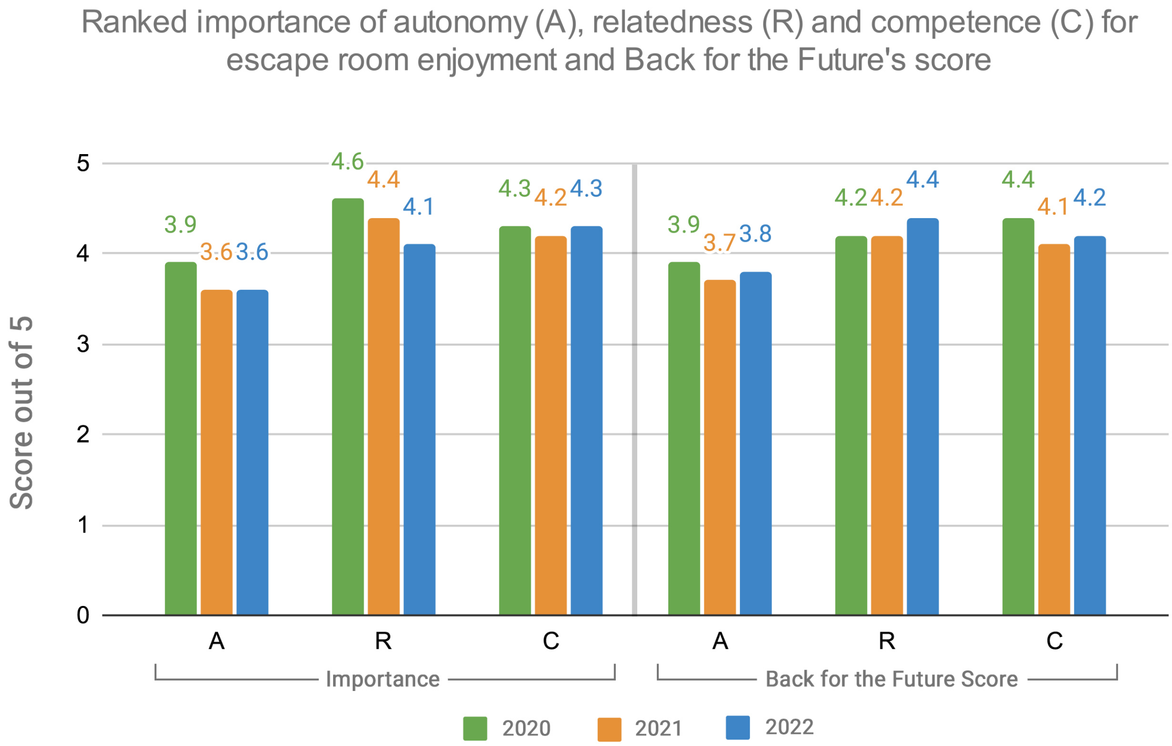

Figure 8. Ranked importance of autonomy (A), relatedness (R) and competence (C) for escape room enjoyment (left) and Back for the Future's score in these categories (right) across three editions.

4.5 ▪ *Post-escape room motivations*

In terms of players' intentions after the game, most were motivated to both talk to others about the escape room (Figure 10) and play another escape room (Figure 11). 2020 showed the highest motivation for both. This dropped significantly in 2021, with more 'quite likely' responses than 'very likely' but increased slightly in 2022. Again, this aligns with the fluctuations in the percentage of non-science enthusiast players.

5 ▪ Results: observations

Figure 12 shows that games were often full or close to full, with 68% of games having five or six players, allowing for relatedness. In terms of player group types, the online version only catered to adult groups and families, as the games ran over the weekend. In 2021 where games ran across the full week, there was a significant increase in the number of student groups, (shown in Figure 13), even though most of the games were hosted in libraries. In 2022 we encouraged libraries to push for more non-student groups and saw a slight increase in families participating.

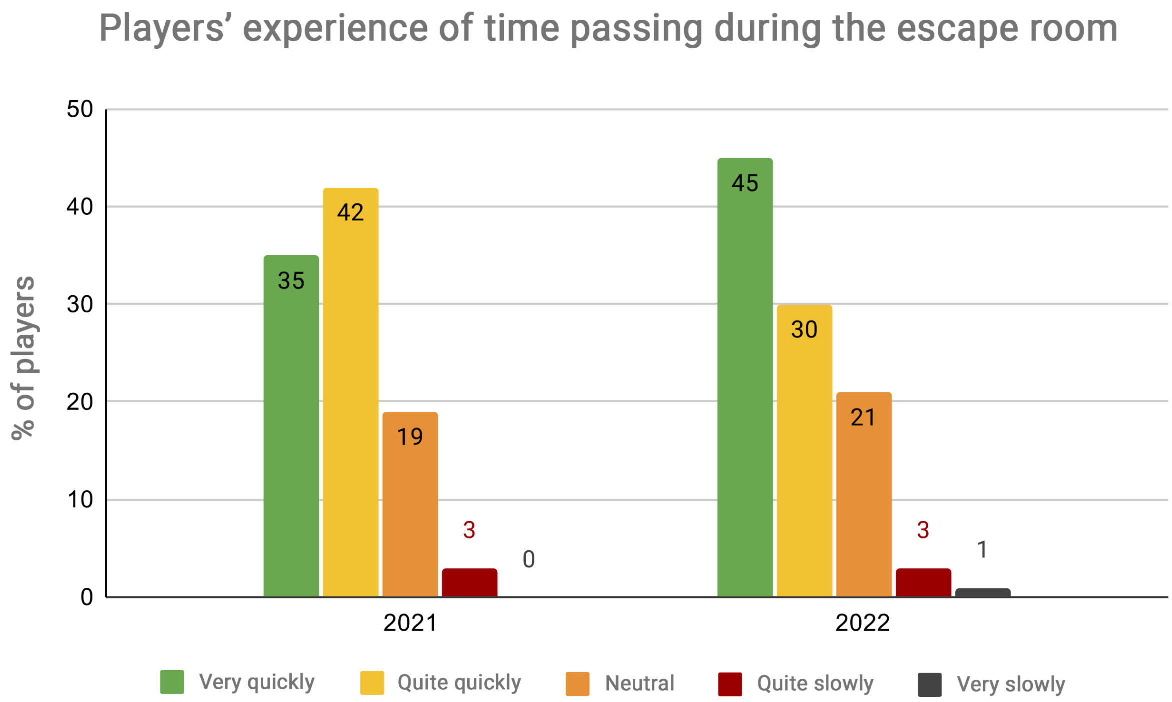

Figure 9. Players’ experience of time passing in the escape room in two editions.

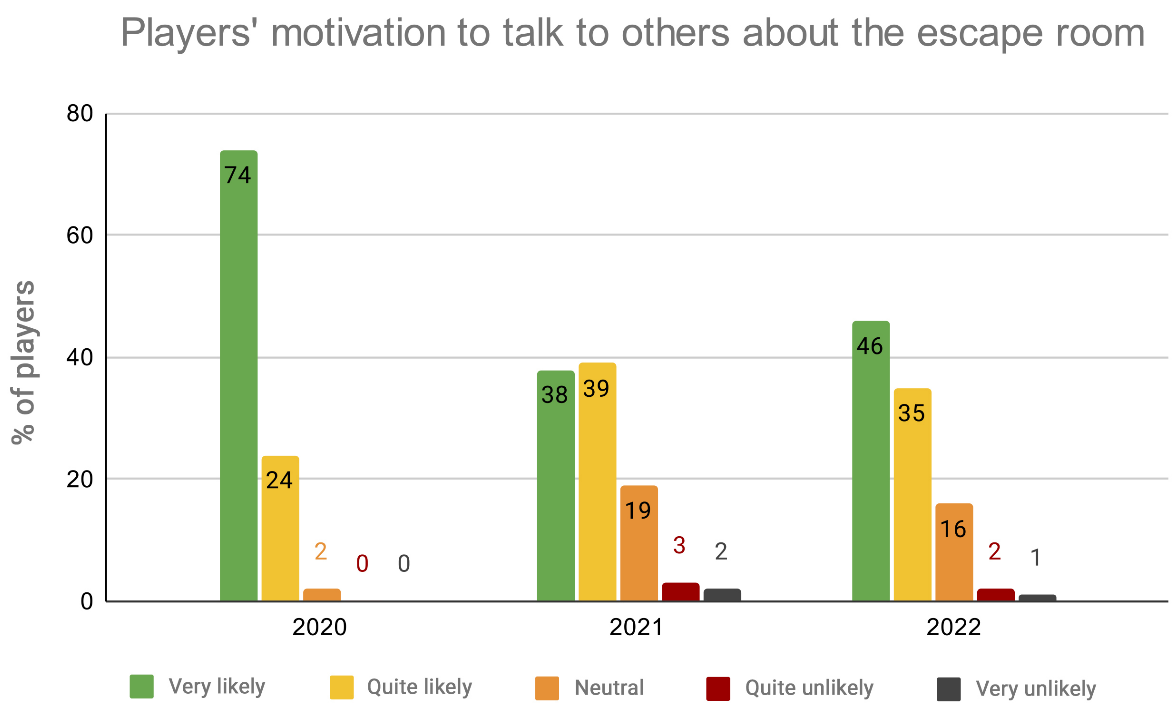

Figure 10. Players’ motivation to talk to others about Back for the Future.

5.1 ▪ *Atmosphere and reactions*

Figure 14 shows there were several trends in the types of atmospheres generated by the games. All games were positive and were mostly social and engaged, signalling behavioural

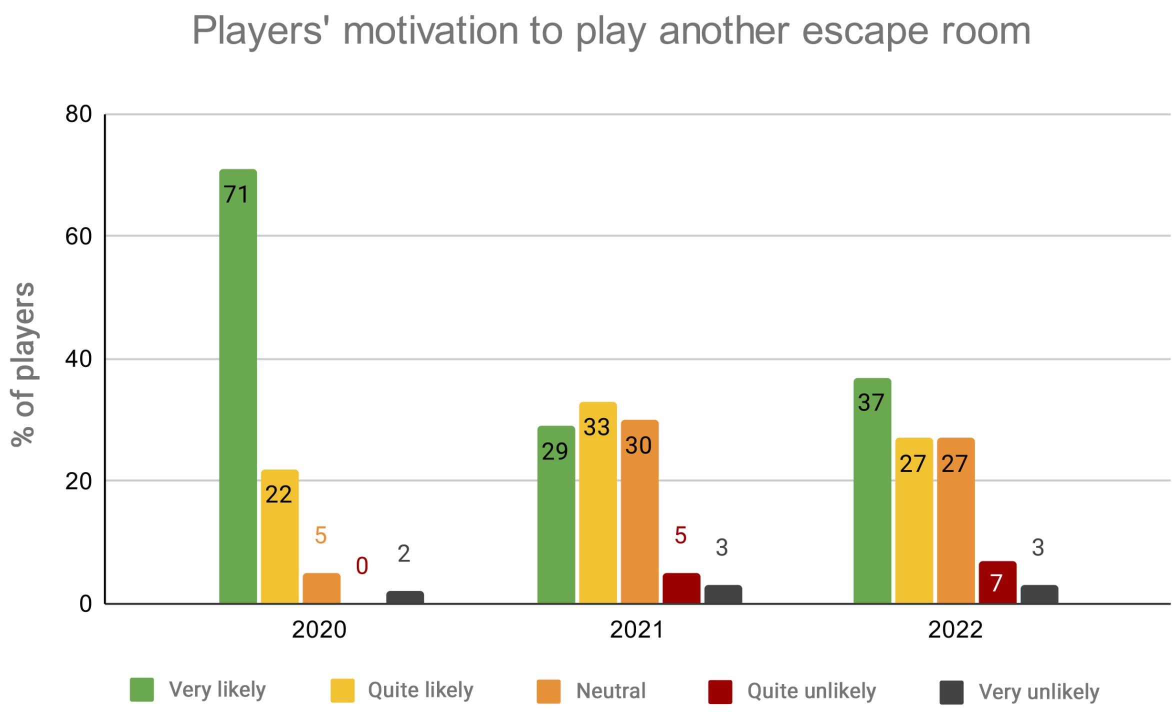

Figure 11. Players' motivation to play a similar escape room.

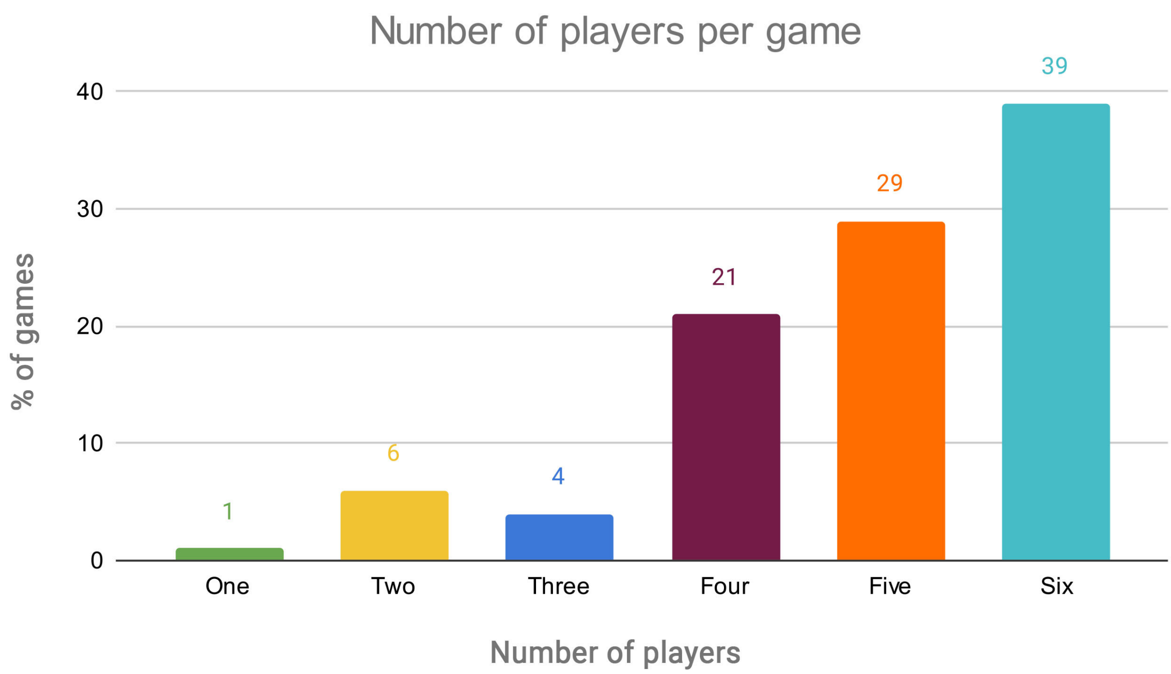

Figure 12. Number of players per game, aggregated across the three editions.

engagement. Games were much more likely to be fun than stressful, and players adopted an organised approach far more often than a chaotic one. In terms of noise, there was a balance between noisy and quiet games, with slightly more on the quieter side, perhaps suggesting cognitive engagement. Players' reactions trended positive overall, though most positive

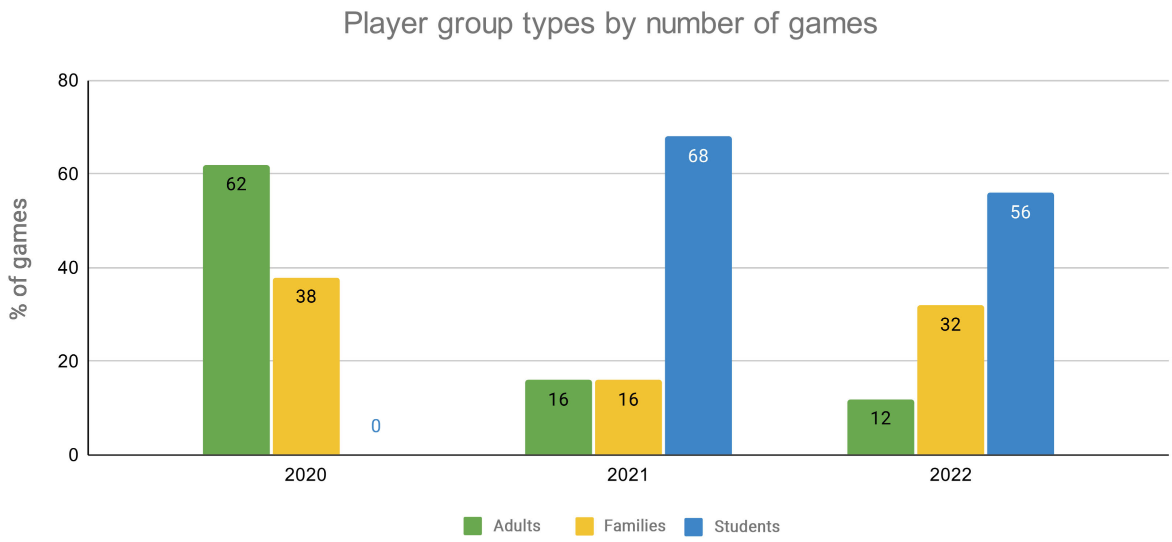

Figure 13. Player group types across the three editions.

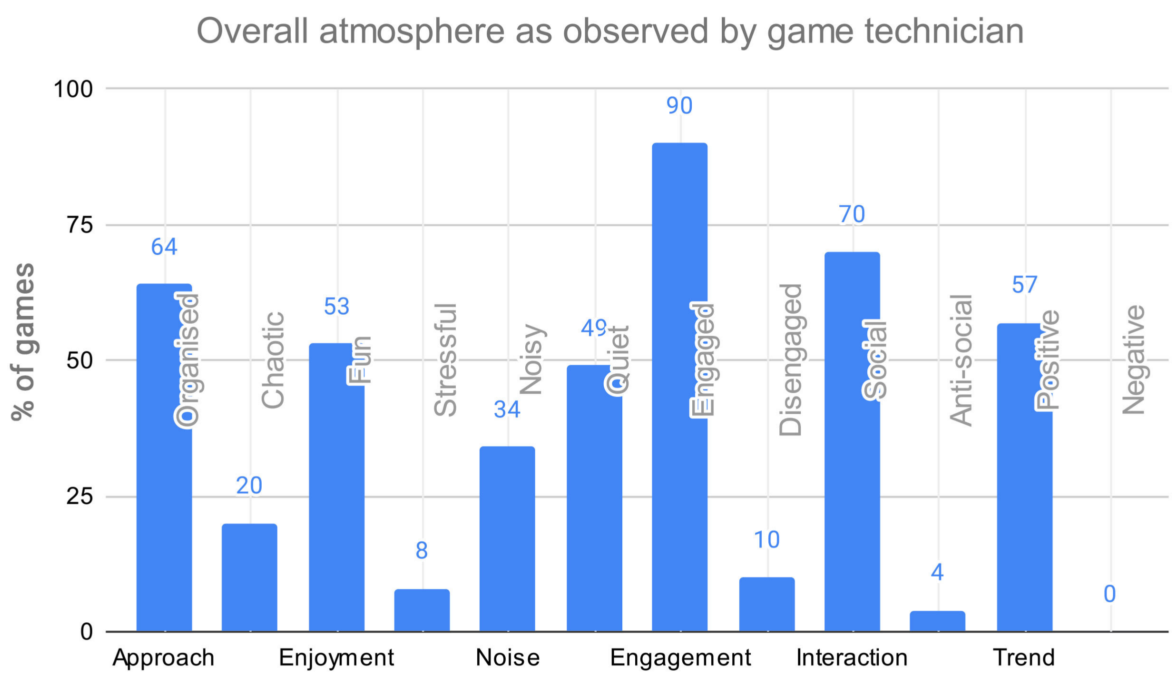

Figure 14. Overall observed atmosphere, aggregated across three editions.

reactions were exhibited in groups rather than individually (Figure 15). This may demonstrate enhanced emotional engagement and satisfaction of the need for relatedness. Joy was the most common positive reaction, followed by laughter and curiosity. Negative reactions were almost exclusively exhibited individually, with boredom and frustration being most common. Observer notes from these games report that negative reactions were temporary, and players exhibiting them would be hooked back into the game by a notable event, such as a puzzle being solved.

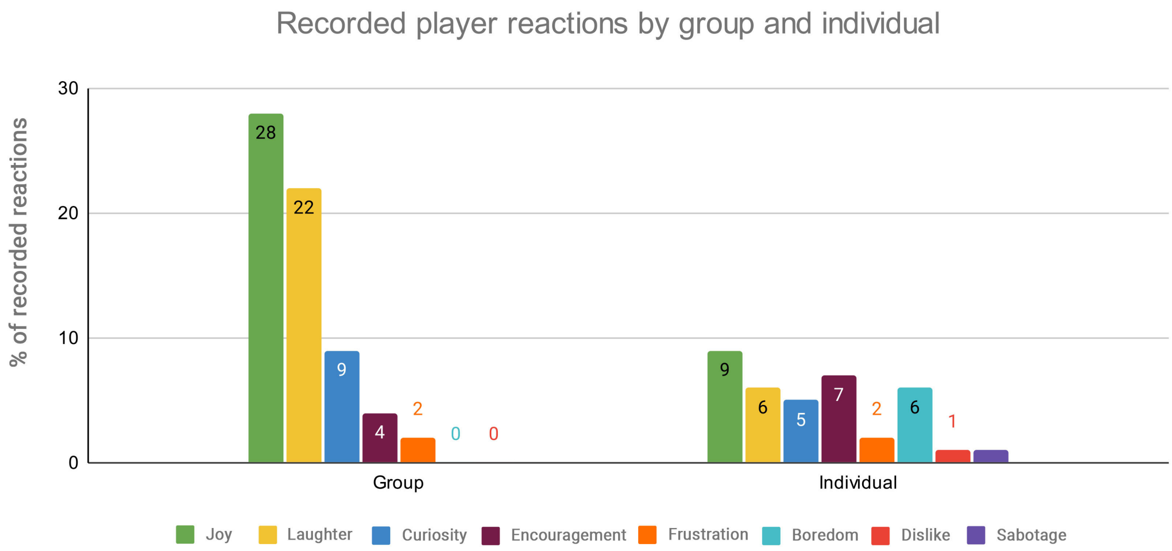

Figure 15. Recorded player reactions by group and individual, aggregated across three editions.

5.2 ▪ *Player support*

While some player groups needed no help from the actor, many did, highlighting the importance of including one. Figure 16 shows there are three peaks in the number of hints required. Where players did need hints, they were most likely to need between 3 and 4. The second highest group needed none, while a smaller number of groups needed many. All

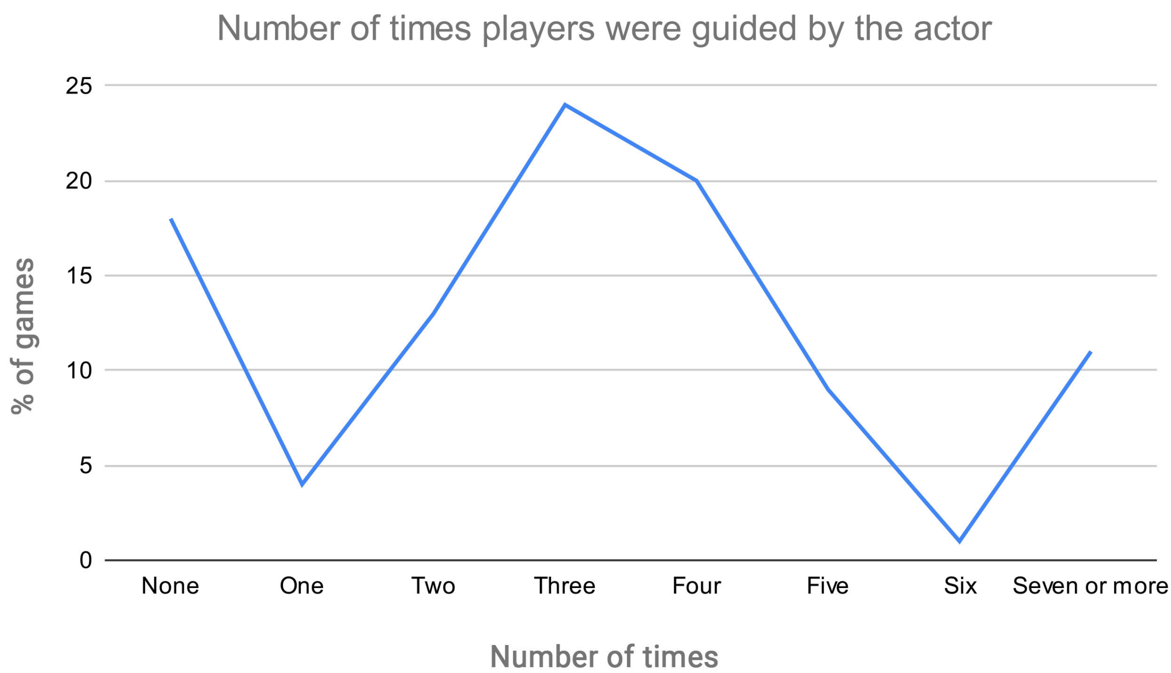

Figure 16. Observer count of the number of times players were guided by the actor.

player groups were able to beat the escape room except for two (3%) and the average completion time was 39 minutes, though this ranged from 27 to 59 minutes. Players only returned to an abandoned puzzle in 26 games (34%) and there was no correlation between this and the size of the group.

6 ▪ Discussion

6.1 ▪ *Engaging non-enthusiasts of science (RQ1)*

Our results indicate that STEM escape rooms can engage those who normally do not seek out science activities. While the online version of Back for the Future had the highest number of science enthusiasts at 86%, this may be due to the escape room being part of European Researcher's Night, requiring players to seek out the games online and book them. Therefore, the audience may have been self-selecting in terms of their enjoyment of science. However, for the 2021 and 2022 editions, we leveraged the networks of local libraries and schools to reach broader audiences and reached 54% and 34% of non-enthusiasts respectively. It is not known why this dropped in 2022. It may be that the impact of the COVID-19 pandemic had led to more people engaging with science content and discussing it regularly, rather than their intrinsic enjoyment increasing. Despite the higher proportion of non-enthusiasts, Back for the Future was awarded similar scores for the quality of its intrinsic motivation factors (SDT) and most players were likely to engage in similar experiences and talk about the game with others. This may lead to informal conversations about science that would not occur otherwise. Meanwhile, observations of the game showed overwhelmingly positive reactions from players, signalling their emotional engagement. This was strengthened by comments from player surveys where the vast majority referred to their enjoyment of the experience. Negative reactions such as boredom were individual and temporary, and these players would often rejoin the game when their interest was piqued. This demonstrates the capacity for escape rooms to re-engage at regular intervals. Interestingly, observations of the game also noted that a good knowledge of science was not necessarily an advantage in the escape room and might even be a hindrance. During one game, a player who had a background in biotechnology became fixated on the model of a molecule they had correctly identified as a bioplastic. They assumed it was related to a bioplastic puzzle and wasted a lot of time on it despite it being a simple prop. This potential for red herrings may allow a more even playing field to be established, where scientific literacy is not always of benefit. Indeed, almost all player groups completed the game, regardless of scientific interest or ability, often supported by the actor.

6.2 ▪ *Play motivators (RQ2)*

Through surveys, we explored which features of the escape room were most important to players' motivation to play. Overall, being able to attempt the puzzles themselves was the biggest draw, followed by the ability to play as a team. While teamplay was second overall, this may have been skewed by 2020 data, where teamplay was ranked as the most important factor. As we transitioned out of the COVID-19 pandemic, the desire for teamplay dropped and this became the 5th and eventually 6th most motivating element. After teamplay, the fact the escape room was a 'game' and it would be 'entertaining' was important, while the scientific content was the 5th most motivating factor of seven options. This provides evidence that escape rooms can generate situational interest, an approach that will be useful for those who need to reach non-enthusiasts of science. Promotion of these activities may benefit from focusing mostly on the puzzles, the game elements and the entertainment factor to draw audiences in.

6.3 ▪ *Player experience (RQ3)*

As described above, players generally felt the time passed quickly during the escape room, suggesting high levels of immersion and therefore cognitive engagement. The difference in loss of time perception between 2021 and 2022 (2022 being higher) suggests that having the actor in the room with players is important and therefore may be a key design choice. The atmosphere of each game varied significantly, depending on each group's dynamics, but did display some general trends. Games were three times more likely to be organised than chaotic, almost seven times more likely to be fun than stressful, slightly more likely to be quiet than noisy, nine times more likely to be engaged than disengaged, twenty times more likely to be social than anti-social and consistently more positive than negative. Similarly, there were overwhelmingly more positive reactions than negative, with laughter and joyful reactions being common, followed by curiosity. Laughter was often tied to interactions with the actor (R), particularly when making jokes that related to the narrative of the room (I). Joy was often linked to puzzles being solved (C), or an individual making a significant contribution (B, R). Boredom, followed by frustration were the most common negative reactions, however these were almost always displayed by individuals rather than groups and were often temporary. For example, one player might grow bored or frustrated and disengage with the game. Then, when the rest of the team celebrated solving a puzzle or something new was discovered, the player's curiosity would be piqued and they would re-engage. Therefore, inserting plenty of opportunities for positive feedback (F) and game progression (C) may enhance re-engagement potential.

According to our systematic observation tallies, over half of the games adopted a strategy of group work, with 11% delegating tasks and just under a third switching between the two. Groups were often large, with 68% having 5 or 6 players (Figure 12), an ideal size according to [Veldkamp, van de Grint et al., 2020]. This meant there were plenty of players to keep working on the puzzles, even when one or two became frustrated or confused. This may also be the reason we did not observe players returning to abandoned puzzles as much as expected, as other players were completing them. The solving of puzzles was not tracked to individual players but in future editions it may be interesting to ask players how much they felt they were able to contribute to the outcome of the game. Generally, it was common for large student or adult groups to split into smaller teams and solve puzzles concurrently, with some players drifting between the teams at random. The latter suggests players can move between puzzles as they choose (A) and can find where they can best contribute (B), highlighting the importance of including a diversity of puzzles. For family groups, it was common for parents or older siblings to support younger members, unless puzzles were complex, at which point they would take the lead. Meanwhile, younger siblings were often better at finding hidden items, further confirming the benefit of diverse puzzles and tasks. In terms of actor intervention, just over half of the games required at least 3 or 4 hints from the actor, with other peaks at many hints or no hints at all. This is an interesting pattern which may reflect levels of confidence or ability.

6.4 ▪ *Engaging design elements (RQ4)*

While our findings do not directly link positive outcomes to our specific design choices, they do demonstrate that our escape room was enjoyable for a variety of audiences. This suggests that the theoretical approaches applied to our design likely had a positive impact on the engagement potential of the game. Through player surveys we have shown that the needs for intrinsic motivation purported by SDT are all deemed important to players. Similarly, by focusing on 'broadening the field' and ensuring that prior scientific knowledge is not needed to solve our puzzles, we have created an experience where school children can compete with adults and non-enthusiasts can compete with science lovers. We have also explored our players' level of flow by asking about their experience of time passing. Most felt the time passed quickly, particularly where the actor was present to encourage engagement and facilitate immersion. Ultimately, more research is needed to not only explore the contributions of these different design elements but also the interplay between them.

6.5 ▪ *Overcoming contextual challenges (RQ5)*

Through staff debriefs, we explored how we had overcome the unique challenges brought by each edition of Back for the Future. In all cases, a common theme for success was the leveraging of additional resources, (particularly technology), while being creative with our storytelling. While we were initially concerned with the level of immersion and social interaction of an online STEM escape room, this edition did engage players. Interestingly, this is the only edition where social interaction (R) scored higher than other intrinsic motivation factors and teamplay was ranked as players' first motivation for playing the game (dropping to 5th and 6th in later years). In the context of the COVID-19 pandemic, it is likely that the psychological need for relatedness was the least satisfied in players' day to day lives and finding an activity that allowed for social interaction was more important. This may be an insightful lesson for science communicators in general. By remaining aware of the broader context in society and understanding our audience's most pressing needs, we may be able to design engagement activities that are much more appealing and impactful.

Creative and on-the-spot storytelling is also an important tool, particularly where a lack of resources might impact the production quality of a non-commercial escape room. If a limitation (such as not being able to move from the spot) can be explained through the setting of the story (i.e. needing to remain still to reduce impacts on the past), players are still able to enjoy the game and be immersed in the experience which is important for sustaining flow. Similarly, having actors who are trained in improvisation can be very useful for overcoming issues on the day. For example, technical lags were explained by the actor as the impacts of players 'altering the time-space continuum'. Even obvious errors can be laughed away with a timely joke and often players are only too keen to join in and become emotionally engaged. It is therefore the authors' strong belief that escape rooms can be adapted to any context and remain engaging, if some creativity and humour are applied.

6.6 ▪ *Limitations*

While we believe this study can provide interesting empirical data that is not yet explored in science communication literature, several limitations should be acknowledged. The sample size was small, limited by the capacity of each game to 6 participants, and the games were delivered largely in the Irish context. It is not possible to generalise to wider populations, and more research should be conducted in different settings. Outside of our school groups, participants were largely self-selecting given the nature of informal science communication and there may be audiences which an escape room will exclude. Our reliance on self-reported data in the surveys may affect reliability, as responses can be influenced by recall errors or social desirability bias. While we have attempted to triangulate this with observation data, this is also subject to observer bias and cannot illuminate the internal experiences of the players. Additionally, we have already highlighted limitations related to budget and team members, which resulted in our observations being carried out by game technicians who may have been distracted by their roles. Funding limitations also restricted us to data collection during the events only, without the potential for follow-up. Therefore, we could only record players' reported intentions rather than their real behaviour post-game. Taken together, the results of this study seek to highlight potential conclusions rather than offer concrete evidence and further research is required.

7 ▪ Conclusion

There is a wealth of evidence to show how escape rooms may be used as a formal learning tool. Here we evidence their use in informal environments for different goals, such as reaching broad audiences, engaging them more significantly and motivating them towards future engagement with science. The puzzles, gamified setting and entertainment factor of escape rooms has appeal with broader audiences, providing enjoyable experiences that players want to repeat. Strategic design choices can allow for enhanced engagement beyond simple participation and towards deeply cognitive and affective experiences. They also have the potential to level the playing field, allowing those without strong science backgrounds to perform just as well as those with them. An appropriate story, a talented improv actor and careful structuring of the puzzles and their pathways can be highly beneficial to achieving these outcomes. These elements become even more important when escape rooms are delivered in different environments and unexpected contexts. Therefore, if implemented correctly, escape rooms are a highly adaptable format and may be leveraged by science communicators to better engage their audiences.

Acknowledgments

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Back for the future survey

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