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Escape boxes: Bringing escape room experience into the classroom

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Abstract

In this paper, we present an escape box as a means to introduce the escape room concept into classrooms. Recreational escape rooms have inspired teachers all over the world to adapt the popular entertainment activity for education. Escape rooms are problem-based and time-constrained, requiring active and collaborative participants, a setting that teachers want to achieve in their classroom to promote learning. This paper explores the adaptation of the escape room concept into educational escape game boxes. These technology-enhanced escape boxes have become hybrid learning spaces, *merging* individual and collaborative learning, as well as physical and digital spaces. The design of the box with assignments on each side puts users face to face with each other and requires them to collaborate in the physical world, instead of being individually absorbed in a digital world. The developed box is a unique concept in the field of escape rooms; the content is adaptable. This paper describes the process leading to the design criteria, the design process, test results and evaluation, and provides recommendations for designing educational escape rooms.

The rise of escape rooms in education

Escape rooms have been finding their way into education worldwide (Breakout EDU, 2018; Sanchez & Plumettaz-Sieber, 2018). Escape rooms are live-action team-based games in which players encounter challenges in order to complete a quest in a limited amount of time. The quests in the first-generation games were “escapes” from a room. Nowadays, the quests vary, players may solve a murder mystery or break into a vault (Nicholson, 2015). Parallel to their immense popularity in the entertainment industry, escape rooms are gaining popularity as teaching and learning environments. It is remarkable that the design of educational escape rooms started bottom-up with enthusiastic teachers who have shared their materials on platforms such as Breakout EDU, which has about 40,000 members (Breakout EDU, 2018; Sanchez & Plumettaz-Sieber, 2018). Teachers

Practitioner Notes

What is already known about this topic

- Recently, escape rooms have been finding their way into education. However, most of the, scarce, studies that have been published are case studies.
- Teachers implement escape rooms to create active learning spaces, where learners need a combination of knowledge and skills to solve the subject-based activities.
- Teachers mention that their educational escape rooms are based on digital escape games and/or their experience as players of escape rooms.
- An inventory study of 175 escape rooms in the entertainment industry hints at important escape room game elements in design.
- Although teachers and pupils are enthusiastic about the educational potential of escape rooms, limitations of educational settings and challenges for implementation in the classroom are described.
- Hybrid learning spaces are a relatively new research discipline. The concept of *hybridity* offers instructional designers a perspective for more and/or innovative solutions in educational settings.

What this paper adds

- This paper gives an overview of the differences in settings between recreational and educational escape rooms. Furthermore, limitations and boundary conditions for escape rooms in education are assigned, resulting in design criteria for the development of educational escape rooms.
- It gives insights in the design process of an educational escape room, taking into account these differences, limitations and boundary conditions.
- The paper explores and shows how the concept of *hybridity* can broaden the solution space for educational designers.
- It informs on the process of educational designers co-creating learning spaces together with secondary education pupils like the intended audience, or with undergraduate and graduate students, who are close to the experiences and interests of the intended audience.

Implications for practice and/or policy

- Guidelines and recommendations inform educational designers and educators on uncovered aspects in designing an escape room game for education.
- We advocate co-creation of learning activities and spaces with the target audience, teachers, teacher educators, educational designers and engineers in electrotechnology and mechanics. Each group has an undocumented wealth of specific experience. The multiple perspectives lead to innovative solutions which align with the educational needs.

develop the rooms based on escape room video games, and/or their experiences in recreational escape rooms (Franco & DeLuca, 2019). Their aim is to create escape rooms to explore an active learning environment which is said to increase pupils' motivation and/or engagement and fosters learning, while using or developing team work and communication skills (Borrego, Fernández, Blanes, & Robles, 2017; Cain, 2019; Hermanns *et al.*, 2017). Learners appreciate the diversity of puzzles of a problem solving and discovery nature, and the need for physical attributes and collaboration. Furthermore, learners described being more active, needing to think more thoroughly than in a regular lesson and enjoying the feeling of autonomy (Cain, 2019; Giang *et al.*, 2018; López-Pernas, Gordillo, Barra, & Quemada, 2019; Watermeier & Salzameda, 2019). One study with 84 participants tested for gender bias (López-Pernas *et al.*, 2019). No gender bias was detected in any of the questions in the surveys that addressed the escape room activity.

Teachers' and learners' perceptions seem to correspond with Linn's four principles to support knowledge integration; making learning accessible, making thinking "visible," helping pupils to learn from each other, and promoting autonomous learning (Linn, 2013). In a systematic review on educational escape rooms, limitations and challenges of implementation in the classroom mentioned by teachers were gathered: restrictions in budget, in classroom availability and time to prepare classes (Fotaris & Mastoras, 2019). Logistic challenges are the large groups and the restricted time to set up a game. On top of that, the activities should be closely aligned to the curriculum (Cain, 2019; Hermanns *et al.*, 2017; López-Pernas *et al.*, 2019).

Apart from its educational potential, the escape room concept has the potential to create so-called *hybrid learning spaces* (Trentin, 2016). With the spread of network and mobile technology, clear distinctions between physical and digital spaces are erased, introducing a so-called *hybrid* conception of space. Adapted to the classroom, the hybrid learning spaces offer the possibility of engaging pupils in a rich variety of activities, combining elements of two worlds: activities with physical tools, fostering experiential learning, face-to-face support by teacher and peers, and the opportunities afforded by digital technology (Stommel, 2012; Zhang, 2008). Nowadays, hybrid learning spaces can also involve bridging other dichotomies in education, for example individual and collaborative learning, opening more or different learning opportunities (Köppe, Nørgård, & Pedersen, 2017; Stommel, 2012).

In the current study, we explored the implementation of escape rooms in education. The leading research question is: how can the escape room concept be adapted to education, taking into account limitations and challenges of educational settings? This paper focuses on the design process in three cycles of the escape room concept into escape boxes and its feasibility in education.

Theoretical background

First, this section describes the escape room concept and design characteristics. Second, differences in recreational and educational settings are explicated, resulting in design criteria for the educational escape room. Lastly, the role of ICT in educational escape rooms is described, as we explored how ICT could address the design criteria set.

The escape room concept and design characteristics

The escape room concept involves a common goal, together with a need for collaboration to solve problems in time and achieve that goal. The activities can take various forms and styles that are up to the creativity of the designer, as shown by Nicholson's (2015) inventory of 175 escape rooms. Players transfer from their real-life context into the game context, such as a crime scene or a submarine in the past. Therefore, the immersion of players during gameplay is very important. Immersion is the process, where a player is lured into a story or particular problem (Douglas & Hargadon, 2001). In games, it is used to a get a player engaged; solving challenges and finishing the game (Annetta, 2010). Using Jenkin's concept of Narrative Architecture (Jenkins, 2004), Nicholson advises developers consistency in the game context (time and place), the character of the players, the activities, the tools and the props. This prevents cognitive dissonance, fosters immersion and therefore engagement of the players (Nicholson, 2016).

Within an escape room, all problems, challenges or activities are called puzzles. Escape rooms are inherently team-based games and the puzzles tend to ensure that every member of a team is active and can contribute (Nicholson, 2015). The puzzles can be categorized as: (1) cognitive puzzles that make use of the players' thinking skills and logic, (2) physical puzzles that require the manipulation of artifacts to overcome a challenge, such as crawling through a laser maze and (3) meta-puzzles, the last puzzle in the game which is often connected to the narrative. Cognitive puzzles seem to predominate in escape rooms (Wiemker, Elumir, & Clare, 2015). Nicholson (2015) identified four ways of organizing the puzzles, see Figure 1. In an open structure, the players can solve different puzzles at the same time. All puzzles need to be solved before the last one. The sequential structure presents the puzzles one after another; solving a puzzle unlocks the next, until the meta-puzzle can be solved. The path-based structure consists of several paths of puzzles. To solve the meta-puzzle, information from previous puzzles is needed. Combining some of the basic structures produces a complex, hybrid structure, which may take, for example, the form of a pyramid.

To solve the puzzles, players require skills such as searching, observation, correlation, memorization, (logic) reasoning, mathematics, reading and pattern recognition (Wiemker, Elumir, & Clare, 2015). After the gameplay, the gamemaster debriefs the players on the process and what they have achieved (Nicholson, 2015). The knowledge and skills required during an escape room, the reflection about what was accomplished, and the necessity to work in teams are appealing to teachers who want to create active and/or hybrid learning spaces (Fotaris & Mastoras, 2019). When introducing the escape room concept in the classroom, educators have to take into account differences between recreational and educational settings.

Recreational versus educational escape rooms

Goals

In contrast to escape rooms in the entertainment industry, educational escape rooms are primarily designed as learning environments. A boundary condition for use in education is that puzzles need to be aligned with the curriculum, and learners need their subject knowledge and skills to reach the intended learning goals (Cain, 2019; López-Pernas *et al.*, 2019). However, in an escape game, players are focused on achieving the game goal within the time limit, and less, or not, on achieving educational goals (Hermanns *et al.*, 2017). So, the design needs to ensure that by reaching the game goal, learners achieve the educational goals set. Biggs (2011) refers to alignment in aspects of an educational design as *constructive alignment.* A resulting design criterion for educational escape rooms is to align *learning goals and puzzles*.

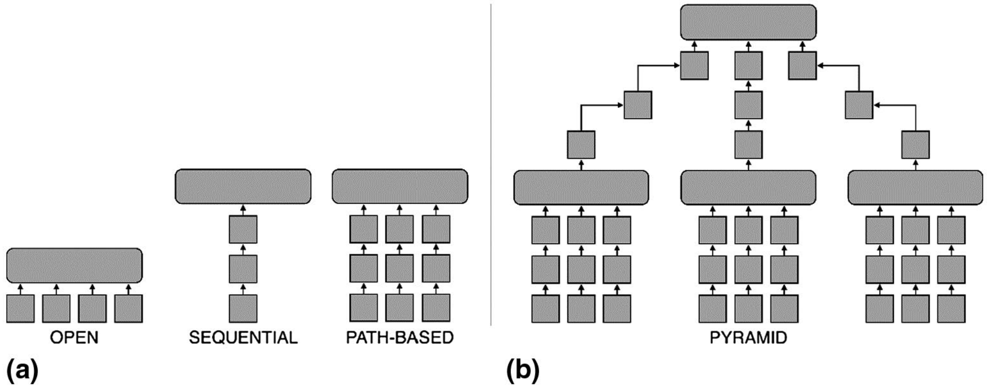

Figure 1: Puzzle structures in escape rooms: (a) basic structures: open, sequential and path-based; (b) a complex, hybrid structure, such as a pyramid. Squares are puzzles and rectangles are meta-puzzles (adapted from Nicholson, 2015)

Pedagogy

The escape room concept involves a common goal, together with a need for collaboration to solve problems and achieve that goal in time. In education, social constructivists advocate that learners construct knowledge in interaction with each other. Based on social constructivism, teachers implement escape rooms to stimulate team-based or collaborative learning (Fotaris & Mastoras, 2019; Hermanns et al., 2017). A resulting design criterion for educational escape rooms is to *ensure active participation within teams*.

Team organization

In recreational escape rooms, teams usually play one after another (Nicholson, 2015). In educational settings, teachers prefer to play with all teams at the same time in one classroom, instead of one team after another, as it reduces the teacher's time and the occupancy of a classroom (Cain, 2019; Fotaris & Mastoras, 2019). Teams playing at the same time might increase competition, resulting in teams working harder. However, it could also distract players and has some drawbacks in relation to the immersion in the game context, such as a "specific" appeal to the team to rescue someone. A resulting design criterion is to *create confined learning spaces*.

Location

In the entertainment industry, an escape room usually takes place in one or more connected, permanent rooms. In an educational setting, classrooms are used for different classes and courses. Consequently, teachers have limited time to set up and clear away activities (Cain, 2019; Fotaris & Mastoras, 2019). A resulting design criterion for educational escape rooms is enable *fast and easy handling*.

Materials

In education, budgets are usually restricted. As a consequence, teachers have limited time and budget for (developing) teaching materials and favor reusable and multipurpose teaching and learning materials (Fotaris & Mastoras, 2019). The consequent design criterion is, in short, *develop sustainable materials*.

Staging

A classroom setting limits the staging (scenery and props) and diminishes immersion in the game context. The game context is important as it links puzzles in a meaningful way. Moreover, as education targets learning for a broader context than the classroom, a game context has the potential to broaden the learners' scope and confront them with outside world problems or socio-scientific issues, such as the pollution of the sea by plastics which is known as plastic soup. The design criterion that facilitates the learners' transfer from the classroom context to the game context is to *foster immersion*, as advised in educational game design literature (Annetta, 2010; Visch, Vegt, Anderiesen, & Van der Kooij, 2013). In addition, immersion is also important to draw the learner into the activity, as it is not as voluntary as a recreational escape game.

Guiding

In the entertainment industry, game masters video monitor and guide teams from adjacent rooms (Nicholson, 2015). Teachers prefer to guide teams within the same room, instead of from an adjacent room (Cain, 2019; Hermanns *et al.*, 2017). Video monitoring limits their view and hearing of group dynamics and the conceptual development of learners. Therefore, the challenge in educational escape rooms is to balance between the teacher guidance and the learners' feeling of autonomy during the escape room gameplay (Giang *et al.*, 2018; Visch *et al.*, 2013). We set as a resulting design criterion to *foster autonomy* for learners.

Table 1 summarizes the main differences in common recreational and educational settings, the boundary conditions and resulting design criteria for the escape room design. As we explored

Table 1: The main differences between recreational and educational escape rooms. The boundary conditions for educational escape rooms and resulting design criteria

Escape room	*Recreational*	*Educational*	***Boundary conditions for educational escape rooms***	***Design criteria educational escape rooms***
Goals	*Primarily* on entertainment	*Primarily* on learning	Puzzles align constructively to curriculum, learning goals, subject knowledge and skills are required to solve them	Align **learning goals and puzzles**
Pedagogy	Players collaborate	Learners work & learn collaboratively	All learners are active; work and learn collaboratively	Ensure **active participation** within teams
Team organization	Teams play one after another	Learners work in the same room at the same time	Teams play at the same time and in the same room, which might distract learners from task	Create **confined learning spaces** within the larger room
Location	One or more connected permanent rooms	Classroom with time slots	Restricted setup and reset times	Enable **fast and easy handling** of escape game
Materials	Preparation time & budget varies	Restricted preparation time & limited budget	Reusable & multipurpose materials	Develop **sustainable materials**
Staging	Fixed scenery, props, sound and smell	Classroom setting	The learners' transfer from the classroom context to the game context	Foster **immersion** within the class context
Guiding	From an adjacent room	Within the same room	Balance teacher guidance and learners' feeling of autonomy	Foster **autonomy**

how ICT can address some of the design criteria that have been set, the next section describes the current role of ICT in educational escape rooms.

Educational escape rooms and the role of ICT

A review of 39 studies on educational escape rooms describes, among other things, how ICT was implemented in 51% of the games. ICT served various goals in escape rooms, depending on the educational discipline implementing the escape room (Veldkamp, van de Grint, Knippels, & van Joolingen, 2020). The medical disciplines and the disciplines science, technology, engineering and mathematics (STEM) are pioneers in the implementation of educational escape rooms.

In medical escape rooms, ICT is mainly used to structure the gameplay, such as locking new puzzles with a QR code, or digitally locking a cardio photo. In addition, medical students needed ICT to search and interpret medical information.

In the field of STEM education, the use of a specific ICT tool is part of the learning objectives in half of the escape rooms. The tool is also used to structure the game and ease the work of the teacher, which is especially important for large groups. In the studies, research is announced to explore ways in which ICT can foster scaling up the escape room concept for large enrolment courses. The development of a digital hint systems to prevent groups lagging behind too much is mentioned regularly. In summary, ICT is used in educational escape rooms (1) to unfold the narrative, puzzles, codes and/or additional information, (2) to foster immersion and to support the narrative, for example with movie messages, (3) to foster learners' subject related ICT skills, and in 3 of the 39 studies, and (4) to monitor the safety of learners and their progression from an adjacent room.

Based on these practices, we implemented various ICT tools to address the following boundary conditions and resulting design criteria for the escape room:

1. active participation by all learners; foster team work and collaborative learning,
2. learners' transfer from the classroom context into the game context; foster immersion,
3. a balance between teacher guidance and learners' feeling of autonomy; foster a feeling of autonomy.

From escape room to escape box

This section starts with a brief introduction of the design methods used for all three cycles in the project, after which each cycle is described in more detail. Our focus on the design process of the educational escape room is a characteristic of design-based research. Design-based research in education aims to develop knowledge about domain-specific learning in relation to the educational materials. The design of the educational materials is a crucial part of the research. These materials can be adapted during the research, which is cyclic in nature (Bakker, 2018). We followed the design cycle of Frederik and Sonneveld (2007), comprising the following steps with feedback loops: analyse and describe the design problem, set design criteria, develop (sub) solutions, design, build, pilot test, test in practice and evaluate the prototype.

In the first cycle, the prototype was pilot tested on the target audience for the escape game (secondary school pupils). The second cycle comprised a test sequence, as advised by escape room designers (Clare, 2016), that is, first, test the escape room with experienced gamers, then on critical friends (non-gamers), and finally on the target audience. In the third cycle, this test sequence was extended with various types of educators, such as secondary school teachers, teacher educators, educational researchers. This completed the multiple perspectives important in educational game development: learner, gamer and educator.

After the first cycle, design teams were extended with engineers in mechanics. In the third cycle, engineers in electrotechnology joined. As more parties co-created together, a participatory design was increasingly applied during the successive design cycles (Simonsen, & Robertson, 2012).

Design cycle one

The first cycle was initiated and performed by two secondary school pupils (16 years), as their final secondary school science assignment.

The goal was to develop an escape room to formatively assess knowledge of mathematics in grade 10 (15–16 years). In January 2017, there were few academic publications on escape rooms. Therefore, the pupils interviewed five developers of educational or recreational escape rooms. Crucial design aspects such as team size, duration, puzzle structures and "do's and don'ts" during the design process were addressed.

The design criteria

In the first cycle, the following criteria were addressed: to align learning goals and puzzles, ensure active participation within teams, sustainable learning materials, create confined learning spaces, enable fast and easy handling.

The resulting prototype was a pop-up escape room consisting of five hexagonal escape boxes. Each team sits around a box. On each box, three sides have an extra front, attached to the bottom of the box. On the sides without fronts, puzzles are visible. After solving all three puzzles, a 3-digit lock can be opened. Subsequently, the three fronts unfold new puzzles, leading to the meta-puzzle, the dismantling of a bomb (see Figure 2). Puzzles were adapted from assignments of a formative assessment test supplied by the teaching method to align *learning goals and puzzles*. With the choice of a (hexagonal) box shape, various design criteria could be addressed. *Confined learning spaces* were thought to be created if teams are sitting around a box. With three starting puzzles, all members could *actively participate* within subteams. Solutions from all subteams were needed to open a lock, creating a moment to bring the teams together. The boxes could be filled with content in advance, and be moved to and from to the classes within minutes, ensuring *fast and easy*

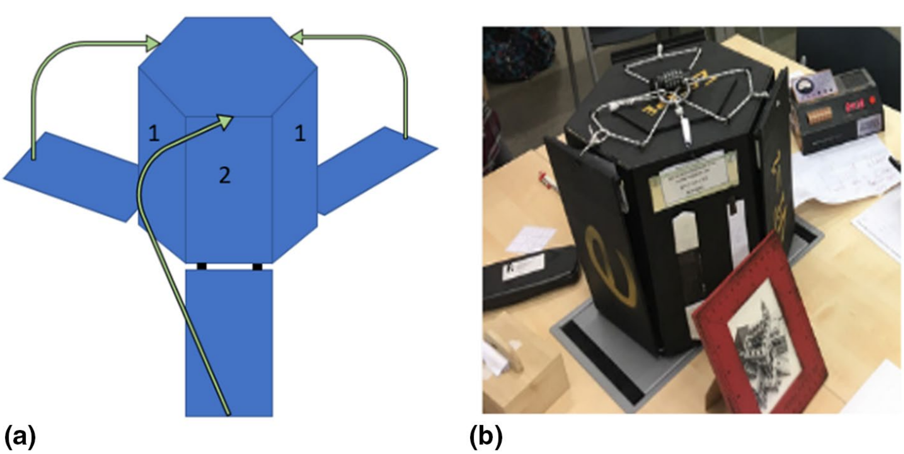

Figure 2: (a) At the start, the three fronts are up, so only the puzzles in place 1 are visible. After solving these puzzles, the lock at the top of the box can be opened and puzzles in place 2 become visible, (b) one box ready for use [Colour figure can be viewed at wileyonlinelibrary.com]

handling. The boxes were enriched with insert covers and drawers. In this way, the content could be reused and the box adapted for other content, addressing the design criterion of developing *sustainable materials*.

Test sequence and method

At first, the escape room was pilot tested with a team of five players using one box (16–17 years). Subsequently, the instructions to some puzzles were rewritten more concisely. No changes were made to the box. The game was played again in two grade 10 classes ($N = 34$; 16–17 years). In each class, teams of three to five pupils used one box. Pupils ($N = 27$) filled in pre and post surveys in relation to the educational goals of the boxes, evaluating alignment of *learning goals and puzzles*, see Appendix A. Classroom observations were made by two observers focusing on the game mechanics and the design criteria, create *confined learning spaces, active participation* within teams, and align *learning goals and puzzles,* see Appendix B. The mathematics teachers of the classes made informal observations on the criteria, develop *sustainable materials* and enable *fast and easy handling*.

Data

Classroom observations showed pupils sitting or standing around the boxes, face to face. The topics of conversations with teammates were on the subject knowledge, strategies and the time left. It was observed that teams split up in two to three subteams, each working on a puzzle, but face to face with other subteams. Within subteams, puzzles were discussed and pupils helped each other on the mathematics, usually when they get stuck. Discussion or explaining mathematics between subteams took place when they had to wait on others' solutions, or when a combination of solutions was needed due to the puzzle organization on the box. Distraction from the task was only observed when other teams loudly expressed their emotions on success or disappointment in solving puzzles and opening locks. The game stopped after the first team dismantled a bomb (the meta-puzzle) in time, although other teams wanted to continue. The developers prepared the boxes in advance in 20 minutes, the set up in the classroom took 5 minutes and the clearing away 10 minutes. During the gameplay, the teachers gathered colleagues to show them the highly engaged pupils.

Conclusions in relation to the box design

This first design cycle was promising. The teachers agreed that the developers had met the design criteria on *sustainable materials* and *fast and easy handling*. In the pre- and post-activity survey (see Appendix A), pupils answered questions on specific subdomains covered in the escape game. The pupils did not have any questions during the surveys, all pupils could relate the puzzles to the specific subdomains of the mathematics course and could indicate which parts they need to rehearse more or less than planned before the gameplay (Teekens & Koelewijn, 2018). It was observed that pupils discussed mathematics, especially when they got stuck or had to wait on each other due to the organization of the puzzles on the box. We concluded that the box had created positive social interdependency, and stimulated communication on the mathematics involved, meeting the design criterion on *active participation within teams.* The unintended effects of *learning by explaining* led to more interest from the developers on collaborative learning in the next cycle.

To create competition and a feeling of urgency, there was only one bomb to dismantle for the whole class. As a consequence, the game stopped for all teams. For the next design cycle, developers needed to create the situation that all teams can complete the game and address all learning goals.

Design cycle two

In the second design cycle, undergraduates in STEM were recruited as developers, as part of a project to engage them with education (Daemen & Van Harskamp, 2018).

The educational goals were to interest pupils in lower secondary education in science phenomena and science careers. Therefore, the developers chose to use a narrative with the pupils in the role of scientists.

The design criteria

As a result of the first design cycle, developers planned to further foster collaborative learning, addressing the design criterion *active participation within teams*. Based on the student developers' experiences as learners, they acknowledged that learning activities or tools could become boring if they have the same appearance, and planned to develop a box with changeable appearances, addressing the criterion of *sustainable materials*. The design criteria were extended with *immersion*, to enhance the learners' transfer from the classroom context into the game context with narrative.

The resulting prototype was a hexagonal escape box consisting of six loose compartments with all different fronts, see Figure 3. The compartments with changeable fronts can be placed at will, creating different boxes (*sustainable materials*). To foster *immersion* in the game context, a narrative was implemented through technology using video messages. In this case, a professor was asking the players to help her to prevent the impact of a meteorite. In addition, the pupils wore lab coats, and safety glasses during experiments. Staff in the role of scientists also wore lab coats, and a clock was ticking audibly. More possibilities for immersion were created inside the boxes. In the bottom and top parts, devices can be placed to generate smoke and smell. In addition, these spaces could also be used to store and transport materials (enable *fast and easy handling*). To stimulate communication and collaboration, the puzzles were designed so that subteams on opposite sides of the box had to exchange information (*active participation within teams*). To substantiate and structure the narrative and the organization of the puzzles, a game engine was implemented (Unity). On a digital screen built into the box, players could fill in answers and get feedback. The puzzle organization was the same as in the first cycle, a next layer of puzzles was unfolded only

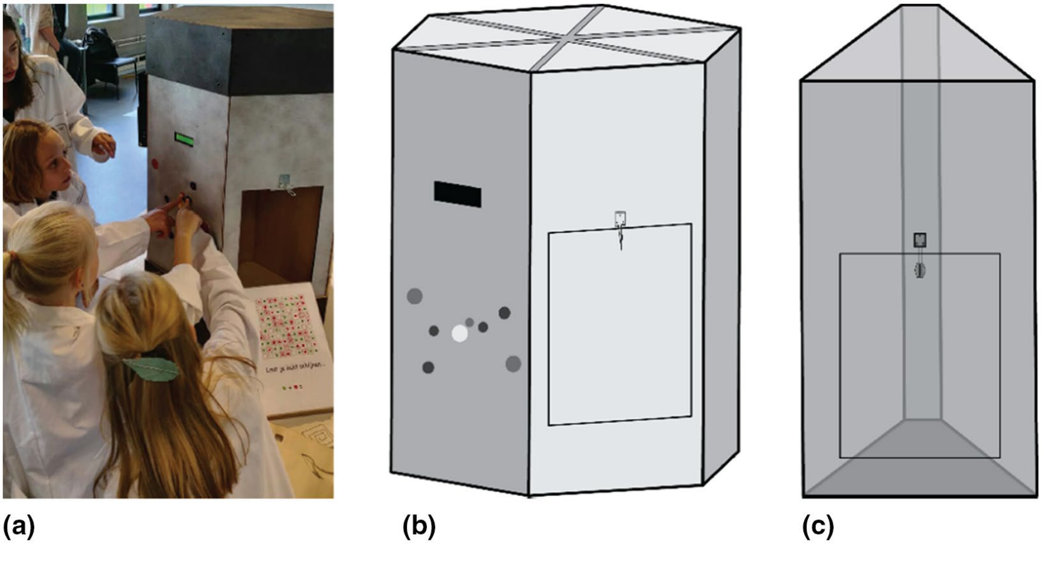

Figure 3: (a) Pupils playing the box on Science Day 2018, showing a front with an opened window on the right, and an LCD screen above a physical game on the left. (b) A sketch of the box design in the same position as on the picture in a. (c) A sketch of one of the six compartments [Colour figure can be viewed at wileyonlinelibrary.com]

after all subteams solved their puzzles. Every box had its own final meta-puzzle, so every team could finish the mission.

Test sequence & method
The puzzles were tested in pilots with gamers (peers of the student developers), and educators and pupils (14 year), using a think-aloud protocol (Jääskeläinen, 2010). The game was played five times during the University's Science Day, one team (four to six players) played on one box at a time. Formal observations were made by three developers, focusing on the design criteria, see Appendix B. Informal observations made by the parents were added. Debriefings with the players focused on their experiences and questions.

Data
Observation notes showed that pupils regularly gathered before the display with the narrative and instructions, discussing the next step to take and (re)forming the subteams. Pupils all participated enthusiastically, running around the box solving the puzzles. Members of subteams on one side of the box discussed the instruction or the puzzle. There was no exchange between subteams on different sides of the box. During the gameplays, pupils asked twice to lower the sound of the ticking clock as it unnerved them. During the debriefings, pupils asked questions on the science phenomena in the game, and questioned the student developers on their studies and the required skills of scientists. One team of pupils was critical on the limited communication due to the height of the box; as the next quotes illustrate: [C2_P4] "Okay, I understand that it's important for scientists to communicate, but we could not do that." Another pupil [C2_P2] added, while pointing at the box: "Agree, I couldn't see or hear them."

Conclusions in relation to educational goals
Based on the observations that pupils asked questions on the science phenomena, scientists' skills and studies of the staff, it was concluded that the educational goals were reached.

Conclusions in relation to the box design
The *immersion* was fostered using a narrative, substantiated with movies in the game engine Unity, staff in the role of scientists and clothing for the pupils. However, ticking clocks could unnerve and distract players, diminishing immersion. Furthermore, the game engine Unity structured adequate unfolding of the puzzles and narrative, and stimulated collaboration in the team by gathering the subteams, addressing *active participation in teams*.

However, the use of the game engine Unity appeared to require teachers with advanced programming skills. This limits the adaptability and re-usability of the boxes for other content. The height of the box limited subteams in their exchange of information and discussion, decreasing collaborative learning. In the next and last cycle, these limitations were addressed using design criteria on *sustainable materials* and *active participation in teams*.

Design cycle three
In the third and last design cycle, graduate students developed escape boxes as part of an educational design course in STEM education.

The educational goals for the next escape rooms included learning objectives on subject knowledge and skills for science and mathematics grade 9-11 (15-18 years), as box content was developed for three different subjects, biology, chemistry and mathematics.

The design criteria were expanded by the design criterion of fostering a feeling of *autonomy* for learners.

The resulting prototype is a smaller, lighter box with changeable fronts. An educator can choose six of the eight available fronts to compile a new game setting. The fronts offer various tools, such as a laptop screen, a magnet board, buttons linked to an embedded microcontroller system (microchip), and hatches with locks (see Figure 4). The storyboard option in Microsoft PowerPoint was used to structure the puzzles and narrative. The narratives for the games were authentic problems, such as plastic soup, carbon emissions and Q-fever (a deadly disease transmitted from livestock to humans). Pupils would wear clothing according to their role in the narrative, such as scientist, farmer or physician. Pre-set hints were revealed for groups lagging behind. This diminished the need for the teacher, fostering *immersion* in the game and increasing the feeling of *autonomy* of the learners. Therefore, we thought there was no need to assign the teacher a role in the narrative.

Table 2 gives an overview of the digital and/or physical aspects of the boxes in relation to the design criteria. An interactive design drawing is available in the Supplementary materials.

Test sequence & method

Due to the learning objectives on subject knowledge and alignment of the subject-based puzzles with the curriculum, the advised test sequence was extended with educators (as described in *From escape room*...). In total, 68 testers in six rounds were involved. Afterward, they filled in an evaluation sheet together, see Appendix C. Based on the tests, the pre-set hints were developed. Finally, the boxes were tested in a classroom setting. At the moment, the boxes are being tested in secondary education for three different themes; plastic soup, Q-fever and mathematics in the carbon emission problem. The preliminary results are based on pupils' post-activity surveys ($N = 54$ pupils, 15–16 years), see Appendix D. In two classes, observations were made by two observers focusing on the game mechanics and the design criteria, *immersion* and *active participation* within teams, see Appendix B. The teachers monitored the lesson.

Data and conclusions in relation to the educational goal of the boxes

Pupils enjoyed the lesson more than a regular science class (4.0/5 point Likert scale). Unlike some types of educational games (Kinzie, & Joseph, 2008), no gender differences were found on the game experience. Pupils perceived that the boxes and the puzzles stimulated working together (4.0/5 point Likert scale). In the survey, pupils could clarify their answer, and made remarks like pupil [C3_P7]: "You need each other to solve the puzzles." Pupil [C3_P4] noted: "Then you can learn from the others and see what they think and do." However, not all pupils were convinced that they had learned through collaborative learning (3.5/5 point Likert scale). Pupils who played the mathematics box expressed in the debriefing that they liked to practice mathematics skills in a technology-enhanced context, but not necessarily a game, although "a game is more stimulating."

(a) (b) (c)

Figure 4: (a) Design of the box, with top "open" to show inner structure, (b) Box ready for play, and (c) after play [Colour figure can be viewed at wileyonlinelibrary.com]

Table 2: An overview of the digital and physical elements of the escape boxes, in relation to the design criteria set

Design criteria	*Digital element(s)*	*Physical element(s)*
Align learning goals and puzzles	–	Adapted puzzles from assignments (such as formative assessment tests) supplied by the teaching method
Ensure active participation	Microsoft PowerPoint structures the unfolding of new puzzles or narrative, when all subteams combined their solutions and entered their solutions	Enough puzzles that all members of a team can be active. Puzzles are designed in a way that subteams need to cooperate to solve a puzzle
Create confined learning spaces	The game starts and ends with video messages from the box, creating coherence and focus on the game context	The hexagonal box with learners sitting around it focuses players' attention on the game and each other
Enable fast and easy handling	–	The (small) boxes can be filled with content in advance, and be moved to and from the classes within minutes.
Develop sustainable materials	The structuring of the game and narrative with Microsoft PowerPoint can be adapted by teachers	A teacher can choose six out of eight fronts with different possibilities. Content can be added and removed, for example, with magnet boards. In this way, the content could be reused and the box have different shapes and be adapted for other content
Foster immersion	Support narrative with movies and sound	Use of narratives in which learners have a role. Role is enriched by clothing and props. All teams can finish their game goal. After evaluation: a role in the narrative for staff/teacher
Foster autonomy	A screen in the box unfolds and structures the narrative and puzzles for learners. Pre-set digital hints pop-up in time, all implemented in Microsoft PowerPoint	Support by teacher on demand

Data and conclusions in relation to the design

Observations showed that pupils were *immersed* in the game contexts, all pupils were engaged and active, and switched easily between physical puzzles and digital aspects of the game. Exclamations by pupils showed that sometimes the pre-set hints came too early, too late or were not adequate for some pupils. Based on the surveys and classroom observations, we concluded that collaboration improved compared to design cycle two, addressing design criterium *active participation in teams*.

Discussion and conclusion

In this study, we explored the adaptation of the escape room concept to an educational setting. The leading research question was: how can the escape room concept be adapted to education, taking into account limitations and challenges of educational settings?

The escape boxes developed over the course of three design cycles succeed in putting learners in direct physical contact with each other, stimulating them to collaborate in a physical world as a result of the shape of the boxes and the organization and design of the puzzles. The puzzles required combining information uncovered by different subgroups and were developed so that learners recognized the knowledge and skills needed to solve the puzzles. The immersion into the game context was fostered by the digitally driven narrative. Learners can be confronted and immersed in real world situations, such as socio-scientific issues such as plastic soup. Structuring of the game through digitally unfolding the puzzles and pre-set hints diminished the need for help from the teacher. However, it did not rule out that need. Developing adequate pre-set hints is complex. The hints were developed based on pilot tests with pupils. However, pupils differ in understanding and reasoning; not all questions could be prevented by pre-set hints, or be delivered when needed. As we observed during the second cycle, hints can be given by staff with a role in the narrative without breaking the immersion for players. A drawback is that staff or teachers will be busier monitoring during the gameplay. In future research, a combination of pre-set hints and teachers with a role in the narrative is worth exploring. In regard to the feasibility of escape boxes in classrooms, the exterior can be adapted and the content of boxes reused. Boxes with puzzles within make it more feasible to set up and clear away in a limited time.

In this research, we used the design criteria as set out in Table 1, to generate ideas and solutions, resulting in a design and prototype. The design criteria also framed our evaluation, resulting in concrete points of attention when implementing the escape boxes in practice. The observations and subsequent evaluations resulted in new ideas or solutions for limitations observed. For example, in three cycles, the design criterion develops *sustainable materials* resulted in boxes with exchangeable fronts. The fronts have different tools and possibilities, offering the possibility to create several variant boxes, which can be filled with different subject-based puzzles. Sometimes, the solutions addressing different design criteria appeared to be conflicting in practice. For example, to ensure *active participation within teams* the first protype was a hexagonal box with a puzzle structure that stimulated pupils to sit face to face and help each other until the last puzzle was solved. In the second cycle, solutions addressing the criteria on *easy and fast handling*, and *immersion* resulted in a bigger box. However, the height of this box prevented exchange of information, and pupils ran around the box to solve the puzzle themselves, decreasing *active participation within a team*. This resulted in adaptations in the third cycle. In short, the design criteria catalysed the three cycles, resulting in thoughtful escape boxes.

As this research focused on the design and feasibility of the box, the next study will further analyse the nature of learning that takes place during gameplay with the escape boxes. Pupils were less convinced of the boxes' fostering of collaborative learning than of the fostering of collaboration. Does the fostered collaboration not result in more collaborative learning, or are pupils not aware of their collaborative learning due to the time constrictions? Other interesting pedagogical issues are the role of experiential learning during the gameplay, and the assessment of pupils' learning over time.

Hybrid Learning Spaces; a new hybridity in co-creating

At first, most educational escape rooms were copies of recreational escape rooms where teams played one after another (Borrego *et al.*, 2017; Eukel, Frenzel, & Cernusca, 2017). As a way to scale up to whole classes or courses, some educators started to use laptops or tablets presenting (locked) puzzles. Other educators introduced a box per team, which included all puzzles in closed envelopes or smaller locked boxes (Healy, 2019; Monaghan & Nicholson, 2017). These boxes lack the option of altering box fronts and the combination of digital and physical elements (see Table 2). It is this combination of elements that created powerful learning spaces fostering learners' transfer from the classroom context into the game context, active participation within teams and a feeling of autonomy.

We explored a new hybridity on top of merging physical/digital spaces and individual/collaborative learning; pupils/students and educators as co-developers. Based on their systematic review on educational escape rooms, Fotaris and Mastoras (2019) advise co-creation with the target audience, to ensure age- and developmentally appropriated puzzles. In our design research, different types of student designers were involved (graduate, undergraduate and secondary education students). This may add noise to the research design, for example as the goals for the student developers' education need to fit in, and limits the availability of some of the data (unpublished student thesis), but adds to the ecological validity of the design process.

The students designed the boxes and the puzzles. As they were close to the target audience, took implicitly or explicitly into account the target audience's motivation in education and games, game customs, and showed sensibility to learners' language and humor. For example, one narrative is "told" by the deadly bacteria. The various engineers used their expertise discussing the box designs and building the boxes. The alignment of the content-based puzzles with school curricula, and educational shaping of the puzzles were the common responsibility of the educators and educational researchers. In addition, to ensure continuity during all cycles, the same two educators were in charge of coaching the students and managed the project. We have experienced that a participatory design with students as co-developers and in close contact with educators, educational researchers and engineers is complex, in organization and discussions. However, the resulting technology-enhanced escape boxes appeared to be unique and innovative, compared to current educational escape rooms. Schools can build their own escape boxes based on this design (see Supplementary materials), using their own selection of specific digital and physical elements (see Table 2). Once built, the boxes can be reused for various subjects due to the adaptable fronts and separate reusable content.

Guidelines for designing educational escape rooms

Based on these results, we recommend the following guidelines for the development of educational escape rooms or educational games,

1. co-creating the game with the target audience. Moreover, gamers among them can add their expertise on game design, game mechanics and narrative structure,
2. starting from scratch, using a design framework, well-defined educational boundary conditions and resulting design criteria. This might lead to a protype that more adequately meets the boundary conditions than copying escape rooms and adapting them to educational needs later would,
3. creating hybrid learning spaces. Hybrid learning spaces can foster the learners' transfer from the school context to the game context, preferably using real world scenarios connecting with the course content. Furthermore, hybrid learning spaces stimulate collaboration, and foster a feeling of autonomy and ownership,
4. planning a series of tests with multiple perspectives important in educational game design: learner, gamer and educator.

Two frameworks for designing educational escape rooms have been published during our project, comprising step-by-step procedures (Clarke *et al.*, 2017; Guigon, Humeau, & Vermeulen, 2018). Our recommendations guide how to take these steps and create immersive hybrid environments where learners are engaged in contextualized real-life problems, work together and learn for a world outside the classroom.

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Statements on Open Data, ethics and conflict of interest

Data are recorded in student reports and archived according legislation of the institutes, Guide Amersfoort, Haagse Hogeschool—University of Applied Sciences, and Utrecht University. Data can be accessed by contacting the first author. U-Talent is a collaboration between Utrecht University, HU University of Applied Sciences Utrecht and nearly 50 schools. Before participation in the U-Talent program, pupils and/or their parents agree to U-Talent's Terms and Conditions; giving permission to record footage and agreeing to potential participation in research. For this study, no personal data are recorded.

There are no conflicts of interest to disclose.

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Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Appendix A
Survey for cycle I: The mathematics escape room

As the questions are similar in the pre- and post-activity surveys, only the text of the pre-activity survey has been translated from Dutch and is shown here.

Before we start the game, we would like to know how you are going to prepare yourself for the mathematics test.

Please fill in a name. You do not have to use your own name. Use a name you are also going to use for the post-activity questionnaires. ……………………

Name of class: …….

1. Which sections of the chapters are you going to study?
2. How are you going to study them?
3. How long are you going to study for the test?
    - I am not going to study for the test.
    - Less than 1 hour.
    - Between 1 and 2 hours.
    - Between 2 and 4 hours.
    - More than 4 hours.
4. Which topics are you going to study? And how are you going to study the topic?

Each row requires one response.

	Reading theory	*Knowing main concepts by hart*	*Making assignments*	*No study of topic*
Linear equations and inequalities				
Quadratic equations				
Equations with square roots				
Equations with fractions				
Simplifying expressions				
Parameters				
Asymptotes				
Graphs on the graphing calculator				
Graph spikes and intersections				

Appendix B
Protocol classroom observations

Most focus points are the same in the three cycles. Clarifying remarks for the reader of this paper are placed between brackets.

Focus points.

- Do pupils understand the puzzles? [criterium align learning goals and puzzles] understanding instruction/recognition of subject knowledge content
- Do the physical elements work adequately?

[Depending on the design cycle: locks, decoder, drawer in box, buttons on box, clothing and props.]

- How do the pupils work in relation to the box? [criterium create *confined learning spaces*]
- How do the pupils work within a team (alone, all together, subteams)? [criterium ensure *active participation within teams*]

Additional points in cycle II and III.

- Do the digital elements work adequately?
- Are the pupils attracted by the layout of the escape game (box, puzzle layout and props)? [criterium foster *immersion*]
- How does the display [with narrative and instruction] work in relation to the whole team? [criterium ensure *active participation within teams*]

Appendix C
Evaluation sheet for testers of escape boxes in cycle III

The debriefing varied in relation to the expertise of the testers and the theme of the game. This is the debriefing sheet for educators on the Plastic Soup escape box. Clarifying remarks for the reader of this paper are placed between brackets.

Thank you for playing the game. We would like to evaluate with you

1. Your experience with the escape boxes
2. The age and developmental alignment of puzzles
3. The curriculum alignment of puzzles
4. The educational goals:

After the gameplay, pupils can

- demonstrate awareness of the plastic pollution problem by explaining the scale of the problem.
- explain that collaboration is necessary to solve the puzzle box.
- be able to list at least three health concerns that are linked to plastic ingestion.
- be able to describe at least three ways to reduce their plastic usage in everyday life.
- explain that there is more than one strategy to tackle the plastic pollution problem, and name two strategies.

5. Some practical aspects

Questions

1. Did you enjoy the escape box? Did you feel immersed in the game? Why (not)? [criterium *foster immersion*]
2. Do you think it is designed for the correct target group? Are the instructions adequate (in movies, puzzles and on the display)? [criterium align *learning goals and puzzles*]
3. Does the escape game align with the curriculum? Do you think the game is challenging enough for the target group? [criterium align *learning goals and puzzles*]
4. What do you think the pupils will take away from the escape game?

For each specific goal: How do you think the game meets the goal? How can we improve the pupils' achievement on these goals? [criterium align *learning goals and puzzles*]

5. Do you think it is doable to set up/clear away between lessons for teachers? [criterium enable *fast and easy handling*]
• Can you make a guess of the playtime needed by pupils?
6. Feel free to give feedback on aspects we did not address…

Appendix D
Post-activity survey cycle III
In the post-activity surveys, questions relating to the theme (Plastic soup, Q-fever, or carbon emission) are different. Here, the post-activity survey for the plastic sup escape box is presented. Clarifying remarks for the reader of this paper are placed between brackets.

Thank you for taking part in playing—I hope you enjoyed yourself!☺
Now you have experienced playing the first plastic soup escape box, I would like to know what you thought of it! Please answer the following questions.

I feel myself as (female, male, ……) ………………..
Have you ever played an escape room before? Yes No.
If yes, what did you enjoy most about playing? …………………
How much do you agree or disagree with each of the following statements (circle the number that applies to you). Strongly disagree (1)—Strongly agree (5).

	Strongly disagree			Strongly agree.	
1. I enjoyed playing the puzzle box	1	2	3	4	5

2. If agree, what did you enjoy most about playing?
3. If disagree, what did you not enjoy?

4. I would like to play more educational escape rooms
5. I think experience of escape rooms is necessary to play the puzzle box.
6. I like science classes

7. I understand that plastic pollution is a worldwide problem
8. I am more aware of the plastic pollution problem
9. I have increased my knowledge on how plastic pollution affects my health
10. I have increased my knowledge on how plastic pollution affects the environment

11. I want to do *more* to help reduce my plastic waste
12. I understand *how* to reduce my plastic waste

13. I think group work helps me to learn [criterium *ensure active participation within teams*]
Why ……………………
14. I learnt about plastic soup by working together on the escape box [criterium *ensure active participation within teams*]
15. The shape of the box and the puzzles stimulated us to work together [criterium *ensure active participation within teams*]
Why ……….
16. I would like to do more group work in science class [criterium *ensure active participation within teams*]
17. Any additional comments or improvements? (all comments are welcome)

Thank you for taking part!