No Escape!

The rise of escape rooms in secondary science education

Alice Veldkamp

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A. Veldkamp
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No Escape!

The rise of escape rooms in secondary science education

No Escape! De opkomst van escape rooms

in het voortgezet onderwijs

(met een samenvatting in het Nederlands)

Proefschrift

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Alice Veldkamp

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Promotor:

Prof. dr. W.R. van Joolingen

Copromotor:

Dr. M.C.P.J. Knippels

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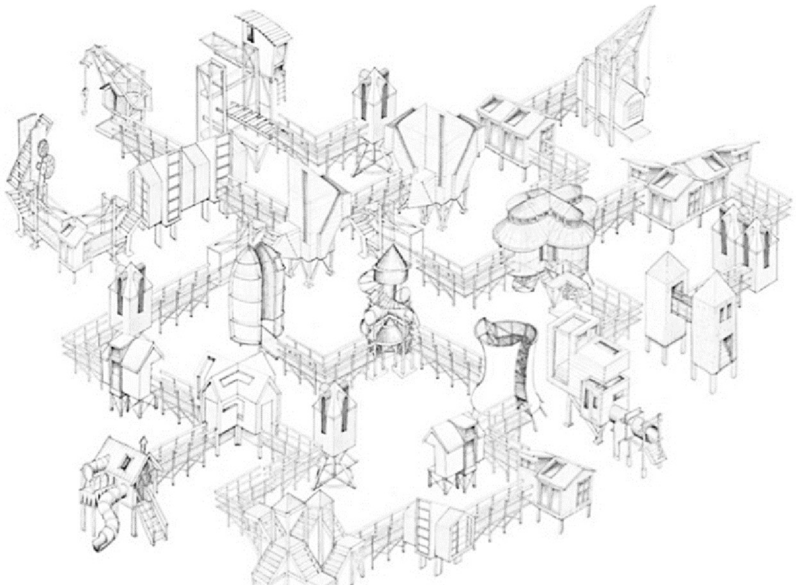
Without love for others, your words and works are useless.

1 Corinthians 13:1-3

A boring and monotonous life would kill even a fungus.

Johanna Westerdijk (1883-1961)
phytopathologist at Utrecht University and
first female professor in the Netherlands.

A globally recognised longing to escape



The lockdown

It is spring 2021, all around the world people feel trapped and are longing to escape; to escape from COVID-19, to escape from rules and live ‘a normal life’. Unique in history is the longing of so many students for a ‘normal’ secondary school life.

Ironically, the subject of this thesis is the use of escape rooms in secondary science education. In escape rooms students forget they are at school and that learning is their main goal. The studies in this thesis took place in the pre-locked past, with coincidently the last study on an escape game with the goal to defeat a zoonosis, like SARS-CoV-2, in a multidisciplinary approach.

Nowadays, live action escape rooms are banned in the 1,5-meter-society. Are the presented studies academic snapshots of the past? Or are the results relevant during corona and post-corona times? These questions will be answered in the last chapter.

This introductory chapter starts with a description of the global rise of escape rooms in the recreational and educational sector, followed by the scope of this thesis and a compact account of the executed studies.

On the history of escape rooms

> *Escape rooms are live-action team-based games where players discover clues, solve puzzles, and accomplish tasks in one or more rooms in order to accomplish a specific goal, usually escaping from the room, in a limited amount of time’ (Nicholson, 2015, p. 1)*

Scott Nicholson published in 2015 an inventory on 175 recreational escape rooms. The paper served to document the current state and the evolution of recreational escape rooms in terms of demographics of players, themes, and design patters.

It was one of the first studies on this new phenomenon in the recreational sector. After the first documented account of a live escape room in Kyoto (Japan), the amount of escape rooms grew rapidly (SCRAP, 2007). Firstly, they appeared all over Asia, then via Hungary to the rest of Europe and over to Australia and North America (Nicholson, 2015; Scherker, 2013). In 2015, according to MarketWatch, 2.800 escape rooms were registered worldwide (French & Shaw, 2015). In 2016, in Poland alone 600 escape rooms operated (Stasiak, 2016). In 2019, an international escape room markets analysis estimated the amount of recreational escape rooms on 60.000 worldwide (Ferguson, 2019).

The escape room designers could draw on various inspirational sources. The designers mention different precursors, both physical and virtual. Mentioned *physical precursors* are live-action-role-playing games, puzzle hunts, treasure hunts, interactive theatre, themed restaurants and haunted houses. *Virtual precursors* are the point-and-click digital adventures, television adventure game shows, alternate reality games and adventure movies (Nicholson, 2015; Penttilä, 2018; Wiemker, Elumir & Clare, 2015). Earlier assumed roots are John Wilson’s interactive text game Behind Closed Doors (1988) or the labyrinth of the Minotaur in Ancient Greece (Fernandez-Vara & Fay, 2021). With different precursors for each designer, escape rooms have become a varied and widespread phenomenon. In 2019, the Netherlands has taken the lead in games per-capita, approaching the availability of one game for every 20,000 people in the country (Ferguson, 2019).

In the slipstream of the upcoming recreational escape rooms, teachers started to develop physical escape rooms for their classes (Stone, 2015). Escape rooms have been developed by teachers for all levels of education, from K-12 to higher education (Fortaris & Mastoras, 2019). The implementation of teacher-made escape rooms is stimulated by platforms initiated by teachers, where materials and experiences are shared (Breakout EDU, 2018; De Groot, 2016; Sanchez & Plumettaz-Sieber, 2019). In the Netherlands, two secondary school biology teachers Anne de Groot and Joris Koot were important in the dissemination of this new learning activity by providing workshops to at least 1300 teachers (De Groot, 2016; Koot, 2018). In 2017 and 2018, Eindhoven (the Netherlands), hosted the world's biggest escape room, called Scapetown. The twenty connected rooms (3000m2) were built and played by students (Klokgebouw, 2018; Spoor, 2017). Teachers also use the designing and creation of escape rooms by students as a teaching strategy, but on a smaller scale (Davis & Lee, 2019; Li, Chou, Chen, & Chiu, 2018; Whitton, 2018).

The phenomenon of escape rooms in education is unique as it emerged around the world spontaneously, and bottom-up, meaning that it was not instigated by national curricula, pedagogical centres, schoolboards, or educational research institutes. Teachers adapt the escape room concept to the classroom, spend time on its development, and use precious teaching time to execute it. This shows that teachers see potential in escape rooms as a teaching and learning activity. This raises questions, as what is the educational potential of escape rooms? Does it fill a niche in the teaching repertoire or is it an alternative for existing activities? What is an adequate design for escape rooms in education? What are adequate principles and guidelines for designing and implementing escape rooms in secondary science education?

Differences between educational and recreational escape rooms

When introducing the escape room concept in the classroom, teachers have to take into account the differences between recreational and educational settings. In this thesis, the main differences between common recreational and educational settings are studied and explicated. In addition, the boundary conditions and resulting design criteria for the escape room design determined. The main differences are listed here to give the reader a preliminary view of aspects teachers have to take into consideration. The main differences are related to the goals, team organisation, location, materials, staging and guiding of escape rooms.

Goals. In contrast to escape rooms in the entertainment industry, educational escape rooms are primarily designed as learning environments.

Team organisation. 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.

Location. In the entertainment industry, an escape room usually takes place in one or more connected, permanent rooms. In an educational setting, teachers usually have only one classroom available, and for a restricted time.

Materials. In education, budgets are usually limited and smaller than would be available for commercial escape rooms (Hess & Downs, 2010; Rabovsky, 2012).

Staging. A classroom setting limits the staging (scenery and props) and diminishes immersion in the 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).

Roots in educational game research?

As the implementation of escape rooms started as a grassroots movement, there was no academic model, framework or theory available on the design and implementation of escape rooms in education, at the start of this research trajectory. Educational escape rooms can be considered as educational games. Raitskaya and Tikhonova (2019) stated that gamification and games is one of the biggest ‘hypes’ over the last decade in educational research The question is whether and to which extent the developed educational escape rooms root in existing knowledge on educational games, game-based learning, serious games, applied games, gamification and so on. In the chapters on Study 1 and 2 these questions are addressed.

The abundant terminology in game science is sometimes mixed up, as it aims at more or less the same goals (Kapp, 2012).

Gamification refers to the use of game dynamics, mechanisms, and frameworks to non-game settings (Deterding et al., 2011; Stott & Neustaedter, 2013). An example of commonly used game mechanisms are incentive systems (Plass et al., 2015). Gamification is usually a playful layer around existing educational systems or public space to motivate players and engage them in a task (Nicholson, 2013; Stott & Neustaedter, 2013). Gamification rewards users for specific behaviour, with the expectation that learning outcomes will be improved (Al-Azawi et al., 2016). A systematic review on gamification in education synthesized common design elements such as a story, interactive dynamics, collaboration, goal-orientated design, a set of rules, and the use of technology (Mora et al., 2017). This does not implicate that specific elements must be used for gamification in education or that more gamification elements result in better learning results.

Game-based learning (GBL) refers to the practice and process of learning with the use of games to achieve specific learning goals (Shaffer et al., 2005). So, games are part of a learning trajectory. The games can be commercial ones, such as SimCity or World of Warcraft to foster English and/or teamwork (Al-Azawi et al., 2016; Li & Tsai, 2013). The games can be adapted to the educational setting, such as MinecraftEdu (Cózar-Gutiérrez & Sáez-López, 2016), or specially designed to aim at specific educational goals (Al-Azawi et al., 2016; Li & Tsai, 2013). A Google Scholar search (15-05-2021) on "game-based learning" AND "systematic review", resulted in 29 articles published between 2011-2021, with most of them issued in the second half of the decade. This search shows that the field of research is relatively young. In addition, the subjects are nearly all digital, AR or VR games. The games are mostly used in formal education and less in informal settings (Jabbar & Felicia, 2015; Li & Tsai, 2013; Pellas et al., 2019; Pellas, & Mystakidis, 2020; Subhash & Cudney, 2018).

Serious or applied games are games for non-game markets, for example the public area, business sector, teambuilding industry or education. They are specially designed to achieve specific goals (Alvarez, 2021; Djaouti et al., 2011). For educational settings, the games are usually called serious educational games or educational games. In serious game design, educational design and game design are combined (Lameras et al., 2017; Whitton, 2018).

The potential of GBL for science education is, according to Li and Tsai's systematic review (2013), to bring authentic science related environments in the classroom, to promote collaborative problem-solving and to provide an affective learning environment. The authentic environments create opportunities for students to enact in authentic science environments which were otherwise unsafe, inaccessible, or abstract. In addition to the importance of authenticity, the suitability for problems without a fixed answer and tasks requiring higher order learning are stressed for science games (Liu, Rosenblum et al., 2014). According to Li and Tsai (2013), the fast feedback leads to students experiencing guidance from the game. Implicit in the reviewed studies is the assumptions that students learned while they were playing, however this was not studied systematically.

The effectiveness on learning with serious games differs. For example, the review of Backlund and Hendrix (2013) showed that 29 out of the 40 studies had positive results in relation to the effectiveness on learning, seven neutral, two negative and two studies were unclear on this aspect. Systematic reviews from later date are more positive (Boyle et al., 2016; Clark, 2016; De Freitas, 2017; Jabbar & Felicia, 2015), also in the context of STEM education (Hussein et al., 2019; Kara, 2021; Li & Tsai, 2013). In addition, Clark (2016) found a key role for the design of the game, beyond the medium of the game.

In relation to designing educational games, the GBL reviews stress the importance of both educational and game design aspects to be considered while developing an educational game. Furthermore, an understanding of the relations between educational and game design aspects for engagement (Connolly et al., 2012; Jabbar & Felicia, 2015) and learning is needed (Ke, 2016; Lameras et al., 2017; Van der Linden et al., 2019). Essential aspects of educational games for engaging and learning are: the players' identity and role during gameplay, immersion & discovery-oriented experience, interactivity, progression & increasing complexity, scaffolding learning, and alignment with curriculum (Annetta, 2010; Ávila-Pesántez, Rivera & Alban, 2017; Ke, 2016; Lameras et al., 2017). It appears crucial to design educational games in such a way, that what is enjoyable about games is not lost: simulations, role play, humour, surprise, puzzles, storytelling, and mystery (Cheng & Annetta, 2012; de Freitas, 2017; Ke, 2016; Vandercruysse & Elen, 2017; Whitton, 2018).

What's in a name?

In this section, the terminology in relation to escape rooms is described. The first physical escape room in Kyoto called itself the Real Escape Game (SCRAP, 2007). Nowadays, games in the genre use a lot of other names: *escape room, live escape, puzzle room, mystery room, live action game, adventure room or room escape game* (Nicholson, 2015; Pentillä, 2018; Stasiak, 2016). Although currently the game is played with more than one room or without a room, the term escape room seems most commonly used, due to the fact that the first games were room escapes.

In relation to the educational setting, the term *escape room* is also most commonly used, followed by *escape game*. A few researchers prefer the term *serious educational escape games* (SEGs), to stress the relation with serious games (Guigon et al., 2018). Since 2019, some researchers and educators in the field of healthcare proclaim to use the term *health care simulation escape room* to work towards a shared mental model and definition in health care education (Anderson et al., 2021). Incorporated in the term health care simulation escape rooms is the funding in an already researched practice of simulation in health care. This practice requires an authentic professional environment, safety to practice and learning, educational goals, a pre-briefing and a debriefing with feedback (INACSL Standards Committee, 2016; Robertiello et al., 2021).

In this thesis, the term *escape room* is used, as it is still the most commonly used term in relation to this type of games. After the development of our so-called escape boxes (Study 3), the term escape game is used too. This term seems more adequate in relation to the developed escape boxes and their games.

This PhD thesis

This PhD thesis presents a sequence of studies that focus on the rise of a new phenomenon in education, educational escape rooms. The overall research questions guiding the studies are:

- *What is the educational potential of escape rooms for secondary science education?*
- *What are adequate principles and guidelines for designing and implementing escape rooms in secondary science education?*

For our first study on escape rooms and their educational potential, we used a phenomenological approach (**Chapter 1**). Neubauer and colleagues (2019) describe phenomenology as the study of the "lived experience" of a particular phenomenon. Usually, researchers interview individuals who have first-hand experience or knowledge of the phenomenon, such as an event or situation. A phenomenological approach searches answers on: In relation to the phenomenon, what have you experienced and how? Which context(s) or situation(s) have typically influenced your experiences of the phenomenon (Creswell, 2013)?

Our research questions in the first study align with those in a phenomenological approach as we wanted to know 1) how teachers and students experience escape rooms, 2) what their perceptions are of the usability of escape rooms for science education in terms of goals and learning outcomes, and 3) what they experience or foresee as boundary conditions and barriers for teachers in implementing escape rooms in their classroom.

Besides the traditional practice of interviews in a phenomenological study, we used various sources to acquire a rich or so-called *thick description* of the phenomenon and its educational potential (e.g., Ponterotto, 2006). Table 1 (pg. 13) shows an overview of the methods, research questions and research design used in the studies.

In a next step, we wanted to evaluate the implementation of current escape rooms and subsequently develop guidelines to design and implement educational escape rooms. As nearly all published studies on escape rooms in education were case studies, we needed to synthesize the practices in a systematic review (**Chapter 2**). We studied for which educational learning goals escape rooms are suitable, what is known about the positioning of escape rooms in the whole learning trajectory, and what comprises the role of the teacher. In relation to game design aspects, the puzzles and their structuring are studied. In addition, the game organisation for whole classes or courses, appropriate team sizes, playtime and how technology supported the escape rooms was researched. The systematic review study provided a richness in outcomes. For the interpretation of the data, a design framework on alignment between game goal, learning goal, pedagogical approach and game mechanics was used (Van der Linden et al., 2019).

Parallel to Study 2, a design-based research study was started (**Chapter 3**). In this study, we researched how the escape room concept can be adapted to education, taking into account the limitations and challenges of educational settings from Study 1. Based on these limitations and challenges of educational settings, boundary conditions were formulated which lead to specific design criteria. In three design cycles in co-participation with students, it resulted in a *proof-of-concept.*

In the fourth and last study (**Chapter 4**), the previous studies come together. By now, a design approach for educational escape rooms had been developed and was used (Veldkamp et al., 2021b). This framework was used in combination with the developed escape boxes (Study 3), and the derived guidelines on designing and implementation educational escape rooms (Study 2 & 3). The results will evaluate the educational potential of escape rooms in relation to learning outcomes, give insights in where and how learning takes place in escape room activities and validate the developed integrated design approach for educational escape rooms. Figure 1 shows a flowchart of the studies and how they are related.

Chapter 5 will give a summary of the results in relation to the main research questions, and will elaborate on practical recommendations, scientific implications, and future directions.

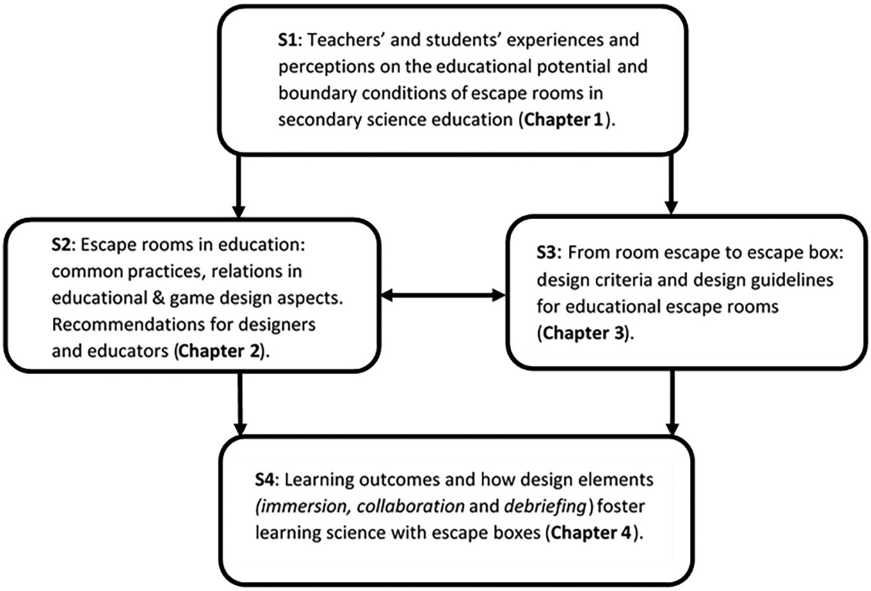


Figure 1 A flowchart of the studies (S), mentioning the focus of the research.

Table 1 The structure of this PhD thesis

Studies	**Research questions**	**Design**	**Methods & participants**
	1. What is the educational potential of escape rooms for secondary science education? 2. What are adequate principles and guidelines for designing and implementing escape rooms in secondary science education?		
Study 1 - Chapter 1 *Beyond the early adopters:* *Escape rooms in science education*	1. How do teachers and students experience escape rooms? 2. What are teachers' and students' perceptions of the usability of escape rooms for science education in terms of goals and learning outcomes? 3. What are experienced or foreseen boundary conditions and barriers for teachers in implementing escape rooms in their classroom?	Phenomenological study	Mixed methods: 202 student questionnaires, 68 student semi-structured interviews, 17 student made movie clips, 14 classroom observations, 39 teacher questionnaires, 11 teacher semi-structured interviews.

Study 2 - Chapter 2 *Escape education!* *A systematic review on escape rooms in education*	1. In educational ERs, what are common practices and theoretical considerations regarding their educational aspects? 2. In educational ERs, what are common practices and theoretical considerations regarding their game design aspects? 3. How are educational and game design aspects related in educational ERs? 4. To what extent have the intended goals of the educational ERs been achieved?	Literature study	Systematic review of 39 studies on educational escape rooms
Study 3 - Chapter 3 *Escape boxes: Bringing escape room experience into the classroom*	1. How can the escape room concept be adapted to education, taking into account limitations and challenges of educational settings?	Design-based research study	Participatory design in three cycles
Study 4 - Chapter 4 *You escaped! How did you learn during gameplay?*	For an escape room activity in secondary science education on zoonoses using escape boxes, 1. to what extent are the learning goals achieved? 2. how do educational game design elements, immersion, collaboration, and debriefing, influence the learning process?	Empirical study	Mixed-methods: 126 pre-test/post-test, 126 experience questionnaires, 14 student semi-structured interviews, 5 teacher semi structured interviews 6 classroom observations

Chapter 1

Beyond the early adopters: Escape rooms in science education

This chapter is based on

Veldkamp, A., Knippels, M. C. P. J., & van Joolingen, W. R. (2021). Beyond the early adopters: Escape rooms in science education. *Frontiers in Education*, *6*(3), 1–11. https://doi.org/10.3389/feduc.2021.622860

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Acknowledgements

AV, MCK, and WvJ designed the Study; AV and MCK developed coding schemes; AV collected data; AV analysed the data; AV drafted the manuscript; AV, MCK and WvJ contributed to a critical revision of the manuscript; MCK and WvJ supervised the study.

Supplementary materials such as the Appendices for this chapter can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2021.622860/full#supplementary-material

Abstract

Case studies report enthusiastically on the implementation of escape rooms in science education. This mixed-method study explores beyond the early adopting teacher, as the perceptions of 50 teachers and 270 students were investigated. Escape rooms are time restricted games where participants work together and accomplish a specific goal. The escape rooms' usability for education in terms of goals, experiences during gameplay, outcomes, and boundary conditions are studied, using multiple data sources: online questionnaires, interviews, classroom observations and movie clips made by students about their experiences. The use of mixed methods and large samples on this topic is a novelty. Results show that teachers of different ages, gender and teaching experience were appealed in particular to the diversity of activities offered that call for multiple skills and teamwork. Students experienced the need to think hard using multiple thinking skills and enjoyed the feeling of autonomy and mastery during gameplay. This is interesting, as an escape room setup is very strict, with few degrees of freedom. According to teachers and students, escape rooms are suitable for processing, rehearsing and formative assessment of science knowledge and skills. However, the time restriction during gameplay appears to be an ambiguous factor in student learning.

1.1 Introduction

Recently, escape rooms have been finding their way into education worldwide, from primary education to professional development, and into science and medical classes in particular (Fotaris & Mastoras, 2019; Veldkamp et al., 2020). "Escape rooms are live-action team-based games where players discover clues, solve puzzles, and accomplish a specific goal (usually escaping from a room) in a limited amount of time" (Nicholson, 2015, p. 1). The goals of the first-generation games were 'escapes' from a room. Currently, the goals are more diversified; players may break into a vault, solve a murder mystery or defuse an explosive device. Implemented by enthusiastic teachers, escape rooms are gaining popularity as teaching and learning environments in science education (Veldkamp et al., 2020). For secondary education, teachers can share their materials on platforms such as Breakout EDU (Breakout EDU, 2018; Sanchez & Plumettaz-Sieber, 2019). As these developments rely on a relatively small group of enthusiastic *early adopting* teachers, it remains unclear what teachers and students in general perceive as the educational potential of escape rooms beyond the novelty factor. For example, their opinion on what educational goals escape rooms are suitable for, what aspects stimulate students' learning, or what consider teachers as boundary conditions for implementing these new learning environments in science education. Research from the perspectives of teachers and their students on the educational potential of this worldwide, bottom-up phenomenon, will help teachers to implement these new learning environments more effectively in order to help foster students' science knowledge and skills.

Escape rooms are inherently team-based games; the assignments tend to ensure that every member of a team is active and can contribute (Wiemker et al., 2015). Within an escape room, all assignments are called puzzles and use a simple loop: a challenge to overcome, a solution and a reward (e.g., a code for a lock, or information needed in the next puzzle). Cognitive puzzles seem to predominate in escape rooms (Nicholson, 2015) and players require skills such as searching, observation, correlation, memorization, math, reading, pattern recognition and compartmentalization to solve them (Wiemker et al., 2015). A gamemaster may provide hints and debriefs to players on the process and what they achieved as far as solving the puzzles (Nicholson, 2015).

Escape rooms are used for various educational purposes. Case studies show that most escape rooms were designed for formal education to foster domain specific skills and knowledge, mostly in medical (Jenkin & Fairfurst, 2019) and science disciplines (Vörös & Sárközi, 2017; Dietrich, 2018; Ho, 2018; Arnal et al., 2019; Healy, 2019). Others were implemented to recruit students, to get to know institutional services (Gilbert et al., 2019), or in informal education to create interest in specific science subjects, such as robotics (Giang et al., 2018). Both students and teachers perceive that while participating in escape rooms, students are more engaged and active compared to regular classes (Cain, 2019). Like in recreational escape rooms, a combination of hands-on and minds-on tasks needs to be achieved with a team in a limited time. In educational escape rooms, these tasks are content-based puzzles. For example, when it is unclear how to solve the task, clues are hidden or essential information needs to be found. Finishing a task usually unlocks a new task, information or tool needed (Glavăs & Stăscik, 2017; López-Pernas et al., 2019; Peleg et al., 2019). Locks only open when a task is solved correctly. This structure provides students with immediate feedback on the correctness of their solution. Monaghan and Nicholson (2017) regard this as one of the powerful aspects of an escape room. In recreational escape rooms, teams usually play one after another (Nicholson, 2015). In educational settings, it varies enormously, usually teams play one team at a time, although a trend is visible that all teams in a class or course play at the same time in the same room (Veldkamp et al., 2020). Usually, the game ends when the first team finishes the game. The review also showed that half of the educational escape rooms is followed by a reflection on the experiences and tasks.

The combination of escape room attributes, such as team-based learning, content-based tasks combining 'hands-on' and 'minds-on', room for failure and reflection on accomplished tasks, is not unique in its own for education. However, their combination in a playful, physical environment seems unique and appealing to teachers. For secondary science education, claimed benefits for the introduction of escape rooms are students working in an intrinsically motivated way, triggered by content-based puzzles, while developing the four C's: critical thinking, collaboration, creativity and communication (Roekel, 2011; Pollock, 2015; Breakout EDU, 2018).

As teachers develop their escape rooms based on their experiences with recreational escape rooms and/or video escape games, little work has been reported on their theoretical foundation in educational science (Veldkamp et al., 2020). However, as the implemented escape rooms are education games, we can resort to theories of Game-Based Learning. De Freitas (2018) review covered systematic reviews and randomized controlled trials on educational games and showed that results on effectiveness were not consonant, but on balance "overwhelmingly positive". Two systematic reviews not covered by De Freitas, resulted in the same conclusion (Backlund & Hendrix, 2013; Vlachopoulos & Makri, 2017). A review of Game-Based Learning in science education argues that the potential for science education is to bring authentic science related environments in the classroom, to promote collaborative problem solving ability and to provide an affective learning environment (Li and Tsai, 2013). Essential aspects of educational games for engaging and learning are: the players 'identity and role during gameplay', 'immersion and discovery oriented experience', 'interactivity' (including collaboration, autonomy and ownership), 'progression and increasing complexity', 'scaffolding learning' (repetition, feedback, rewards, debriefing) and 'alignment with curriculum' (Annetta, 2010; Ke, 2016; Lameras et al., 2017; Ávila-Pesántez et al., 2017). Educational escape rooms can address all these aspects (Veldkamp et al., 2020). Innovators and early adopting teachers (Rogers, 1962) around the world are enthusiastic about the educational potential of their escape room. Therefore, the aim of this study is to explore what teachers and students in general perceive as the educational potential of escape rooms for secondary science education, regarding goals and learning outcomes. In research on educational games, the user experience is an important concept studied to improve the satisfaction, usability and the interaction between player(s) and game (Nagalingam & Ibrahim, 2015). Thus, the research question in this study is: 'What do teachers and students perceive to be the educational potential of escape rooms in secondary science education?', decomposed into the following subquestions:

1. *How do teachers and students experience escape rooms?*
2. *What are teachers' and students' perceptions of the usability of escape rooms for science education in terms of goals and learning outcomes?*

3. *What are experienced or foreseen boundary conditions and barriers for teachers in implementing escape rooms in their classroom?*

The results will be compared with the benefits of educational escape rooms as claimed by educational platforms and help teachers to implement these new learning environments more effectively in order to help foster students' science knowledge and skills.

1.2 Methods

This descriptive study aimed at inquiring about teachers' and students' experiences and perceptions when using an escape room as a teaching and learning environment. Fifty teachers and 270 students participated, in the context of a national 'Escape the Classroom' Challenge, that was organized by the Dutch national organisation for biology teachers and practitioners. From 100 secondary schools in the Netherlands, seventh grade biology classes joined the challenge, which had biology and science topics as its theme.

The game started plenary with a video clip explaining the context of the game, its rules and the need for teamwork. The teams within a class consisted of 4–6 students and solved the same set of six connected content knowledge-based cognitive puzzles. The puzzles addressed both familiar and new concepts such as life, inanimate, dead, biological levels of organisation, and the scientific method. To give an example, one puzzle called 'Guess what?', was based on the child's game 'Guess who?'. In this puzzle, students need to cross out the right answers on content-based questions, until the remaining answers show information needed in the next puzzle. The students had to relate the puzzle to the child's game Guess who? otherwise they did not know how to solve it as there were no instructions given. The role of the teacher was not described, except for checking the students' solutions of one of the puzzles. The game ended when the first team opened the locked vault, within 40 min. The vault contained a prize. The teacher decided whether the escape room was followed by a plenary debriefing in the classroom.

The escape room was developed by the organisation, "Escape The Classroom" (Escape The Classroom, 2017). None of the researchers were involved in its development. The escape room was published on a website, on which schools could enrol. Subsequently, enrolled schools were asked whether they would participate in this study. Experience with escape rooms within the team of seventh grade teachers was not required nor advised. Consequently, we expected that the sample of teachers participating in the escape room activity, was not limited to early adopters, and would consist of a fair representation of the teacher population.

1.2.1 Data collection

Table 1.1 shows the data that were collected from various sources to obtain multiple views from teachers and students on their experiences with and opinions about the escape room. Multi-method triangulation was used to increase the internal validity of the study (Meijer et al., 2002).

Classroom observations during the escape room activity were done in fourteen classes. Schools selected for observation were chosen based on travel distance. In each class one or two observers made notes following a protocol with prescribed points of focus on behaviour of teacher, students and the interactions in one or two randomly chosen groups within the class (see Supplementary Appendix C). During gameplay, the observers did not interact with either the students or the teacher.

Immediately after the "Escape the Classroom" event, 270 students were either interviewed or invited to fill in an online questionnaire (see Supplementary Appendix B). Four questions in the questionnaire asked for demographic data and previous experiences in escape rooms. Six questions inquired about user experiences and possible educational goals. One of these questions gave response options, three were half-open-ended (multiple choice with the option to add or explain an answer) and two were open-ended questions. The questionnaire also included room for other remarks. The questions had been pretested with three students using a think-aloud protocol (Jääskeläinen, 2010). Students from the teams observed during the gameplay, were invited for an interview. Seventeen interviews (10–15 min) took place with a total of 68 students. The interviews used the same questions as the questionnaires with the addition of one open-ended question on the learning outcomes (see Supplementary Appendix B). The students give their response to each of the questions and could react to each other's response. Finally, just before the start of the escape room activity, teachers could ask their students who were willing to produce a movie clip of the classroom experiences. The guidelines were brief: send in a short movie clip (1–2 min), showing your experiences during the escape room, as we wanted the students' open view. Seventeen classes sent in their clips.

Table 1.1 The various data sources

Data source	N
Classroom - observations	14
Classroom - movie clips	17
Students - online questionnaires	202
Students - interviews	68
Teachers - online questionnaires	39
Teachers - interviews	11

[a] in groups of 4-6 students

Fifty teachers were either interviewed (N = 11) or completed an online questionnaire (N = 39) after the escape room activity, see Supplementary Appendix A. Teachers were interviewed individually, immediately after the classroom observations. The questionnaires and interviews for teachers were nearly the same as for the students with the exception that the question on the learning outcomes was replaced by open-ended questions on years of teaching experience, what stimulates students in an escape room, what are success factors, boundary conditions and barriers for the teachers in implementing an escape room in the classroom. Table 1.2 lists the main characteristics of the teachers and the students.

1.2.2 Data analysis

Interviews with students and teachers were transcribed verbatim and analysed per question, except for the open-ended questions. Answers to open-ended questions in the interviews and on the questionnaires were categorized, counted and analysed by one researcher, using a process of open coding with the main concepts from the questions as sensitising concepts (Boeije, 2010). Results were discussed with two researchers. A total of four coders analysed the video clips. For each video clip, the visual content was described and the audio transcribed verbatim. Two coders independently analysed the clips using a coding scheme, in relation to students' view on the experience, student behaviour, teacher behaviour and game elements. The initial agreement between the three pairs of coders in the description and coding of the clips was respectively 71, 77, and 81%. Researchers differed in the grain size of the image descriptions and whether or not soundtracks were transcribed verbatim by the various researchers. Intersubjective agreement was reached after discussion. Finally, all documents from interviews, classroom observations and movie clips were read, reread and hand-coded for overall emerging themes by the first author and checked by two other researchers (Boeije, 2010). During the triangulation process, it was studied whether the results from interviews, classroom observations and video clips aligned and clarified or deepened results from the questionnaires.

1.3 Results

This study explored how teachers and students perceive the educational potential of escape rooms in science secondary education, regarding: user experiences, the usability of escape rooms in terms of learning goals and learning outcomes. In relation to future escape rooms, the experienced or foreseen boundary conditions and barriers for implementing escape rooms in science class were studied.

Table 1.2 Gender, age and teaching experience for participants in the two main types of data collection

Students	**Questionnaires**	**Interviews**
N (female : male)	202 (113:89)	68 (43:25)
Average age (y)	12.0 (R 11-14)	- [a]
Teachers		
N (female : male)	39 (35:4)	11 (8:3)
Age groups (y)		
20-30	9 (8:1)	6 (4:2)
30-40	13 (11:2)	3 (2:1)
40-50	5 (5:0)	1 (1:0)
50 +	11 (10:1)	1 (1:0)
No response	1 (1:0)	
Average teaching experience (y)	11.2 (R 1-27)	9.2 (R 0-20)

Note: R = range
[a] Age unknown

1.3.1 Students' and teachers' experiences with the Escape the Classroom Challenge

Students' experiences

The majority of students (88%) in the questionnaires responded positively about their experience, with 9% neutral and 3% negative. On the question about what aspect of the escape room activity they appreciated the most, answers could be categorized according to three themes: 1) game elements, 2) working and learning in an escape room, and 3) experiences. Table 1.3 summarizes these answers.

The puzzles were most appreciated because of their "diversity" and aspects such as "the discovering of new things", as students clarified in the interviews. The highly appreciated cracking codes and/or opening the vault and objects such as black lights and red filters were associated by students with the game-like character of the escape room. It was noteworthy that available 3D models (e.g., a torso) that had a decorative function were mentioned, too. Aspects such as winning, competition or the prize were less often mentioned. Nearly one-fifth of the answers on the questionnaires fell in the category of working and learning in an escape room, in which teamwork was the most frequently mentioned aspect, followed by 'discover or think for yourself'. When students identified the least appreciated aspects, they named the flip side of the same coin (see Table 1.3), explaining in interviews their frustrations with "getting stuck and not knowing how to continue", "not finishing the game", "a non-functioning" team, and the difficulty of the puzzles.

The analysis of classroom observations and movie clips confirmed these findings, showing students behaviourally engaged: constantly interacting with materials, puzzles and discussing them with team members. The cracking of codes and/or opening of the vault featured in nearly all clips (15/17), whereas the prize was hardly mentioned (2/17). The added images (e.g., ticking clocks) and texts ("Are they going to make it?"), as well as exciting tunes, stressed their excitement about the escape room. Throughout students' gameplay, a range of emotions was observed within teams or single persons: tension, confusion, excitement, disappointment or frustration. In the classroom observations, frustration was seen in 9% of the groups, when students got stuck and had no clue how to proceed. After trying a while, these students showed non-functional behaviour, such as sitting apart from the team and/or discussing their weekend.

Teachers' experiences

The escape room as a learning environment seemed to appeal to teachers of different ages, gender and teaching experiences, as seen in Table 1.2. The teachers were asked in questionnaires and interviews about what stimulates students during gameplay and what are success factors. According to the teachers, students were mainly stimulated by competition, the prize or the excitement, as seen in Table 1.3. This is remarkable, as winning or the prize were not often mentioned by the students. The puzzles and teamwork were more appreciated by students than teachers had imagined. It is noteworthy that provided objects, such as black lights, red filters and biological 3D models, were very appreciated by students, but not mentioned at all by teachers. For the teachers, the main success factors for escape rooms in classrooms are the diversity of puzzles and the need for and development of teamwork skills.

Table 1.3 Most and least appreciated aspects of the Escape the Classroom Challenge according to students & Stimulators for students to be engaged and success factors of escape rooms (ERs) in the classroom according to teachers, indicated in the open-ended questions on the questionnaire (Q) and mentioned in the interview (I). It was possible for participants to skip a question or give more than one answer.

	Most and least appreciated aspects of the ER, according to students				**Stimulators for students and success factors, according to teachers**			
	a. most appreciated		**b. least appreciated**		**c. stimulators**		**d. success factors**	
Aspects	**NQ=202**	**NI=55**	**NQ=200**	**NI=50**	**NQ=38**	**NI=11**	**NQ=37**	**NI=11**
Everything	14	0						
Nothing			35	10				
Game elements	*151*	*28*	*153*	*28*	*52*	*17*	*18*	*12*
Puzzles	46	9	33	6	8	3	5	0
Cracking codes & vault	43	1	20	0	0	0	0	0
Losing or not finishing			47	2				
Getting stuck			36	14				
Objects, e.g., blacklights	26	3	2	1	0	0	0	0
Competition	14	5			26	6	11	10
(Unknown) prize	17	2			11	2	0	0
Other aspects	5	8	15	5	7	6	2	2
Working & learning in an ER	*40*	*23*	*13*	*2*	*18*	*9*	*51*	*17*
(aspects of) teamwork	20	10	4	0	8	2	13	4
Discover or think for yourself	11	2			0	0	2	1
Variation in puzzles	0	9			4	2	15	3
Affiliation curriculum							5	4
Other aspects	9	2	9	2	6	5	16	5
Experiences	*12*	*8*	*7*	*10*	*14*	*7*	*29*	*7*
Exciting or challenging	8	6	0	0	13	4	15	5
Duration (too short or long)			4	8	0	0		
Motivating	4	2	3	2	1	3	8	1
Other aspects							6	1
Total	217	0	208	50	84	33	98	36

Note: N_Q= Number of questionnaires; N_I= Number of interviewed participants.

Table 1.4 Previous experiences of participants with recreational or educational escape rooms (ER), and whether these experiences were helpful in completing the Escape the Classroom Challenge.

	Students		Teachers	
	N_Q = 202	N_I = 68	N_Q = 39	N_I = 11
Had experience with at least one of the ER types	70	48[a]	24	7
…of which educational ERs	28	6	8	5
…of which recreational ERs	56	32	21	6
	N_Q = 200	N_I = 34		
Previous experiences helpful?				
Yes	47	13		
No	87	17		
Maybe	66	4		

Note: N_Q= Number of questionnaires; N_I= Number of interviewed participants.

[a] For 10 of the interviewed students, it was unclear which type of ER they visited.

Table 1.5 Potential educational goals for escape rooms mentioned by students and teachers in the questionnaires (N_Q) and interviews (N_I)

Educational goals	students		teachers	
	N_Q = 202	N_I = 62	N_Q = 39	N_I = 11
Acquiring new content knowledge and skills	71	0	13	2
Processing content knowledge and skills	101	44	27	9
Rehearsing content knowledge and skills	85	46	31	11
Formative assessment	103	25	29	8
Summative assessment	0	2	3	0
Enhancing teamwork	139	4	38	8
Enhancing motivation for biology	97	0	33	9
Fun lesson	114	7		
Getting to know each other	47	3		
Other goals		6	5	6

Note: NQ= Number of questionnaires; NI= Number of interviews.

Previous experiences with escape rooms

Teachers and students were asked for previous experiences with escape rooms. As seen in Table 1.4, only 8 out of the 39 teachers in the questionnaires, had already experienced educational escape rooms. Therefore, the majority of the participating teachers in the study would not be considered to be early adopters or innovators (see Rogers, 1962). Students were asked whether previous experiences had been helpful in this escape room or could have been helpful. Although, students seem to think differently (see Table 1.4); the reasoning in their explanations was alike: in escape rooms, the required way of thinking is the same, while the content can vary.

1.3.2 The usability of escape rooms for science education

Although students and teachers might have very different perspectives on education, their perceptions of the usability of escape rooms for the various educational goals were comparable; therefore, we discuss them in the same section.

Educational goals

The goals most often mentioned by teachers in the questionnaires were non-content related goals: “to enhance teamwork” (38 out of 39 teachers) and “increase motivation for biology” (33 out of 39 teachers), see Table 1.5. However, data on students’ perceptions did not confirm that students expected escape rooms to increase motivation for the subject of biology. The data sources on students were not congruent on this aspect, 48% of the students named it as a possible goal in the questionnaires, but it was not mentioned in the interviews or in any of the other data sources. Students, like the teachers, also mentioned two non-content related goals most often in the questionnaires; these were “to enhance teamwork” (69%) and “a fun lesson” (56%). The most frequently mentioned content-related goals were the same for teachers and students, although the ranking differed: formative assessment and processing and rehearsing of content knowledge and skills.

Apart from being the goal most frequently mentioned by teachers and students (see Table 1.5), teamwork emerged as a recurring theme in all data sources. In interviews, students explained that the mutual dependence in an escape room is higher than in regular teamwork assignments due to time constraints and the diversity of the puzzles that need to be done at the same time. Furthermore, students mentioned that it is not possible to improve the work of peers before handing it in, as can be done with regular team assignments. In interviews, a few teachers wondered whether teamwork skills are a boundary condition for participation or are developed during gameplay. They observed that teams varied in their teamwork skills and seemed to develop them hardly at all. This observation was confirmed by the classroom observations and student comments in interviews such as “[..] you needed to know how to collaborate, otherwise things mess up”. It was observed that none of the teachers gave instructions about teamwork before the escape room activity; afterwards in the debriefing with the class, few of the teachers (3/14) discussed aspects of teamwork or strategies for teamwork. The movie clips showed teams of students working as one group or divided into subgroups. In the clips, the students’ added comments varied from “working very well” to “a little fight”.

As shown in Table 1.5, both teachers and students perceived an escape room as a good learning environment for 1) processing, 2) rehearsing, and 3) formative assessment of content knowledge and skills. As the argumentation on these three goals was largely similar, we discuss them together. In the interviews, students mentioned that escape rooms seem very suitable for these goals because they cannot skip questions, there are no answer keys or informational books available for easy checking, there is a time constraint and they do not want to consult the teacher. Consequently, you need to think harder, students explained. Teachers and students who considered escape rooms less suitable for formative goals mentioned that in the end, students get no precise overview of their knowledge gaps. Students added that teamwork limits the view of their own capacities, and in case of grading, mutual dependence was viewed negatively. Another argument mentioned only by students was that escape rooms require additional thinking skills than those practiced in regular lessons; for instance, they mentioned “linking information” and “out-of-the box” thinking and suggested to keep the type of formative and summative assessments congruent. Except for two, all students responded negatively about the use of an escape room as a summative test, using the same arguments as mentioned above.

Only one-third of the teachers and students who responded to questionnaires assigned acquiring content knowledge as a suitable goal for the use of an escape room. In the interviews, teachers and students were even more critical on that point. None of the 68 interviewed students thought this was a good idea, as the acquisition of knowledge calls for tranquillity and reflection, which conflicts with acting within time constraints. In addition, teachers pointed out that the development of science knowledge requires careful relating (and understanding) of the concepts, and they concluded that an escape room is too unstructured and random for that purpose. Furthermore, some students and teachers stated that thinking skills such as “linking” and “out-of-the-box thinking” are prerequisites for acquiring content knowledge and skills. In addition, it was argued that unknown knowledge in an unstructured environment with uncertainties about what to do and how to proceed asks too much from most students.

Evaluation of learning

“What did you learn in the escape room?” During the interviews, sixteen of the student groups reported that they learned new knowledge, or strengthened and/or enhanced their knowledge. For example, “I knew that there are animal cells, but I didn’t know what they looked like”; “Well, more on biology, much more! I had forgotten, for example, what an organ was, now I’ll remember it better because it was fun to do”. The students’ answers can be categorized as referring to 1) biological content matter and skills, 2) information and thinking skills and 3) social and mental skills. Most students had difficulty concretizing the biological content matter and skills for the puzzles they had completed. However, students could describe more concretely the various non-domain-specific skills they had used. Besides teamwork and out-of-the-box thinking, students described the following information skills; to get an overview of the information, to select, to relate and to combine information. The social and mental skills they described were to reduce stress, to persist, and to “stay nice to peers under pressure”. A few students observed that “focusing under stress is harder”. In classroom observations, it was noted that students were very active and focused on the (cognitive) puzzles. A repetitive theme in student interviews was the perception that they needed to think “hard”, “deep”, “fast”, “smart”, “critically” or “thoroughly” during gameplay, for reasons mentioned in section “Educational Goals”. Students seemed very cognitively engaged in the escape room. It was observed that students’ engagement dropped spontaneously, when the first team opened the vault and started celebrating their victory.

1.3.3 Escape rooms in the future

Foreseen and perceived boundary conditions and barriers

By means of open-ended questions on the questionnaire and in the interviews, teachers were asked about boundary conditions and barriers when implementing an escape room in science education. The teachers' answers can be categorized as addressing the following themes: 1) escape rooms as learning environments, 2) organisational aspects of implementing escape rooms and 3) required personal qualities of teachers and students (see Table 1.6). According to the teachers, in an escape room as a learning environment the puzzles need to be aligned with the curriculum, be very clearly described and doable, and enhance teamwork. Half of the organisational aspects mentioned concerned time: time available within the curriculum, time to develop an escape room, time to set it up and the time required to reset the game between classes. A few teachers mentioned time for reflection with the students afterwards as a boundary condition for learning. In the interviews, required personal qualities for teachers and students were mentioned. Teachers need monitoring skills and students need internal motivation for this type of puzzle, competitiveness and curiosity. The teachers were also asked about barriers to implementing educational escape rooms in their class. The boundary conditions related to time all reappeared as barriers (71%, data not shown). Additional barriers for teachers were, for example, the balance between the teacher's time investment and the student's learning outcomes.

Future use of escape rooms in the classroom

Despite the barriers mentioned, most teachers (31 out of 39) intended to use an escape room in the classroom again; see Table 1.6. The rest of the teachers (8 out of 39) were doubtful, referring to the boundary conditions and barriers mentioned before. The students' willingness to experience future escape rooms in the classroom was high (87% in the questionnaires); see Table 1.6. In their explanations (not shown), students reasoned that it worked better or faster for them than regular lessons, because they are more active, need to think harder, there is more diversity in the activities and it is more exciting. Only 2% of the answers referred to greater motivation for biology. In the questionnaires, 2% of the students did not want any more escape rooms, for no outstanding reasons. According to nearly all of the teachers (36 out of 39), escape rooms are suitable for all age groups in secondary education and pre-vocational education. Two teachers perceived escape rooms as suitable only for lower secondary education and pre-vocational education. However, one teacher reasoned that escape rooms are suitable for all age groups in secondary education, but not for pre-vocational education. In interviews, teachers at pre-vocational schools commented that their students would require more internal and external guidance during the game.

Table 1.6 The number of students and teachers who want to participate in future educational Escape Rooms and the teachers' boundary conditions for its implementation in their classroom. It was possible for participants to skip the question.

Future educational escape rooms?				
	students		teachers	
	N_Q = 210	**N_I = 68**	**N_Q = 39**	**N_I = 11**
Yes	175	68	31	11
Maybe	21	0	8	0
No	5	0	0	0
Teachers' boundary conditions for future educational escape rooms				
			N_Q = 37	**N_I = 11**
ER as a teaching and learning environment			19	24
Aligned with the curriculum or students' knowledge			8	6
Puzzles (doable, challenging, clear, diversity)			6	4
Enhance teamwork			1	5
Other			4	5
Requirements for students and teachers			3	21
Requirements for students				
internal motivation			0	3
other			0	4
Requirements for teachers				
coaching skills			0	7
other			3	7
Organisational aspects			22	12
Time: curriculum, development, preparation, reset, etc.			12	7
Other: finances, availability of material, suitable classrooms, etc.			10	5
Total			44	57

Note: N_Q = Number of questionnaires; N_I = Number of interviewed participants.

1.4 Conclusion and discussion

This study explored the perceptions of teachers and their students on the educational potential and degree of support for escape rooms in secondary science education. We focused on user experiences, usability for science education and boundary conditions and barriers for future escape rooms. In addition to discussing the main outcomes on these aspects, the following topics are addressed: the merging themes in overall data, claims made by educational platforms (see "Introduction" section), recommendations and directions for future research on escape rooms in science education.

1.4.1 User experiences

In this study, only 13 out of the 50 teachers (in questionnaires and interviews), had experienced an educational escape room before. The educational escape room appealed to science teachers of different ages, gender and teaching experiences, which is in accordance with Nicholson's inventory of adult visitors to recreational escape rooms (Nicholson, 2015). Teachers perceived that students were competition or prize driven and engaged in their work. They appreciated the diversity of content related activities, the need for or development of teamwork and the increased motivation for biology. However, based on this study, the assumed development of teamwork and communication skills is doubtful. Nearly all students enjoyed the escape room as a learning activity, and looked forward to the next one. No gender differences in preferences were shown, unlike for some types of educational games (Kinzie & Joseph, 2008). The most appreciated aspects (diversity of puzzles with a problem-solving and discovery nature, the need for physical objects and cooperation), are characteristics of exploratory and problem-based play (Kinzie & Joseph, 2008). Kinzie and Joseph showed that in order to attract both girls and boys in the underlying science content and skills, educational games need to use both types of play (2008). Students perceived that in escape rooms, the way of thinking that is required is the same, whereas the content can vary.

1.4.2 Usability for science education

In our study, students described being more active, mutual interdependent and thinking more thoroughly or critically than in a regular lesson (see "Educational Goals" section). Hence, escape rooms seem to create environments for collaborative learning, as important elements in collaborative learning are positive goal interdependence, complementary roles, dividing information or other resources and constructive competition (Johnson and Johnson, 2009). Students enjoyed the feeling of autonomy, discovery, ownership and mastery during gameplay. Educational games need to be designed in a way that they give room for these experiences (Arnab et al., 2015; Barab et al., 2010; Lameras et al., 2017; Sin et al., 2014). Interesting in the current study is that students experienced autonomy, ownership and discovery, even though the escape room setup was very strict and had few degrees of freedom, due to its design involving codes and locks. In this respect, the escape room is an example of Trninic's proposed integration of guided repetition and discovery by students (Trninic, 2018), with the opportunity to scaffold learning processes without losing the students' feeling of ownership, discovery and victory.

Nearly all teachers considered escape rooms to be suitable learning environments for all ages and school types. However, they seem suitable mainly for enhancing teamwork, for increasing motivation for a subject, in this case biology, and for processing, rehearsing, and formative assessment of content knowledge. A review study confirms that educational escape rooms are used mainly for these goals (Veldkamp et al., 2020). This current study shows their rationale, as two-thirds of the teachers and students in the questionnaires perceived that an escape room is not suitable for acquiring new biological knowledge. Teachers stated that the development of biological knowledge requires careful linking and understanding of the concepts, which conflicts with the seemingly unstructured environment. Students also reasoned that learning new content knowledge requires more tranquillity and reflection than the gameplay can offer. Students perceived that for all escape rooms the strategic thinking is the same, whereas the content of the puzzles can vary. This has, according to some students, consequences for the use of an escape room as an environment for assessment. In their opinion, the ways of assessment in the formative and summative assessment need to be congruent. This form of congruence is called constructive alignment (Biggs, 2011). A few teachers and students suggested that thinking skills such as “linking” and “out-of-the-box thinking”, might be prerequisites for acquiring or fostering content knowledge and skills. Likewise communication and teamwork skills appeared necessary to finish in time. Appropriate use of social skills is mentioned by Johnson and Johnson (2009) as requisite for collaborative learning. An escape room might be a suitable environment to enhance these skills, if initial instructions, coaching and debriefing are provided on these skills, as Seto’s study showed (2018).

An escape room is a time restricted game. In an educational setting it addresses various educational aspects. Time restriction enhances the authenticity of medical educational escape rooms, as the ability to work under (time) pressure is a medical professional skill. (Wu et al., 2018; Brown et al., 2019; Gómez-Urquiza et al., 2019). Students perceived that time restriction improved their ability to delegate tasks related to patient care and kept them focused on providing care (Brown, et al., 2019). In the current study, time restriction appears to be an ambiguous factor in learning. On one hand, it gives urgence to players’ thinking, acting, and creates mutual dependency. On the other hand, it limits ‘learning by explaining’ and time to reflect on the content. The stress involved might prevent the connection of incoming information with pre-existing knowledge (Vogel et al., 2018) or newly formed memory cells to survive (Kim et al., 2015; Price & Duman, 2020). In addition, the learning process during gameplay stops for all students once the first team opens the vault and sets the fastest time. Offering a vault for every team can tackle this problem. To conclude, the time pressure during the gameplay, urges the need for a thorough reflection on the content knowledge afterwards.

1.4.3 Boundary conditions and barriers for future escape rooms

Limited time is also the main theme teachers mentioned about barriers for implementing educational escape rooms; e.g., regarding development and setup of an escape room. The boundary conditions most mentioned by teachers were common requirements for any type of learning activity (e.g., alignment with curriculum). Despite the barriers, most teachers 42 out of 50 teachers intended to implement a future escape room. Time is for teachers a limited resource and one of the greatest constraints to any innovation, whether at the individual, classroom, or school level (Collinson and Cook, 2001; Hargreaves, 1990). Therefore, it is surprising that so many teachers find time to adapt the concept of escape rooms for their classes. These pioneering teachers mentioned that the development is time-consuming, especially in relation to effective time with students, however it is satisfying to see students active in class (Vörös & Sárközi, 2017; Boysen-Osborn et al., 2018; Guigon et al., 2018; Mosley et al., 2018; Franco & DeLuca, 2019; Järveläinen & Paavilainen-Mäntymäki, 2019; Morrell & Ball, 2019). Specific time consuming aspects are alignment to the curriculum (Brown et al., 2019), testing prototypes (López-Pernas et al., 2019), and organizing the gameplay (Dietrich, 2018). As these teachers are early adopters and teachers in general are very limited in their time, science centres develop escape rooms, schools can visit or borrow (Peleg et al., 2019; Science Centre Delft, 2020).

1.4.4 Emerging themes in overall data

After qualitative analysis, the triangulated data shows the following recurring (sub)themes: engagement (cognitive, behavioural and affective) and teamwork. A review study on serious games also distinguishes these aspects of engagement (Hookham & Nesbitt, 2019). A meta-study on engagement in education showed that engagement positively influences academic achievement (Fredricks et al., 2004). Behavioural engagement is associated with development of basic skills and prevents dropping out. Cognitive engagement is related to analysis, synthesis, and deep-level understanding of content. Affective engagement encompasses positive and negative emotions and is presumed to influence the willingness to do work. None of the reviewed studies comprised an intervention that evoked all of these aspects of engagement, like the escape room in our study.

The emerging themes, engagement and teamwork, correspond with those found in a study on escape rooms in medical education: engagement, frustration and teamwork (Hermanns et al., 2017). Our data showed subcategories of engagement; cognitive, behavioural and emotional. Affective engagement relates to the emerging theme of "frustration" in the study of Hermanns et al. (2017). However, in our study, frustration was only one of a range of observed emotions, and strong affective engagement was shown during gameplay. In both studies, the background of the frustration is the same: getting stuck while having time pressure. The theme of teamwork is discussed within other sections.

1.4.5 Confirmation of the claims made by educational platforms

Educational platforms that promote and help science teachers with the introduction of educational escape rooms claim that students work actively together on a diversity of content-based puzzles, triggered in different ways and intrinsically motivated, while developing the four C's: critical thinking, collaboration, creativity and communication (Pollock, 2015; Breakout EDU, 2018). The triangulated data confirm that students worked in an engaged way on a diversity of content-based puzzles. Students were indeed triggered in different ways, felt cognitively engaged and described different thinking skills. The claimed critical thinking was not specifically investigated in this study. Collaboration and communication skills seem boundary skills needed in order to understand and solve the content-based puzzles. The creativity fostered needs to be defined in more detail, as the creativity needed in escape rooms is the creativity to find the teachers' programmed answers, not to solve open-ended problems.

1.4.6 Recommendations and future research for secondary science education

Students' engagement positively influences academic achievement (Fredericks et al., 2004). Students' engagement will be enhanced when tasks provide extrinsic rewards, cultivate intrinsic interests, create a sense of ownership, provide opportunities for collaboration, permit diverse forms of talents, are authentic and fun to do (Newmann et al., 1992). This study showed for all these criteria, except 'the cultivation of intrinsic interests', that educational escape room address them. At the same time, the criteria may function as guidelines for designers of an educational escape room in order to assure its educational potential. Based on this study, we would recommend puzzles that create mutual interdependence in a team with a combination of discovery learning, different thinking skills, cracking codes or vaults and physical objects.

It is promising that students experienced the need to think harder than in regular lessons and to use different thinking skills, and they "learned a lot". However, students could not give very concrete descriptions of their' self-reported learning of content knowledge. On the contrary, the social, team and thinking skills they used were described very specifically. The incongruence between perceived and actual learning is in line with findings on other educational escape rooms (Veldkamp et al., 2020) and practical work or inquiry that enhances knowledge of science (Abrahams & Millar, 2008; Minner et al., 2010). These studies conclude that without active linking of knowledge during the intervention or reflection afterwards, the interventions appeared not to be effective in enhancing content knowledge. Therefore, we recommend designing puzzles in a way that it requires discussion about the content, and a debriefing on the process and content afterwards. Another important focus of further research is the balance between the teachers' scaffolding and students' feeling of mastery and ownership, which may lead to more guidelines for teachers and the prevention of students dropping out during gameplay. To enhance the educational potential of educational escape rooms, it would be interesting to develop an escape room by design based research, based on design criteria taking into account the differences between the goals and context for recreational and educational escape rooms.

This study is limited as the sample of teachers is not-randomized; teachers volunteered to participate in the National Challenge and in this study. As only 13 out of the 50 teachers had previous experiences with educational escape rooms, this study gives a more generic view of teachers' perceptions on the educational potential escape rooms (see Table 1.4). Participating teachers did not make a differentiation for their specific subject, as escape room puzzles can be adapted to all sciences as they make use of concepts, problem solving and calculations. As seen in this study, the attraction of escape rooms is the diversity of content-based activities, the need for different skills, and the engagement of the students. In addition, science teachers also mention teaching of content knowledge and skills in authentic contexts such as crime scenes makes escape rooms attractive (Ferreiro-Gonzáles et al., 2019; Healy, 2019; Peleg et al., 2019).

In conclusion, case studies stated that early adopting teachers and students are enthusiastic about the implementation of escape rooms in education. This study shows that teachers of different ages, gender and teaching experiences are attracted to the activity. In addition, this study demonstrates that the student engagement consists of cognitive, behavioural and affective engagement. Furthermore, it appoints why the game is appreciated by both boys and girls, and which game elements are preferred. There is a high degree of support among science teachers and students for the educational potential of escape rooms in secondary science education as an engaging, problem-based environment for processing, rehearsing, and formative assessment in which thinking and teamwork skills are required, with the opportunity for teachers to scaffold learning processes without losing students' feeling of ownership, discovery and victory.

Chapter 2

Escape education!
A systematic review on escape rooms in education

This chapter is based on
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AV and LvdG designed the study; AV and LvdG collected data; AV and LvdG analysed and discussed the data; AV drafted the manuscript; AV, LvG, MCK and WvJ contributed to a critical revision of the manuscript; MCK and WvJ supervised the study.

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Abstract

The global increase in recreational escape rooms has inspired teachers around the world to implement escape rooms in educational settings. As escape rooms are increasingly popular in education, there is a need to evaluate their use, and a need for guidelines to develop and implement escape rooms in the classroom. This systematic review synthesizes current practices and experiences, focussing on important educational and game design aspects. Subsequently, relations between the game design aspects and the educational aspects are studied. Finally, student outcomes are related to the intended goals. Educators in different disciplines appear to have different motives for using the game's time constraints and teamwork. These educators make different choices for related game aspects such as the structuring of the puzzles. Unlike recreational escape rooms, in educational escape rooms players need to reach the game goal by achieving the educational goals. More alignment in game mechanics and pedagogical approaches is recommended. There is a discrepancy in perceived and actual learning of content knowledge in recreational escape rooms. Recommendations in the article for developing and implementing escape rooms in education will help educators in creating these new learning environments, and eventually help students to foster knowledge and skills more effectively.

2.1 Introduction

Worldwide, recreational escape rooms have inspired teachers to adapt the popular entertainment activity for education (Sanchez & Plumettaz-Sieber, 2019). Escape rooms (ERs) are live-action team-based games in which players encounter challenges in order to complete a mission in a limited amount of time. Originally, the nature of the mission was an "escape" from a room. Nowadays, the missions vary; players may solve a murder mystery or break into a vault (Nicholson, 2015). However, the "escape room" moniker is the term most used for this type of games (Wiemker et al., 2015).

Parallel to the immense popularity in the entertainment industry, ERs are gaining popularity as learning environments in primary, secondary, higher education, and professional development programs (Sanchez & Plumettaz-Sieber, 2019). The implementation of educational ERs started bottom-up with enthusiastic teachers. They share materials on platforms such as Breakout EDU which has about 40,000 members (Breakout EDU, 2018; Sanchez & Plumettaz-Sieber, 2019). These developments rely on early adopting teachers adapting the recreational ER concept. Teachers develop the rooms based on ER video games, and/or their experiences in recreational ERs (e.g., Franco & DeLuca, 2019). This bottom-up phenomenon of ERs in education is unique and increasing. There is a need to evaluate their use, and a need for guidelines to develop and implement educational ERs (Jenkin & Fairfurst, 2019). A systematic review of current practices and experiences will help educators in creating these new learning environments, and eventually help students to foster knowledge and skills more effectively.

2.1.1 Escape rooms for education

Escape rooms have been used for various educational purposes: to recruit students (Connelly et al., 2018; Gilbert et al., 2019), for students to get to know institutional services (Guo & Goh, 2016; Wise, et al., 2018), or to increase students' earthquake preparedness (Novak et al., 2018). A different purpose is the ER as a research environment, for example to observe students' information search behaviour (Choi et al., 2017), learning processes in student teams (Järveläinen & Paavilainen-Mäntymäki, 2019), or the use of teamwork and leadership skills among students (Warmelink et al., 2017). Other case studies describe students developing ERs to foster design skills (Li et al., 2018; Ma et al., 2018). Escape rooms have been designed to foster domain specific skills and knowledge, such as nursing (Adams et al., 2018; Brown et al., 2019), medicine (Cotner et al., 2018), pharmacy (Cain, 2019; Eukel et al., 2017), physiotherapy (Carrión et al., 2018), chemistry (Dietrich, 2018), physics (Vörös & Sárközi, 2017), computer science (Ho, 2018), mathematics (Arnal et al., 2019), history (Rouse, 2017), and English (López, 2019) or to support the development of generic skills (Craig et al., 2019).

Like recreational ERs, these ERs combine hands-on and minds-on activities to be achieved with a team in a limited time. In a classroom setting, teachers try to create authentic environments with meaningful activities and room for failure. For education, each of the ER characteristics is not unique on its own. However, their combination seems unique and appealing to teachers.

ERs have emerged spontaneously in education through platforms such as Breakout EDU (Breakout EDU, 2018). These platforms are mainly driven by educational practitioners who copied and adapted recreational ERs. As a consequence, little work has been reported on their theoretical foundation in educational science. However, as developed ERs share features with educational games, we can resort to theories of Game Based Learning (GBL) to provide the start of a theoretical approach to educational ERs. Systematic reviews on GBL found, in most studies, improved knowledge acquisition, content mastery and motivation as an effect of educational games (Conolly et al., 2012; Subhash & Cudney, 2018). These reviews stress the importance of both educational and game design aspects to be considered and require an understanding of the relations between educational and game design aspects for engagement (Connolly et al., 2012; Jabbar & Felicia, 2015) and learning (Ke, 2016; Van der Linden et al., 2019). Important game design aspects are a narrative which contextualises knowledge and skills needed, with a role for students contributing to ownership and autonomy in their learning (Annetta, 2010; Jabbar & Felicia, 2015; Subhash & Cudney, 2018). Furthermore, unambiguous feedback, rewards and increased complexity (levels or progressive challenges) scaffold the learning process. The feature interactivity is related to collaborative learning. Both concepts refer to arrangements that involve two or more students working together on a shared learning goal. Van Leeuwen and Janssen's review study (2019) on the teacher role during collaborative learning showed a crucial, yet challenging role of teachers to remain a central figure in supporting collaborative learning, without taking control of the moments in which opportunities to learn arise for students. In addition, educational ERs align with situated learning theory (Lave & Wenger, 1991) which states that situated or scenario-based learning should take place in the environment in which it would normally be applied.

2.1.2 The escape room concept and design characteristics

A wide range of scenario's for ERs is possible, as Nicholson's inventory of 175 recreational ERs has shown (2015). Players need to 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 educational games, it is used to get a learner engaged, solving challenges and finishing the task (Annetta, 2010). Consistency in the game context (time period and place), the characters of the players, the activities, the tools, and the props is recommended to prevent cognitive dissonance (Nicholson, 2016). Within ER literature, all activities are called puzzles and they use a simple game loop: a challenge, a solution and a reward (e.g., a code for a lock, or information needed in the next puzzle). Puzzles can be categorized as: a) cognitive puzzles that make use of the players' thinking skills and logic, b) physical puzzles that require the manipulation of artefacts to overcome a challenge, such as crawling through a laser maze and c) meta-puzzles, the last puzzle in the game in which the final code or solution is derived from the results from the previous puzzles (Wiemker et al., 2015). Cognitive puzzles seem to be predominant in ERs (Nicholson, 2015; Wiemker et al., 2015).

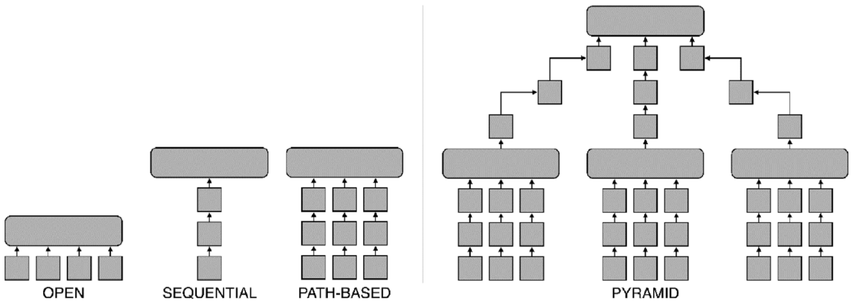

Figure 2.1 Puzzle structures in escape rooms: a) basic structures: open, sequential and path-based; b) a complex, hybrid structure, such as a pyramid. Squares are puzzles and rectangles are meta-puzzles (adapted from Nicholson, 2015)

Nicholson (2015) identified four ways of organizing the puzzles, see Figure 2.1. In an open structure, the players can solve different puzzles at the same time. All other 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. 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, reasoning, math, reading, and pattern recognition (Wiemker et al., 2015). After the gameplay, the gamemaster debriefs the players on the process and what they have achieved (Nicholson, 2015; Wiemker et al., 2015). The skills required and reflection about what was accomplished hint at the idea that ERs can be used in education.

2.1.3 Recreational versus educational settings of escape rooms

In contrast to recreational ERs, which intend to attract a broad audience, educational ERs are developed for a specific target group with well-defined learning goals. Educational developers aim for a high success rate; success gives students positive learning experiences, and solving all puzzles will help to achieve all learning goals. Consequently, designing ER puzzles is challenging. Firstly, the puzzles need to align with the curriculum. Secondly, puzzles need to prevent boredom and frustration, that both of which may lead to dropping out of the game (Hermanns et al., 2018). Thirdly, the puzzles' outcomes need to be numerical or alphabetical codes due to the locks involved, which limits how questions are posed. In the entertainment industry, an escape usually takes place in one or more connected permanent rooms, whereas in an educational setting such a space is usually not available. Instead, classrooms are used and teachers have limited time to set up, reset and clear away materials. Another important difference is the number of participants playing at the same time. An ER is usually designed for one team with a limited number of players (on average 3-7) (Nicholson, 2015). In education, teachers need to organize an ER activity for a whole class or course, up to hundreds of students (Cain, 2019; Hermanns et al., 2018).

Due to the differences between recreational and educational settings in classrooms, educators need to adapt the ERs concept and make choices on various educational and game design aspects. This review aims to synthesize the practices and their theoretical considerations on these aspects. The following research questions (RQs) are explored in this systematic review.

1. In educational ERs, what are common practices and theoretical considerations regarding their educational aspects?
2. In educational ERs, what are common practices and theoretical considerations regarding their game design aspects?
3. How are educational and game design aspects related in educational ERs?
4. To what extent have the intended goals of the educational ERs been achieved?

Regarding the educational aspects (RQ1), we studied the target groups, learning goals, the game's positioning in the course curriculum and the teacher's role. Studied game design aspects (RQ2) are: puzzles and their structuring, the game organisation, team size, playtime and the use of technology.

2.2 Method

This systematic review consists of the following steps based on Hannes and Lockwood (2012): 1) search strategy, 2) selection, 3) quality assessment, 4) data extraction and 5) data synthesis.

We conducted a search on the 1st of June 2019. Databases SCOPUS and Google Scholar were searched, with the search string ("escape room" OR "escape game") AND ("education*"), identifying respectively 61 (SCOPUS) and 1401 (Google Scholar) records, see Figure 2.2. All SCOPUS records also showed up in the Google Scholar search. These duplicates were excluded, as well as internal duplicates; in total 67 records. In the second step, two researchers independently screened the remaining 1395 publications' title, abstract, and keywords on defined inclusion/exclusion criteria.

As we intended to synthesize practices on ERs with physical elements for teams in classroom settings, exclusion criteria were 1) ERs for one participant and 2) completely virtual or digital ERs. These games differ in gameplay, puzzles and therefore puzzle design, game design and settings. Inclusion criteria are 1) the accessibility of the publications written in English, German or Dutch, 2) an experimental study on the development and evaluation of an educational ER, with 4) a design for classroom settings, with restricted setup and reset times. This excludes permanent environments such as library settings, as it has consequences for the design criteria regarding setup and reset times and game organisation.

Full text versions of the 91 studies identified at initial screening were obtained, and a checklist of all inclusion/exclusion criteria was used to establish whether to include studies in the review. This final selection process resulted in 36 publications (see Figure 2.2). Three additional studies were found by chain-referencing from the studies selected for inclusion, based on the same inclusion/exclusion criteria. The final data set consisted of 39 documents, including research articles, conference proceedings, conference papers and short reports in medical journals.

In the third step, the quality of the data set (39 documents) was assessed in light of the research questions. For research questions one to three, on specific game design and educational aspects, all studies meeting the inclusion criteria were included; 39 documents. For research question four concerning student outcomes, only peer reviewed studies with assessed learning outcomes (e.g., pre- and post-tests) were included, resulting in 3 articles (see Figure 2.2).

In the data extraction step, the four educational aspects (target groups, learning goals, the game's positioning in the course curriculum and the teacher's role), the five game design aspects (puzzles and their structuring, the game organisation, team size, playtime and the use of technology), were used as sensitising concepts, following Boeije (2010). Sensitising concepts are guiding concepts; they function as the researcher's lens through which to view the study and extract data in relation to these concepts. In addition to these aspects common in educational and (educational) game theories, the studies' field of discipline, the authors' intentions for implementing educational ERs, methodology, conclusions, and recommendations were extracted. Nicholson's (2015) categorisation of puzzle structures was used to classify the puzzle organisations in the studies, see Figure 2.1.

A team of three researchers conducted this review so that at least two researchers assessed each study and extracted data with 96% agreement.

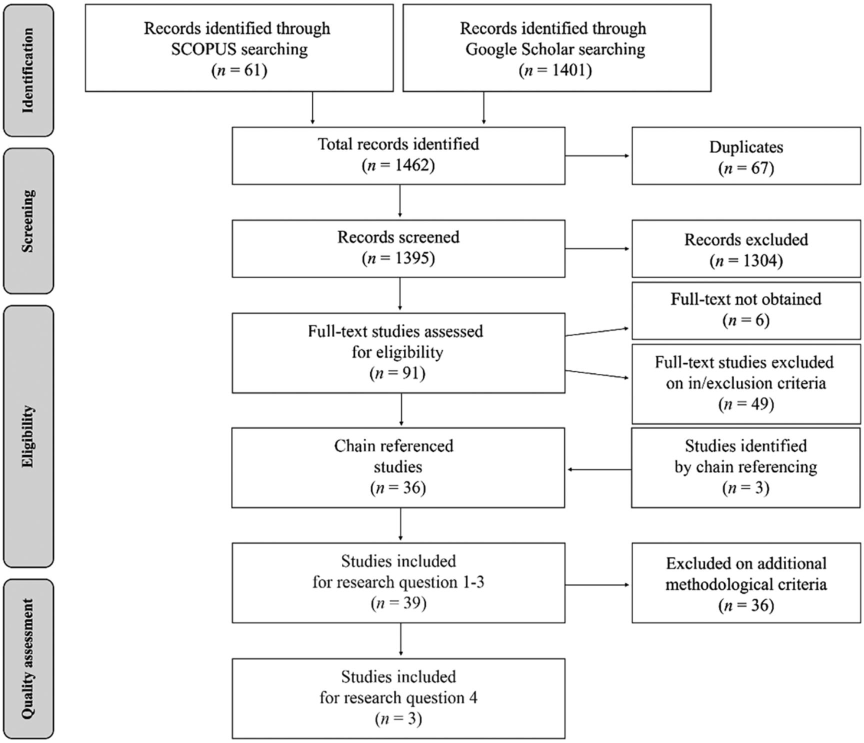

Figure 2.2 Flow diagram illustrating the review selection process

2.3 Results

2.3.1 Dataset characteristics

The 39 included studies were published between 2017-2019: 2017 (N = 8), 2018 (N = 13), and 2019 (N = 18; till June 2019). The studies, nearly all single case studies, are described in various types of documents: peer reviewed articles (N = 24), conference papers (N = 2), conference proceedings (N = 6), short notices or communications (N = 5), a poster (N = 1) and a book chapter (N = 1). Nineteen studies were carried out in the USA, most of the rest in European countries. The developed ERs were tested by various numbers of players (N = 10-213).

2.3.2 Common practices in educational aspects

Target groups

In the studies, target groups are participants from secondary education (N = 3), higher education (N = 31), professional development programs (N = 3), both higher education & professional development (N = 1), and one ER was open for everyone, see Appendix A. Three of the 39 ERs were developed for informal education, all in the field of Science, Technology, Engineering and Mathematics (STEM). The rest of the ERs were developed for formal education in various disciplines. The majority, 21 ERs were developed for various medical disciplines. Fifteen ERs were developed for STEM education, two ERs covered the field of communication strategies, leadership and teamwork skills, and one ER introduced learning theories.

Learning goals

The studies describe learning goals in different levels of detail. To distinguish different types of goals, the goals are summarised at an abstract level in Appendix A. The learning goals describe (1) specific content knowledge and content related skills, (2) general skills, and (3) affective goals.

For 33 ERs, the learning goals are a combination of content knowledge goals and related skills, such as clinical skills. The ERs are used to foster (N = 18) and to demonstrate or assess students' knowledge and skills (N = 14). Less often, ERs are used to introduce (N = 7), to extend or to integrate (N = 3) content knowledge and skills.

Looking at the learning goals on general skills, most of them involve practising or developing teamwork and communication skills (N = 20), problem solving (N = 11), critical thinking and/or analytic thinking/ reasoning skills (N = 7). In comparison to STEM ERs, medical ERs describe more general skills and affective goals, all relating to (future) career situations, such as performing under pressure, insight in one's professional functioning, formulating professional developmental goals. Examples of formulated affective goals are: to increase situational awareness, or on the bias of framing patients. Four out of twenty-one medical ERs describe learning goals solely on job relevant general skills and affective goals (Franco & DeLuca, 2019; Friedrich et al., 2019; Seto, 2018; Wu et al., 2018). The authors' rationale for these stand-alone ERs is that in debriefings on learning, the reflections on these skills easily get lost in reflections on subject specific goals. For STEM ERs, the rationale for goals on teamwork and communication is their role in active, team-based and collaborative learning and it has been shown to promote deeper understanding of content and transferability of a skill beyond the classroom (Ho, 2018).

The positioning of the game

An overview of the positioning of the educational ERs in the course curriculum is given in Appendix A. The positioning appears to be related to the educational setting, informal or formal, and the educational goals. For informal education, all three ERs are developed as stand-alone activities; a playful way to introduce people to STEM subjects such as robotics (Giang et al., 2018), or entomology (Healy, 2019).

In formal education, six out of 36 ERs are stand-alone activities. The rest of the ERs is embedded in a course curriculum; taking place at the introduction of a course (N = 2), during a course in addition to lectures (N = 11), or as assessment (N = 11). In six studies, these data are lacking. Students were assessed midterm (N = 3), or just before the final exams (N = 7). One study lacks these data. In six ERs, students were graded, using different systems. Some educators had socio-dynamic motives, as points were given to the first three teams to finish in time to prevent teams conferring (Gómez-Urquiza et al., 2019), or for attending the activity and additional points for all teams finishing in time (López, 2019). Other grading systems are closely related to the learning goals. Students were individually graded on performances during the gameplay or based on their reflection reports regarding their performances in relation to the learning goals (Franco & DeLuca, 2019; Järveläinen & Paavilainen-Mäntymäki, 2019). Clauson et al. (2019) assessed team performances during game play and individual performance using a post-test. In two ERs without assessment goals, students were graded to ensure that students take the ER activity seriously and to prevent passing on the solutions of the puzzles to other teams (Cain, 2019; Ho, 2018).

The teacher's role

Teachers are crucial in the learning process, also in collaborative learning (Hattie, 2009). When to interrupt in students' collaboration and what to address is challenging for teachers (Van Leeuwen & Jansen, 2019). In the studies included in this review, teachers have a role at the introduction of the game, during and after gameplay. In the introduction, players are introduced to game rules, such as the use of mobile phones, the role of collaboration and less often, the learning goals. Movies, emails, audio tapes or information sheets were also used instead of oral instruction (e.g., Cain, 2019; Franco & DeLuca, 2019).

During the gameplay, different aspects of the role of teachers and staff can be distinguished: 1) monitoring, 2) guiding, 3) providing hints, and 4) debriefing. In the studies, the assigned role varies from one aspect to all aspects, see Appendix A. In six studies, it is mentioned that players are solely monitored, see Appendix A. Staff members monitor the team's progression for safety reasons and to check whether players follow the rules. In contrast to recreational ERs (Nicholson, 2015), the monitoring usually takes place within the same room. In three studies, staff members adopt a role in the narrative, such as witnesses (Ferreiro-González et al., 2019), to keep the players immersed in the game narrative, as is an important precursor in game theories for engagement of players, see Section 1.2. In four studies, staff members monitor players from adjacent rooms, as seen in Appendix A. The rationale is, assumingly as in recreational ERs, the continuing immersion and feeling of ownership in players during the gameplay. However, in none of the studies we found that students felt less immersed when staff was physically in the same room. Students did feel frustration and less ownership when staff gave guidance too early (e.g., Giang et al., 2018; Järveläinen & Paavilainen-Mäntymäki, 2019), or gave no guidance when needed (Hermanns et al., 2018).

Studies refer to the guiding role of teachers as game masters described by Nicholson (2015), (Carrión et al., 2018; Giang et al., 2018; Mills & King, 2019). This is remarkable, as Nicholson compares the role of gamemasters to the role of good teachers; only intervene in the process when needed. In our review, some studies describe the nature of the guiding; affirming and encouraging students to work as a team (Carrión et al., 2018), giving instructions (Järveläinen & Paavilainen-Mäntymäki, 2019; Morrell & Ball, 2019), verifying answers and reasoning (Guigon et al., 2018; Monaghan & Nicholson, 2017), or checking whether techniques or skills are correctly performed (Adams et al., 2018; Eukel et al., 2017; Franco & DeLuca, 2019; Gómez-Urquiza et al., 2019). In four ERs, staff guided so that teams made roughly the same progress, preventing teams from diverging too much with one team ahead of the others finishing the game and the learning process for all teams, see Appendix A.

Nineteen studies mentioned that hints were provided during gameplay. Twelve studies described hint rules and systems. The use of specific hint rules and systems prevails more in ERs with assessment goals (7/11) than without assessment goals (5/28). Used hint rules are 1) teams get a restricted number of hints (Brown et al., 2019; Eukel et al., 2017; Franco & DeLuca, 2019; Gómez-Urquiza et al., 2019), 2) the first hints are free, but if more hints are needed, a time penalty is given (Adams et al., 2018; Cain, 2019; Clauson et al., 2019; Vergne et al., 2019), and 3) players had to earn a hint by making a small knowledge test which takes time (López-Pernas et al., 2019). Hints can be delivered to players personally or by pre-set hint cards. For pre-set hint cards, developers need to know precisely what players need at which moment (Eukel et al., 2017; Ho, 2018). Motives for the use of hint cards are not described. We assume that the cards are used to prevent disruption to the players' immersion and feeling of ownership, elements of various educational theories (see Section 1.1).

In addition to feedback by staff, locks provide immediate and unambiguous feedback to learners, which is important in the learning process (see Section 1.1). Monaghan and Nicholson (2017) regard this as one of the powerful aspects of an ER. However, other educators reflect on the loss of direct feedback by teachers on learning opportunities. This is due to the time constraint, as you cannot stop time and discuss the situation (Franco & DeLuca, 2019; Mills & King, 2019).

The role of the teacher after the gameplay is to debrief. A debriefing is a common element in recreational ERs (Nicholson, 2015). In this review, more than half of the studies (25/39) mention a form of debriefing, usually in facilitated small group discussions. The duration ranges from five minutes to two hours, which reflects the importance given to the debrief by the educators. We have listed and summarized components of the debriefs mentioned. In general, a debrief start with 1 and 2, followed by 3-7 in no particular order.

1. Time to decompress after the intense gameplay, with room for primary reactions. This phase is also known in recreational ER as a cooling down period (Nicholson, 2015).
2. Exchange of experiences on the gameplay, as developers want to get feedback on the activity.
3. Questions and concerns of participants. Participants can ask questions and verify their reasoning.
4. Discussion of the puzzles, content course knowledge and skills needed to solve them. The relation to the learning goals is seen as crucial, to

solidify the learners' knowledge as they recall and elaborate on the course content.

5. Extent of content knowledge. For example, to connect the knowledge and skills to other contexts, or discuss new topics encountered during gameplay.
6. Feedback on students' performances. The feedback is given in relation to learning goals and is important in ERs with an assessment goal.
7. Reflection on the individual learning process and formulating goals for future developmental goals or job skills.

Students acknowledge the role of debriefing in the learning process, for example, on the postulation "debriefing helped to understand the course content," 84.5% of 142 students agreed (Friedrich et al., 2019, p. 2).

2.3.3 Common practices in game aspects

Puzzles and puzzle structure

In all 21 medical ERs, a sequential puzzle path is used, as seen in Appendix A. Cain's (2017, p. 2) choice for this structure is intentional; "a consequence of the sequential nature of the learned process by the students. Besides, the linearity reduced the variability in 'paths', and eased the guidance of the teachers while the 24 teams were playing at the same time." This argument applies when a large number of teams is at work, and course content has a sequential nature. The use of sequential puzzle structures in other medical ERs seems self-evident. A possible explanation is that it resembles the common practice of case based or simulation-based education (Jenkin & Fairfurst, 2019).

The fifteen STEM ERs show a greater diversity in puzzle paths; sequential, path-based and hybrid puzzle paths, as summarized in Appendix A. The use of a sequential puzzle path is explained four out of five times; students need to work according to a learned sequential analytic or other method (Healy, 2019; Järveläinen & Paavilainen-Mäntymäki, 2019; Vergne et al., 2019), or follow the historical footsteps of a scientist during his discovery and its consequences in time (Dietrich, 2018). The choice of path-based or hybrid structures is motivated by the stimulation of active or collaborative learning by means of positive social interdependency. By forcing teams to split, students need to discuss the relation of the puzzles and build on each other's knowledge. The hybrid structures found in STEM rooms have a strong linearity. Puzzles done in parallel lead together to the unfolding of a next layer of puzzles (Ferreiro-González et al., 2019; Guigon et al., 2018). The rationale is that more linear pathways are easier for students to understand, therefore less guidance is needed, and progression is easier to monitor (e.g., Guigon et al., 2018; López-Pernas et al., 2019). Among the 39 ERs, the open structure appears to have been used once, in an ER on communication and teamwork skills (Clarke et al., 2017).

The description of the puzzles showed that some puzzles were based on puzzles common in recreational ERs, such as sudokus, rebuses, crosswords, jigsaw puzzles, cryptograms and riddles. Other puzzles resembled course tasks with a puzzle twist added. Some studies mentioned the use of intentional deceivers, red herrings, a common feature in recreational ERs.

Game organisation

Even within the relative short time period spanning this review, an evolution in educational ER organisation can be seen. Most of the first ERs were copied from recreational ERs, usually with only one team at a time playing (Nicholson, 2015). If more or all teams play at the same time, it will considerably reduce both the time investment for the educators and the occupancy rate of the rooms. However, it requires more materials and trained staff. Carrion et al. (2017) and Clauson et al. (2019) describe settings where two teams at the same time play in different rooms. In Guigon et al. (2018), two teams play independently in the same room. In one third of the studies, educators scale the game up to whole classes. Here teams play in competition with each other, though they are sometimes forced to cooperate at some point (Ho, 2018; Morrell & Ball, 2019).

We see two developments in the designs where all teams play at the same time. First, instead of one room where the gameplay takes place, the game spreads over the whole building or area (e.g., Boysen Osborn et al., 2018; Franco & DeLuca, 2019). The second development is the use of boxes. The use of "a box with a lock" is common practice, thanks to Breakout EDU (see Introduction). In other studies, big boxes are used that include all puzzles in locked files or smaller locked boxes. One box centres the activities of one team and, all teams work alongside each other in the same room (Healy, 2019; Monaghan & Nicholson, 2017). Digital technology used to facilitate upscaling ERs for whole classes is discussed in Section 3.3.5.

Team size

Appendix A shows the group sizes in the studies. A group size of two was used once, to require students to work on all the puzzles, and thereby on all concepts and skills (López-Pernas et al., 2019). In 24 of the 32 studies which mention the team size the range is 3-6 players, as educators want to prevent "free-riding", and create more participation and immersion of students during gameplay (Adams et al., 2018; Cain, 2019). Four additional studies advised a group size in this range after their gameplay with larger numbers, see Appendix A. These studies, all medical, explained that not everyone in the pilots was or could be active, as is conditional for active or collaborative learning.

Two studies specifically researched the team size in their educational ER. The outcome of one study is that, with a group size of four, everyone can be active and involved in the group process (Watermeier & Salzameda, 2019). Another study researched the team size in relation to the required playtime. Teams with more than six participants required more playtime than teams with six participants. And none of the teams with group sizes higher than six were able to escape in time due to the observed loss of communication and organisation in teams with higher numbers (Eukel et al., 2017). A team size up to four or five players is advised in ERs with individual grading. (Ho, 2018; Järveläinen & Paavilainen-Mäntymäki, 2019).

Playtime

The playtime in ERs is constrained, giving urgency to the players' actions. Table 2.1 shows the number of ERs with a specific amount of playtime. This is the time players actually spend on the puzzles, without the instruction before the gameplay and the debriefing afterwards. The range of the playtime is 20-120 minutes, with most games lasting 60 minutes. The choice for a specific playtime is seldom underpinned by specific pedagogical reasons. If explicated, one refers to the common practice of recreational ERs. Other studies refer to classroom time slots (e.g., Franco & DeLuca, 2019). The playtime is not related to formal or informal education, or a specific discipline, see Appendix A. In informal, formal, STEM or medical education, the median is alike, 60 minutes.

The allowed playtime (maximum duration of the gameplay) and their number in the studies (N = 39). The range is 20-120 min., the median is 60. For five escape rooms, this data is lacking in the studies.

In medical studies, the time constraint is considered not only as a game design aspect, but also an educational aspect, as collaborating under time constraints is a life-saving skill in medical professions. In other disciplines or settings, the restricted time is a way to create social interdependence; everyone is needed to finish all the puzzles in time.

For education, it is important that as many students as possible reach all goals in time, and frustration, dropping out, or trial-and-error behaviour are prevented. In two studies where none of the teams succeeded, students mentioned being frustrated, showed trial-and-error behaviour, and were most critical about achieving the educational goals (Hermanns, 2018; Mills & King, 2019). These studies conclude that playtests to define a realistic playtime are crucial in an ER design.

The use of digital technology

As seen in Appendix A, twenty ERs implemented digital technology. In four studies, technology is used to monitor the safety and progression of learners from an adjacent room (see Appendix A, 'Role teacher and staff'). In nine out of the 21 medical ERs, technology is mainly used to structure the gameplay and so ease the work of the teacher, which is especially important for large groups. Examples are the unlocking of puzzles by scanning a QR code or the combination of technologically mediated validation of answers, linked to the unlocking of a code or a cardio photo (e.g., Cain, 2019; Franco & DeLuca, 2019; Gómez-Urquiza et al., 2019, Hermanns et al., 2018). Students also need IT tools to search and interpret medical information (e.g., Brown et al., 2019; Eukel et al., 2017; Monaghan & Nicholson, 2017).

Table 2.1 The number of escape rooms with a specific amount of playtime.

Allowed playtime (min.)	Number of escape rooms with a specific playtime
20	1
30	4
45	3
60	20
75	1
80	1
90	3
120	1
Total number of escape rooms	34

In nine out of fifteen STEM ERs, IT tools are used mostly as part of the learning goals (e.g., Borrego et al., 2017; Giang et al., 2018; López-Pernas et al., 2019). In addition, the technology is used to structure the game, especially for large groups (Guigon et al., 2018; Järveläinen & Paavilainen-Mäntymäki, 2019). Technology is also used to support the narrative and to enhance immersion, for example with a security video footage of a crime scene.

2.3.4 How are educational and game aspects related to educational escape rooms?

Implementing GBL requires an understanding of the relations between educational and game design aspects, see Introduction. In the previous sections, common practices in educational ERs in relation to specific educational and game design aspects are synthesized. Subsequently, the following relations become evident.

Goals & related aspects

The function of an ER in the learning trajectory and the specific learning goals are decisive for its design. Sequential puzzle pathways were implemented when learning goals comprised a sequential process which students had to follow, or when students were assessed individually. Path-based and specific hybrid structures were implemented ensuring that all participants are active and interdependent, to scaffold active and collaborative learning.

ERs with learning goals solely on introducing a subject, general skills or affective goals, are all stand-alone activities. ERs that are intended to foster content knowledge and related skills are embedded in a course curriculum, usually positioned in addition to lectures. ERs with formative assessment goals are positioned either mid-term or just before the final exams. Whether or not students are assessed during game play has consequences for the role and amount of staff, the group size of students, and the (fair) delivery of hints. The use of hint rules or systems prevailed more in ERs with an assessment goal.

In STEM ERs, the implementation of technology is often related to the learning goals. Technology is also used to scale up for large enrolment, resulting in the need of less staff in other roles.

Group size and playtime

The aspects of group size and playtime in the educational ERs are independent of the setting, target group, discipline or any other studied aspect. This is remarkable for the aspect of playtime, as STEM and medical educators appoint different roles for the restricted time in the learning process during escape games. The playtime seems more determined by available time slots and the assumed common practice in recreational ERs.

2.3.5 To what extent have the intended goals of educational escape rooms been achieved?

In 36 out of the 39 studies, the educators' intentions to implement an ER is 1) to explore an active learning environment which is said 2) to increase students' motivation and/or engagement, 3) to foster learning, while 4) practising or developing teamwork and communication skills. To what extent these goals have been achieved will be discussed in this section.

To explore an active learning environment

The most important intention for implementing educational ERs for educators is to explore an active learning environment. The studies usually refer to a specific pedagogy such as active, collaborative, team-based and/or game-based learning, see Appendix A. The studies concluded that the development of an active learning environment was successful. However, in their considerations educators refer not only to pedagogies such as active, collaborative or team-based learning, but also to practices in recreational ERs, or seem based on classroom practice (as seen in Section 3.2 and 3.3). This makes sense as the current educational ERs are not designed from theory by designed based research but adapted from a recreational activity. In Section 4.4 a framework is introduced, which recognises the current practice of a complexity in the educators' decisions with a variety of considerations and guides alignment of the various decisions on specific crucial parts of educational ER design.

To increase students' motivation and/or engagement

The studies based their conclusions on 'informal observations', meaning observations without pre-set points of attention. In addition, participants gave feedback after the gameplay in group discussions and/or in post activity surveys. As the studies used different questions, postulations and answer scales, it is not possible to aggregate the answers. However, in all studies a vast majority of students enjoyed the activity and educators concluded that students were highly engaged and active during the activity.

Sometimes, it is stated that students become intrinsically motivated for learning by playing ERs (e.g., Giang et al., 2018; Peleg et al., 2019; Watermeier & Salzameda, 2019). However, we found no basis for these conclusions. Moreover, extrinsic factors such as competition, time constraints and grading, were involved. We assume that the researchers interpreted the motivation for winning as intrinsic motivation for learning, more discussion on this topic in Section 4.1.4. One study with 84 participants tested for gender bias (López-Pernas et al., 2019). The male participants showed a high inclination towards gaming, whereas the females showed a statistically significant lower interest. However, no gender bias was detected in any of the questions in the surveys that addressed the ER activity.

To improve learning

In the studies, participants were asked about their learning in feedback sessions and/or post activity surveys. The participants ranging from a majority to all, perceived that the ER environment helped them achieve the learning goals, and/or agreed on implementation in their curriculum.

Only three studies measured the achievements on the learning goals by means of a pre- and post-knowledge test. In addition, one of the studies compared the learning outcomes of the ER with the regular case activity on infectious diseases (Cotner et al., 2018). Both activities were perceived positively. The ER was preferred by eighteen of the nineteen students, but only eleven of the nineteen students indicated they learned better from the activity. The scores dropped in the post-test for the regular case activity, from 90.5 to 82.1. After the ER, neither a knowledge drop or gain was shown. A debriefing session after the ER was not mentioned. A limitation is that only nineteen students participated in the study. In Clauson et al. (2019), the overwhelming majority of students (96%, N = 51) experienced that the debrief on the pharmacy knowledge improved clinical skills and facilitated learning. However, the pre-test/post-test showed no significant results. In the third and last study, a cross-sectional pre-test/post-test research design was used to assess the students' performances (N = 74) (Eukel et al., 2017). Students' mean score for the post-test, 81%, was statistically higher than the mean score for the pre-test 56%, $p<0.001$. A week passed between the pre-knowledge test and the escape game. As the prospect of an ER with a competitive character might have stimulated students to study the content knowledge in the meantime, the knowledge increase cannot be solely attributed to the game. So, out of the three studies, one showed a disputable improvement in content knowledge after an educational ER, while most students experienced learning.

Interestingly, López-Pernas et al. (2019) showed that their students' engagement (N = 124) and their perceived learning in ERs are related. Moreover, the students who were already comfortable with the course topic were the ones who made the most of the ER. In this regard, it is interesting that studies evaluating ERs with goals to acquire new knowledge contained the most critical remarks on the effectiveness of learning (Giang et al., 2018; Mills & King, 2019; Vörös & Sárközi, 2017). The last study concluded that students only retained information that had helped them solve the puzzles, and for deeper understanding of new topics additional classes are needed. Giang et al. (2018) and Mills & King (2019) have similar conclusions.

To practise and develop teamwork and communication skills

Twenty-one studies mentioned practising or developing teamwork and communication skills as intentions for implementing an educational ER. Nineteen studies evaluate these goals based on educators' informal observations and/or students' self-perception. Four ERs have goals solely on general skills, such as teamwork and communication skills (see Appendix A). Educators and students agreed that the activity promoted teamwork and communication. For example, in Friedrich et al. (2019), 79.5% of the 142 students did so, and 76.1% regarded it a valuable addition to the curriculum. Seto (2018) concluded that their ER addressed every competency in the team skill domain, and strengths and challenges could be indicated and discussed with students afterwards. Likewise, studies combining content knowledge and skills with general skills, concluded that teamwork and communication are practised and/or developed in ERs. The study on learning in teams during an ER, concluded that team dynamics were more diverse with time limited (Ho, 2018). Based on the studies, we conclude that, with an adequate design, teamwork is conditional to finish an ER in time and it is possible to assess and discuss the teamwork and communication skills afterwards.

2.4 Conclusions and discussion

The main purpose of this article is to review common practices and their theoretical considerations in educational ERs, regarding specific educational aspects (RQ1) and game design aspects (RQ2), how these aspects are related (RQ3), and to what extent the goals of these ERs have been achieved (RQ4). In nearly all studies, educators developed an ER to explore an active learning environment aiming to increase students' motivation and engagement and fostering learning, while developing teamwork, communication and other general skills.

2.4.1 Common practices and their theoretical considerations on educational aspects (RQ1)

In this review, target groups of the ERs are participants from secondary education, higher education, professional development programs, and "everyone". The described ERs are mostly implemented in formal education; the majority in medical education (22/39), and STEM education (15/39). The learning goals describe specific content knowledge and content related skills, general skills, and affective goals. In medical ERs, the content related goals are combined with goals on general skills and affective goals related to profession. The general goals that are mentioned most often are teamwork and communication skills. In STEM ERs, the rationale for stimulating students' teamwork and communications skills is the relation with active and collaborative learning. In informal education, all ERs are stand-alone activities. In formal education, depending on the educational goals, most ERs are imbedded in the course curriculum and take place either at the start of a course, in addition to lectures or just before the final exams. One third of the ERs was developed to assess students. Grading systems differed in who was graded (team or individual) and what was graded (solely the gameplay or with the preparation and reflection on learning afterwards). The diversity was due to the different learning goals of the ERs. Moreover, some educators used socio-dynamic motives for their grading. Van Leeuwen & Jansen (2019) showed that the teacher's role in collaborative learning is crucial, and when to interrupt in students' collaboration and what to address is challenging for teachers. This seems even more challenging in educational ERs. We see this firstly, reflected in the different aspects of the role teachers adopted during the gameplay: monitoring, guiding, providing hints, and debriefing. Secondly, in the studies, the assigned role variates enormously, from one aspect to all aspects. The students' reactions show that the intervening of teachers is more delicate and challenging as the students' immersion and highly valued feeling of autonomy appear at stake. These elements are important in GBL theory (see Section 1.2) and appear guiding in decisions whether or not staff is in the same room during gameplay, staff has a role in the narrative, or pre-set hints are used. Only half of the studies mention a debrief on goals and content after the play game. The debriefs vary in components and duration (5-120 min), due to the assigned educational value of debriefing. All components together cover the elements of Lederman's model on debriefing as a systematic evaluation of theory and practice (Lederman, 1992).

The studies do not describe considerations for all choices made in relation to the studied educational aspects. The considerations 1) refer to theories on collaborative learning, game-based learning or game theories, 2) refer to common practices in recreational ERs and /or 3) seem based on classroom practice.

2.4.2 Common practices and their theoretical considerations on game design aspects (RQ2)

In educational ERs, various forms of puzzle structures are used, seemingly less complex than in recreational ERs. When the nature of the learned process is sequential or students are graded on their performances during the gameplay, educators choose a sequential pathway. Another rationale for the overall use of sequential puzzle paths in medical ERs is that it resembles the common practice of case and station-based education. In STEM ERs, besides sequential puzzle paths, path-based and hybrid puzzle paths are also used to create positive social interdependency and stimulate collaborative and active learning. A trend is visible in upscaling the game for more or all teams at the same time. This means that either the “room” aspect of the ER concept is abandoned, or the “escape” aspect, as the use of an all-inclusive puzzle box per team requires a “break in”. A group size of 4-6 players seems most suitable for immersion, participation and group communication during game play. It seems independent of the discipline or educational setting (informal or formal). The playtime has a range between 20-120 minutes, with a median of 60 minutes, independent of the educational setting or discipline. This is remarkable as STEM and medical educators ascribe different roles to the restricted time in the learning process during escape games. The playtime seems more determined by available time slots and the assumed common practice in recreational ERs. Technology is implemented in educational ERs for various reasons; 1) to monitor the safety and progression of students from adjacent rooms, 2) to foster students’ subject related IT skills, 3) to support the narrative and enhance immersion, and mostly 4) to structure the gameplay by verifying answers and unfolding new puzzles, codes or additional content knowledge. Educators intend to research the possibilities for the last two reasons more thoroughly, to upscale the activity for the whole class with limited staff, and to create autonomy and ownership for students. Related research in the field of educational ERs describes the development of open-source tools (‘decoders’) to validate players solutions (Ross, 2019), the implementation of digitally pre-set hints and the role of technology in creating immersive authentic learning environments which confront learners with outside world problems (Veldkamp et al., 2020a).

The studies do not describe considerations for all choices made in relation to the studied game aspects. The considerations 1) refer to theories on collaborative learning, game-based learning or game theories, 2) refer to common practices in recreational ERs and /or 3) seem based on classroom practice of case based and simulation-based medical education.

2.4.3 Relations between educational and game design aspects (RQ3)

Educators start their design process with defining educational goals, which guide choices on the puzzle path, the role of technology and the teacher’s role during the gameplay. Moreover, these aspects are interrelated too. Two models on designing educational ERs are those of Clarke et al. (2017) and Guigon et al. (2018). The model of Clarke et al. (2017) corresponds to a step-by-step plan to design a recreational ER (Clare, 2015), adding educational aspects as learning goals and their evaluation. It was tested on staff (N = 13). Guigon et al. (2018) developed a model based on a model for roleplaying games in education, which was tested on twenty participants. In this model, an ER consists of rounds of puzzles. The gameplay is followed by a debriefing.

Both models provide a rather linear view of the design of ERs and their use in classrooms. The current review, however, shows that more complex patterns of goals, puzzle paths, teacher support and grading occur in the design of educational ERs.

2.4.4 Achievement of intended goals (RQ4)

In all studies, a vast majority of students enjoyed the activity and was highly engaged during the activity, more than in comparison to regular classes. Educators used ERs mostly in addition to lectures to foster or assess knowledge and skills, and they were satisfied with the goals reached. ERs also seem suitable to experience new phenomena, but less to acquire new knowledge. Only three out of the 39 studies assessed learning by means of a pre-test/post-test, and only one study showed a disputable improvement in content knowledge. This is in contrast with the self-perceived learning of participants and their teachers. With an adequate design, teamwork and communication skills are conditional to finish in time. Moreover, it is feasible to assess and discuss the teamwork and communication skills of students afterwards.

The findings on the discrepancy between perceived and actual learning of content knowledge are in line with other findings on educational games (Garris et al., 2002) and on practical work (Abrahams & Millar, 2008; Minner et al., 2010). Based on their research, these studies advise active linking of knowledge during and after the interventions. In educational ERs, the restricted time gives the players' actions urgency and a strong motive for teamwork. Reflective breaks do not align with a time constrained gameplay; players lose time and immersion, which are both important in ERs. However, a debrief with active linking of knowledge can take place afterwards and, according to Sanchez & Plumettaz-Sieber (2019), fosters learning. More research is needed on the systematic evaluation of sustained learning of content knowledge and content related skills, including a debrief.

For educational ERs educators define educational goals and a game goal. The educators' intention is that by reaching the game goal, students achieve the educational goals set. Matching game goals and learning goals is relevant to the design of educational games in general. For instance, Van der Linden et al. (2019) present an "intrinsic integration" theory that states the importance of game goals and learning goals and analyses the implication of this for the relation between game mechanics and pedagogical approaches (see Figure 2.3).

Applying this to ERs, one can see that specific pedagogical approaches can be related to specific game mechanics, or in this case, ER characteristics, such as the puzzle structure. In our review, we have seen that in medical ERs, approaches such as team-based or collaborative learning do not align with game mechanics like sequential puzzle structures or a team size higher than six participants. Whereas in STEM ERs, collaborative learning was better aligned with the puzzle structure and team size.

The use of intentional deceivers, red herrings, copying recreational ERs was not positively evaluated (e.g., Mills & King, 2019). Although this common game aspect, as part of the game mechanics might add to the atmosphere, the red herrings in those ERs did not align with the pedagogical approach and achieving the learning goals in a restricted time. One can argue that messiness might contribute to simulating authentic situations. In Monaghan and Nicholson's ER (2017), messiness was created by presenting ambiguous medical information students had to analyse as part of the learning goals. Here, alignment in game and learning goals, pedagogy and game mechanics resulted in satisfaction of students and educators.

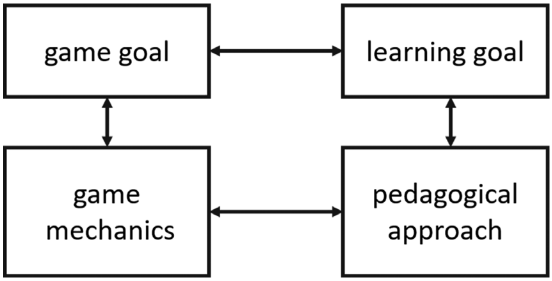

Figure 2.3 The design framework on alignment between the game goal, learning goal, pedagogical approach and game mechanics (van der Linden et al., 2019).

In Appendix B we have summarized a number of recommendations, based on our outcomes and in line with the intrinsic integration theory. We expect that these will help educators in the design and implementation of ERs. In combination with more systematic evaluation of students' outcomes, these recommendations might help the development of highly engaging learning environments where students foster knowledge and skills.

To conclude, ERs found their niche in educational settings, bringing time constrained authentic work settings or outer world situations into the classroom. The problem-based and meaningful activities in educational ERs provide environments that activate students and requires them to collaborate. This also means that teamwork and communication skills are conditional for finishing the ER in time. Consequently, ERs also have potential to help improve these skills. However, this requires embedding them in the teaching and learning situation at large, for instance by providing preparation and debriefing activities. The outcomes of this review study and the introduced framework shows that educators' decisions on educational ERs are a complex of set of interrelations, which need to be aligned in order to implement an educational game which achieves the desired students' behaviour and outcomes. This framework can not only help educators align their choices in the described educational and game aspects, grounded in theory and related pedagogy. Furthermore, the framework can guide educational researchers in research focus on the interrelations and alignment.

Appendix A: Summary table on educational and game design aspects in studies on educational escape rooms

Authors	Motivation implementation	Target-group	Discipline	Learning objectives	Positioning in course curriculum	Role teacher and staff	Puzzle pathway	Game organisation	Team size	Play time (min.)	IT tools
Adams, Burger, Crawford, & Setter, 2018	To explore an active learning environment using GBL and adult learning theory, to motivate and engage students in order to develop TWS, communication skills and critical thinking.	PD&HE	MED	To demonstrate content knowledge and related skills, to develop TWS, com. skills and critical thinking.	Formative assessment.	Monitoring & guiding in room: assess performed skills. Hint system: 3 free, more hints -> time penalty. Debriefing: 2, 4.	U	One team	6-14	60	N
Arnal et al., 2019	To demonstrate a teaching environment using collaborative learning for future career, to motivate and engage students towards maths.	HE	STEM	To foster content knowledge and related skills (e.g., mathematical reasoning), to use TWS, awareness of possibilities ER as educational environment.	U	Monitoring & guiding in room: hints.	U	All teams	U	U	Y
Borrego, Fernández, Blanes, & Robles, 2017	To explore an environment to motivate students, to foster learning.	HE	STEM	To demonstrate and foster content knowledge and related skills.	In addition to lectures.	Monitoring from adjacent room.	H	One team	U	60	Y
Boysen Osborn, Paradise, & Suchard, 2018	To explore an environment to increase students' engagement and foster medical knowledge and teambuilding.	HE	MED	To demonstrate and foster content knowledge and related skill (e.g., recognise poisonings related to course content).	Formative assessment; midterm exam.	Monitoring in room, no hints. Debriefing: 3, 4.	S	All teams	5	60	N
Brown, Darby, & Coronel, 2019	To explore an active learning environment for urosepsis simulation.	HE	MED	To foster content knowledge and related skills (e.g., administration proper medicines, interpreting lab results).	In addition to lectures.	Monitoring & guiding in room: hints. Hint system: one hint card. Debriefing: 2, 4, 7.	S	One team	6-8	60	Y

Authors	Motivation implementation	Target-group	Discipline	Learning objectives	Positioning in course curriculum	Role teacher and staff	Puzzle pathway	Game organisation	Team size	Play time (min.)	IT tools
Cain, 2019	To explore an active learning environment, to increase students' engagement and prevent free riding in group work.	HE	MED	To foster content knowledge and related skills.	In addition to lectures.	Monitoring & guiding in room: Hint system: 1 free hint, more needed: time penalty. Hint also given to groups lagging behind. Debriefing: 1, 4.	S	All teams.	5-6	45	Y
Carrión et al., 2018	To explore GBL, enhancing active learning, increase students' engagement and foster medical knowledge.	HE	MED	To assess content knowledge and related skills, to integrate content knowledge of two different subjects, to practice English.	Formative assessment; prior to exam.	Monitoring & guiding in room: role GM, encouraging to work as a team.	S	Two teams parallel in same room.	14-16	60	N
Clarke et al., 2017	to evaluate a design framework for educational ERs, the feasibility of the ER and acceptance of staff.	HE	OTH	To foster communication strategies and skills, leadership, TWS.	Stand alone.	Monitoring from adjacent room.	U	One team.	3-6	20	Y
Clauson et al., 2019	To explore an environment to assess student readiness for advanced pharmacy practice experiences, while developing TWS, problem solving, critical thinking.	HE	MED	To assess content knowledge and related skills and TWS, critical thinking, problem solving, to develop reasoning skills.	Formative assessment; prior to exam.	Monitoring, observing & guiding in room. Hint system 1 free hint, more needed -> time penalty. Debriefing: 2, 3, 4, 6.	S	Two teams in different rooms.	5-6	60	N
Cotner, Smith, Simpson, Burgess, & Cain, 2018	To explore an active learning environment.	HE	MED	To foster content knowledge and related skills.	In addition to classes.	U	U	U	U	U	U
Craig, Ngondo, Devlin, & Scharlach, 2019	To explore an environment to foster course subject, and to increase TWS and students' ability to work in time.	HE	OTH	To foster content knowledge: (communication strategies), and related course skills (communication, TWS) and ability to work in time.	Stand alone.	Monitoring in room. Debriefing: 4, 6, 7.	P	One team.	4-6	30	N

Authors	Motivation implementation	Target-group	Discipline	Learning objectives	Positioning in course curriculum	Role teacher and staff	Puzzle pathway	Game organisation	Team size	Play time (min.)	IT tools
Dietrich, 2018	To explore active learning strategy using GBL to motivate and engage students in order to develop TWS, comm skills.	HE	STEM	To demonstrate and extent content knowledge and skills, develop communication skills and TWS.	In addition to lectures.	Monitoring in room. Debriefing: 4, 5.	S	All teams.	5-7	60	N
Eukel, Frenzel, & Cernusca, 2017	To explore a form of GBL, to foster knowledge.	HE	MED	To foster content knowledge and related skills, using TWS.	In addition to lectures.	Monitoring & assess on performed skills from adjacent room. Hint system: 4 pre-set hint cards.	S	One team.	5	75	J
Ferreiro-González et al., 2019	To explore GBL, to foster active learning, and to motivate and engage students.	HE	STEM	To foster content knowledge and related skills (e.g., analytic thinking).	In addition to lectures & practicals.	Monitoring & guiding in room, by use of characters answering questions.	H	One team.	6-10	60	Y
Franco & DeLuca, 2019	To explore an activity with active learning approach to simulate interdisciplinary teamwork environment, to foster critical thinking and problem solving.	HE	MED	To assess and develop teamwork, critical thinking, problem solving, leadership.	Formative assessment; midterm exam.	Monitoring, observing for feedback & assessing in room. Hint system: 2 free hints. Debriefing: 1, 2, 6, 7.	S	All teams.	6	90*	Y
Friedrich, Teaford, Taubenheim, Boland, & Sick, 2019	To explore GBL to engage students, to foster learning and communication skills	HE	MED	Awareness of importance of interprofessional communication and to develop interprofessional communication, and TWS.	Stand alone.	Monitoring in room. Debriefing: 4, 5, 7.	S	One team.	8	45	N
Giang et al., 2018	To explore an environment to motivate and engage students.	ALL	STEM	To get introduced to new subject and related skills, to develop problem solving skills.	Stand alone.	Monitoring, observing & guiding in room: role GM, providing hints. Debriefing: 3, 4, 6.	P	One team.	3-5	30	Y
Glavaš & Stašcik, 2017	To demonstrate a teaching environment to motivate and engage students towards maths.	HE	STEM	Awareness of possibilities ER as educational environment.	U	Debriefing: 2.	U	One team.	4-5	60	Y

Authors	Motivation implementation	Target-group	Discipline	Learning objectives	Positioning in course curriculum	Role teacher and staff	Puzzle pathway	Game organisation	Team size	Play time (min.)	IT tools
Gómez-Urquiza et al., 2019	To explore an environment to assess theoretical and practical knowledge.	HE	MED	To assess content knowledge and related skills, to develop TWS and performing under pressure.	Formative assessment.	Monitoring, assessing performed skills & guiding: hints in room. Hint system: 2 free hints.	U	One team.	5	30	Y
Gordon, 2017	To explore an active learning strategy, to foster collaborative learning, to motivate and engage students.	HE	MED	To acquire new content knowledge and skills, to develop TWS.	Introduction to new subject.	Debriefing: 2, 4.	S	One team.	U	U	N
Guigon, Humeau, & Vermeulen, 2018	To evaluate a design framework for educational ERs, to motivate students by active learning.	HE	STEM	To foster content knowledge and skills.	In addition to lectures.	Monitoring & guiding in room, in a way that teams make same progression, verifying reasoning. Debriefing: 3, 4, 7.	H	Two teams in different rooms.	5	90	Y
Healy, 2019	To explore an active learning strategy to inform students on the study entomology in engaging way.	SE	STEM	To get introduced to new subject and related skills, to develop TWS, communication skills and problem solving.	Stand alone.	Hint system: 4 free hints. Debriefing: 3, 4, 5.	S	All teams.	5	60	N
Hermanns et al., 2018	To explore an active learning strategy to engage students.	HE	MED	To foster content knowledge and related skill, to develop TWS, com. skills, problem solving and critical thinking.	U	Monitoring in room. Debriefing: to increase understanding, 2.	S	All teams.	4-5	60	Y
Ho, 2018	To explore a learning environment to motivate and engage students, foster content knowledge and skills.	HE	STEM	To foster content knowledge and skill, to develop critical thinking.	In addition to class.	Monitoring in room. Hint system: pre-set hints. Debriefing	H	All teams.	4-5	60	Y

Authors	Motivation implementation	Target-group	Discipline	Learning objectives	Positioning in course curriculum	Role teacher and staff	Puzzle pathway	Game organisation	Team size	Play time (min.)	IT tools
Järveläinen & Paavilainen-Mäntymäki, 2019	To research learning strategies in groups, to motivate students by active learning.	HE	STEM	To assess content knowledge and related skills.	Assessment: prior to final exam.	Monitoring & guiding in room: affirm, hints and direct instructions.	S	One team.	4-6	45	Y
Kinio, Dufresne, Brandys, & Jetty, 2019	To explore with a learning environment to activate and motivate and engage students in job related roles.	HE	MED	To foster content knowledge and related skills.	In addition to lectures.	U	U	U	3-4	60	N
López, 2019	To explore an active learning activity to motivate an engage students.	HE	STEM	To assess content knowledge and related skills, to develop TWS.	Formative assessment; prior to exam.	Monitoring & guiding in room: hints. Hint system: hints unlimited, received after small test which takes time.	H	All teams.	2	120	Y
Mills & King, 2019	To explore with active and exploratory learning.	HE	OTH	To acquire new content knowledge and related skills.	Start of higher education.	Monitoring and guiding from adjacent room, as GM: feedback and hints. Debriefing: 1, 7.	U	One team.	4	60	Y
Monaghan & Nicholson, 2017	To explore an active learning environment, to foster collaborative learning.	HE	MED	To foster and extent content knowledge and related skills; use TWS, problem solving skills, awareness of frequency and risks of sepsis, awareness of framing patients.	In addition to lectures.	Monitoring & guiding in room, by use of characters: check solutions, provide key to new puzzle. Debriefing: 4, 7.	S	All teams.	<5	60	Y
Morrell & Ball, 2019	To explore an active learning environment based on adult learning principles, to increase student engagement.	HE	MED	To formative assess content knowledge and skills, use TWS.	Formative assessment.	Monitoring, assess & guiding: check solutions, indicate how to continue. Hint system: 3 free hint. Debriefing: 3, 6, 7.	S	All teams; need to cooperate to unfold next layer of puzzles.	U	60	Y

Authors	Motivation implementation	Target-group	Discipline	Learning objectives	Positioning in course curriculum	Role teacher and staff	Puzzle pathway	Game organisation	Team size	Play time (min.)	IT tools
Mosley, Rogers, & Smith, 2018	To explore an active learning environment for simulations.	PD	MED	To acquire new content knowledge and related skills, situational awareness, awareness of confirmation bias.	Stand alone.	Debriefing: 4.	U	One team.	U	60	N
Nelson, Calandrella, Schmalbach, & Palmieri, 2017	To explore a problem-based active learning environment.	HE	MED	To foster content knowledge and related skills, use problem solving skills.	Stand alone.	Guiding: hints provided.	S	One team.	6-8	80	Y
Peleg, Yayon, Katchevich, Moria-Shipony, & Blonder, 2019	To explore an active learning environment using collaborative learning, to motivate and engage student, to bridge gap classroom and real world while developing TWS.	SE	STEM	To foster content knowledge and related skills, to develop observation skills.	U	Monitoring & guiding: hints for teams lagging behind. Debriefing: 2, 3, 4.	H	All teams; need to cooperate for last puzzle.	4-6	60	N
Seto, 2018	To explore an active learning environment for simulation training of TWS.	HE	MED	To develop TWS, to reflect on one's functioning, and to set developmental goals.	U	Debriefing: 7.	U	One team.	5	30	N
Styling, Welton, Milijasevic, Peterson, & Sia, 2018	To explore an environment to engage participants, to raise awareness around patient safety and required practices using collaborative learning.	PD	MED	Awareness of patient safety and required practices, to acquire new content knowledge and related skills, using TWS.	Stand alone.	U	S	One team.	U	U	N
Vergne, Simmons, & Bowen, 2019	To explore an active learning environment using collaborative learning, to motivate and engage student, to foster lab skills, critical thinking, problem solving, and TWS.	HE	STEM	To assess content knowledge and related skills, to develop critical thinking, problem solving, and TWS.	Formative assessment; end of semester.	Hint system: two free, 3 -> time penalty. Debriefing: 4	S	One team.	4-6	60	N

Authors	Motivation implementation	Target-group	Discipline	Learning objectives	Positioning in course curriculum	Role teacher and staff	Puzzle pathway	Game organisation	Team size	Play time (min.)	IT tools
Vörös & Sárközi, 2017	To explore an active learning environment using GBL to motivate and engage students in order to develop knowledge, TWS, com. skills and problem solving.	SE	STEM	To get introduced to new content knowledge and related skills, to develop TWS, comm. skills and problem solving.	Stand alone.	Monitoring & guiding in room, by use of characters. Debriefing: 2, 4.	S	All teams.	4-6	90	N
Watermeier & Salzameda, 2019	To explore an active learning environment to review knowledge, to engage students with different learning styles using problem solving skills.	HE	STEM	To assess content knowledge and related skills, to develop problem solving and TWS.	Formative assessment: prior to exam.	Monitoring & guiding: hints per station after time span to prevent lagging behind, or on request.	H	One team.	4	60	N
Wu, C., Wagenschutz, H., Hein, J.	To explore learning environment using experiential and collaborative learning.	HE	MED	To foster leadership competencies: leading self, communication skills, problem-solving, TWS, systems thinking, to positively impact the team's connection, in high-pressure situation.	U	Debriefing: 4, 7.	U	U	7-10	U	N

Appendix B: Recommendations for practitioners on implementing educational escape room

Based on this systematic review, the following recommendations will help educators to design more aligned ERs for the classroom. The rationale behind a lot of design choices are the students' immersion and their highly valued feeling of autonomy.

Alignment. We recommend looking at alignment of learning goals, game goal, pedagogics and game mechanics in the design of educational ERs. When choosing pedagogical approaches in support of the learning goals, alignment with game aspects, such as puzzle structure, type of puzzles and team size, are very important to achieve the educational goals. When choosing approaches such as team-based or collaborative learning, an aligned puzzle structure can be path-based or hybrid, creating interdependence between the players. When using a hybrid structure, a degree of linearity is advised, as it will help guide the players and it is easier to monitor for staff (see Section 2.3.3).

Dare to 'leave' the room. When adapting ERs for whole classes at the same time, the option of abandoning the 'room' aspect of escape rooms is worth considering. Options are to create station-based tasks in more rooms, or to use one box that includes all puzzles and equipment for each team (see 4.1.2). The implementation of freely available technology can structure puzzle paths, validate answers linked to unlocking new information, present pre-set hints for teams lagging behind, and enhance immersion in an out of school context (see Section 2.3.3; Chapter 3; Ross, 2019).

The role of the teacher. Teachers and staff have a better view on the players' behaviour guiding in the same room than with digital monitoring from an adjacent room. The players' immersion seems not to suffer from the presence or intervention of staff balancing the need of students and their feelings of immersion and autonomy. Consequently, the organisation of monitoring devices is not needed and the game organisation less complicated. The role of the teacher and staff during the gameplay is delicate and challenging as students' immersion and feeling of autonomy can be disrupted. Giving the teachers and staff a role in the narrative in which they can be questioned by the students, might prevent this (see Section 2.3.2).

Debriefing. The implementation of a debrief, with the elements described in Section 2.3, seems crucial. This would actively link knowledge and decontextualize that knowledge for use in future situations (Sanchez & Plumettaz-Sieber, 2019). To finish an ER in time, teamwork and communication skills are conditional. When fostering of teamwork and communication skills is a goal of the ER, a specific debrief or an ER solely on these social skills is advised, as reflection on these goals is usually lost in a reflection on other educational goals (see Section 2.3.2).

Grading. When players are assessed on performances during gameplay, smaller team sizes (4-5 players) and a sequential puzzle path are recommended (see Section 2.3.2 and Section 2.3.3). Let the learning goals decide who is graded (team or individual) and what is graded (solely the gameplay or the preparation and reflection of the student included) (see Section 2.3.2). The precautionary measure to grade students in order to activate them, seems unnecessary as participants of all ages are highly engaged by the ER as learning activity. The need for grading to prevent teams exchanging codes or answers might be related to the age of the target group (see Section 2.3.2).

Chapter 3

Escape boxes: Bringing escape room experience into the class-room

This chapter is based on

Veldkamp, A., Daemen, J., Teekens, S., Koelewijn, S., Knippels, M.C.P.J., & van Joolingen, W.R. (2020). Escape boxes: Bringing escape room experience into the classroom. *British Journal of Educational Technology*, *51*(4), 1220–1239. https://doi.org/10.1111/bjet.12935

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ST and SK pitched the original idea; ST, SK, AV and JD designed the studies; AV supervised the studies; ST, SK and AV collected data; AV and ST analysed and discussed the data; AV drafted the manuscript; AV, JD, MCK and WvJ contributed to a critical revision of the manuscript.

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Abstract

In this chapter, 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 article 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 chapter describes the process leading to the design criteria, the design process, test results and evaluation, and provides recommendations for designing educational escape rooms.

3.1 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 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 et al., 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 et al., 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 et al., 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 article focusses on the design process in three cycles of the escape room concept into escape boxes and its feasibility in education.

3.2 Theoretical background

Firstly, this section describes the escape room concept and design characteristics. Secondly, 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.

3.2.1 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: a) cognitive puzzles that make use of the players' thinking skills and logic, b) physical puzzles that require the manipulation of artefacts to overcome a challenge, such as crawling through a laser maze and c) meta-puzzles, the last puzzle in the game which is often connected to the narrative. Cognitive puzzles seem to predominate in escape rooms (Wiemker et al., 2015). Nicholson (2015) identified four ways of organising the puzzles, see Figure 3.1. 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 et al., 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.

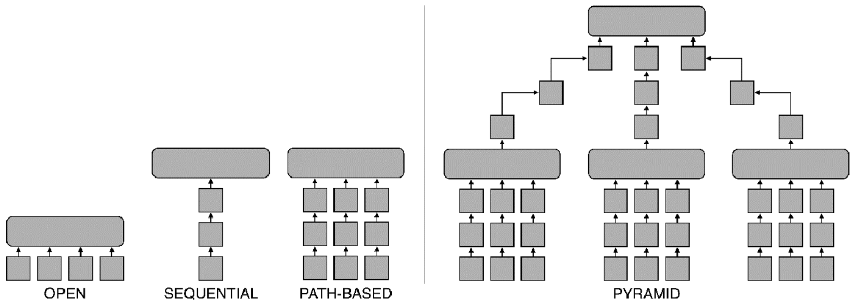

Figure 3.1 Puzzle structures in escape rooms: a) basic structures: open, sequential and path-based; b) a complex, hybrid structure, such as a pyramid. Squares are puzzles and rectangles are meta-puzzles (adapted from Nicholson, 2015).

3.2.2 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 focussed 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.

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 organisation

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.

3

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 favour 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 et al., 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 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 3.1 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 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.

3.2.3 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 et al., 2020). The medical disciplines and the disciplines Science, Technology, Engineering and Mathematics (STEM) are pioneers in the implementation of educational escape rooms.

Table 3.1 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 participatio**n within teams
Team organisation	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 space**s within the larger room
Location	One or more connected permanent rooms	Classroom with time slots	Restricted set-up 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**

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 a) to unfold the narrative, puzzles, codes and/or additional information, b) to foster immersion and to support the narrative, for example with movie messages, c) to foster learners' subject related ICT skills, and in 3 of the 39 studies d) 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 teamwork 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.

3.3 From room escape 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), i.e., 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).

3.3.1 Design cycle one

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

Educational goal

The goal was to develop an escape room to formatively assess knowledge of mathematics in grade 10 (15-16 yr.). 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.

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.

Prototype

The resulting prototype was a pop-up escape room consisting of 5 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 3.2). 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 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**.

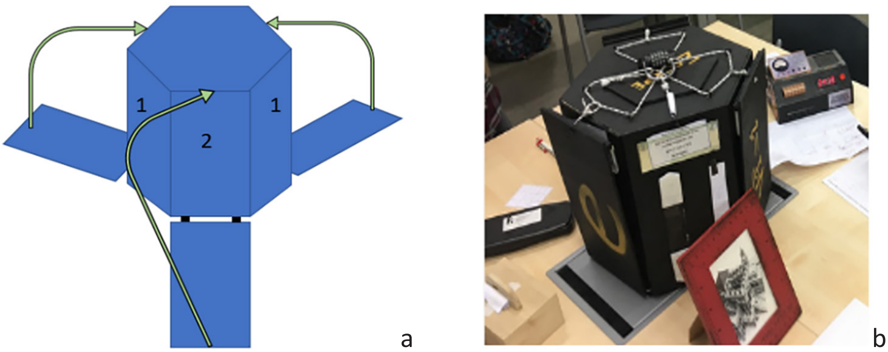

Figure 3.2 a. At the start, the 3 fronts are up, so only the puzzles in place 1 are visible. After solving these puzzles, the lock at the top of the box can be opened and puzzles in place 2 become visible, b. one box ready for use.

Test sequence & method

At first, the escape room was pilot tested with a team of 5 players using one box (16-17 yr.). 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 yr.). In each class, teams of 3-5 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 focussing 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 2-3 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 organisation 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 organisation 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.

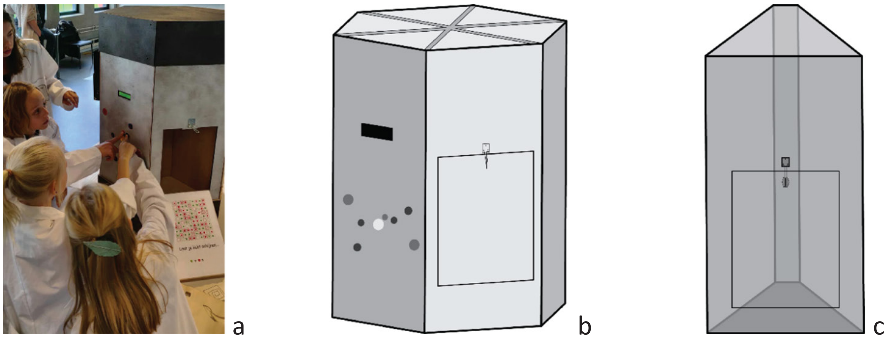

Figure 3.3 a. Pupils playing the box on Science Day 2018, showing a front with an opened window on the right, and an LCD screen above a physical game on the left. b. A sketch of the box design in the same position as on the picture in a. c. A sketch of one of the six compartments.

3.3.2 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).

Educational goals

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.

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.

Prototype

The resulting prototype was a hexagonal escape box consisting of six loose compartments with all different fronts, see Figure 3.3. 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 organisation 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 organisation was the same as in the first cycle, a next layer of puzzles was unfolded only 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 yr.), using a think-aloud protocol (Jääskeläinen, 2010). The game was played 5 times during the University's Science Day, one team (4-6 players) played on one box at a time. Formal observations were made by three developers, focussing on the design criteria, see Appendix B. Informal observations made by the parents were added. Debriefings with the players focussed 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 by 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. Further, 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**.

3.3.3 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.

Educational goals

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 yr.), as box content was developed for three different subjects, biology, chemistry and mathematics.

Design criteria

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

Prototype

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 3.4). 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 3.2 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 6 rounds were involved. Afterwards, 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 y), see Appendix D. In two classes, observations were made by two observers focussing on the game mechanics and the design criteria, **immersion** and **active participation** within teams, see Appendix B. The teachers monitored the lesson.

Table 3.2 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 focusses 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 6 out of 8 fronts with different possibilities. Content can be added and removed, e.g., 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 & conclusions in relation to the educational goal of the boxes

Pupils enjoyed the lesson more than a regular science class (4.0/5 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 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 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.”

Data & 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**.

3.4 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 organisation and design of the puzzles. The puzzles required combining information uncovered by different subgroups and were developed so that learners recognised 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.

Figure 3.4 a. Design of the box, with top ‘open’ to show inner structure, b. Box ready for play, and c. after play

In this research, we used the design criteria as set out in Table 3.1, 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 **develop 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 focussed 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.

3.4.1 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 et al., 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 3.2). 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 humour. 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 organisation 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 3.2). Once built, the boxes can be reused for various subjects due to the adaptable fronts and separate reusable content.

3.4.2 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., 2016; Guigon et al., 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.

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'm not going to study for the test
    - Less than one hour
    - Between 1 and 2 hours
    - Between 2 and 4 hours
    - More than 4 hours

1. 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 article 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, 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 article 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 3 health concerns that are linked to plastic ingestion.
- be able to describe at least 3 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?
5. 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**]
6. 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?

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 article 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 see 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	1	2	3	4	5
5.	I think experience of escape rooms is necessary to play the puzzle box.	1	2	3	4	5
6.	I like science classes	1	2	3	4	5
7.	I understand that plastic pollution is a worldwide problem	1	2	3	4	5
8.	I am more aware of the plastic pollution problem	1	2	3	4	5
9	I have increased my knowledge on how plastic pollution affects my health	1	2	3	4	5
10.	I have increased my knowledge on how plastic pollution affects the environment	1	2	3	4	5
11.	I want to do more to help reduce my plastic waste	1	2	3	4	5
12.	I understand how to reduce my plastic waste	1	2	3	4	5
13.	I think group work helps me to learn [criterium **ensure active participation within teams**]	1	2	3	4	5
14.	I learnt about plastic soup by working together on the escape box [criterium **ensure active participation within teams**]	1	2	3	4	5
15.	The shape of the box and the puzzles stimulated us to work together [criterium **ensure active participation within teams**]					
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!

Chapter 4

You escaped! How did you learn during game-play?

This chapter is based on

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AV and WvJ designed the Study; RN and AV designed educational materials; MH and AV collected and coded data; MH, AV and WvJ analysed and discussed the data; AV drafted the manuscript; AV, RN, MH, MCK and WvJ contributed to a critical revision of the manuscript; MCK and WvJ supervised the Study.

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Abstract

This study investigates the influence of the educational game design elements immersion, collaboration, and debriefing, on fostering learning with educational escape rooms. We based the design of the escape room on an educational game design framework that aligns the learning goal and the game goal, i.e., escaping from the room. One-hundred-and-twenty-six students, aged between 16 and 20, played the escape room. Measures for learning were pre-and post-tests. The game experience was measured through questionnaires, classroom observations, and interviews with students and teachers. The results show a knowledge gain between pre-and post-test. Correlational analysis showed that all three design elements contributed to students' appreciation of the escape room, whereas only immersion had a direct contribution to knowledge gain. Based on the qualitative data it appeared that the used escape boxes contributed most to perceived immersion. Immersion helps students focus on each other and the tasks. Also, a narrative with distinct roles for each student helped to evoke immersion. Unexpectedly, these roles also scaffolded collaboration except for students in the school that engaged in a collaborative learning pedagogy. The study confirms the usability of the framework for game designs, based on theories for the design of physical and hybrid educational games.

4.1 Introduction

Game-based learning, in which games are used to motivate students and foster their content knowledge and skills, is subject to increasing research and review studies (Backlund & Hendrix, 2013; Baptista & Oliveira, 2019; De Freitas, 2018). In this context, the adaptation of the popular recreational 'escape room' by teachers is a worldwide, spontaneous phenomenon in education (Veldkamp et al., 2020b). The time-constrained and problem-based puzzles require active, collaborative participants, which makes an escape room an interesting setting for teachers (Nicholson, 2018). The teaching of content knowledge and skills in authentic contexts such as crime scenes (Ferreiro-Gonzáles et al., 2019) is especially attractive for teachers in Science, Technology, Engineering, and Mathematics (STEM) education. Both students and teachers perceive that while participating in escape rooms, students are more engaged, active and learn more compared to regular classes (Cain, 2019; Veldkamp et al., 2021a).

Although teachers and students are generally enthusiastic about the implementation of escape rooms in education, the outcomes on the acquired content knowledge are disappointing (Veldkamp et al., 2020b). As the current educational escape rooms are mostly copycats of recreational escape rooms and not grounded in educational or game theories, there is room for improvement. In this study, an escape room was evaluated, which was developed using a design-based approach and a framework grounded in theories on game-based learning and persuasive game design. This study aims to explore how important educational game design elements: immersion, collaboration, and debriefing, foster learning in a hybrid escape room for STEM.

4.1.1 Escape rooms in education

Escape rooms are gaining popularity as learning environments in all levels of education and for various educational purposes (Fortaris & Mastoras, 2019; Sanchez & Plumettaz-Sieber, 2019). Embedded in the course curriculum, escape rooms are designed to explore an active learning environment which is said to increase students' motivation and/or engagement and domain-specific skills and knowledge while fostering teamwork and communication skills (Veldkamp et al., 2020b).

Like recreational escape rooms, educational escape rooms combine hands-on and mind-on activities incorporated in a quest and to be solved with a team in a limited time (Nicholson, 2015). In education, each of the escape room characteristics is not unique on its own. However, the combination seems unique and appealing to teachers, as they want to create authentic environments with meaningful activities and room for failure for their students (López-Pernas et al., 2019).

Secondary science students appreciate the diversity of puzzles, their problem-solving and discovery nature, and the need for physical attributes and collaboration (Veldkamp et al., 2021a). These are characteristics of exploratory and problem-based play. To attract both girls and boys in the underlying science content and skills, both types of play are needed (Kinzie & Joseph, 2008). When tested for gender bias; no gender bias was detected in any of the questions that addressed the escape room activity (López-Pernas et al., 2019; Veldkamp et al., 2021a).

In educational escape rooms, students are cognitively, behaviourally, and affectively engaged (Veldkamp et al., 2021a; Hermanns et al., 2018). A meta-study on engagement in education showed that engagement positively influences academic achievement. Cognitive engagement is related to a deep level understanding of content. Behavioural engagement is associated with the development of basic skills and prevents dropping out. Affective engagement encompasses positive and negative emotions and influences the willingness to do work (Fredericks et al., 2004). None of the reviewed studies comprised an intervention that evoked all these aspects of engagement, unlike escape rooms.

The escape room as a learning environment appeals to teachers of different ages, gender, and teaching experiences (Veldkamp et al., 2021a). The attraction for STEM teachers' seems to be the teaching of content knowledge and skills in authentic contexts such as crime scenes (Ferreiro-González et al., 2019; Healy, 2019), secured laboratories (Peleg et al., 2019; Vergne et al., 2019; Watermeier & Salzameda, 2019), computer networks (Borrego et al., 2017; Ho, 2018), or students follow the historical footsteps of a scientist during his discovery and its consequences in time (Dietrich, 2018). In medical escape rooms, the required collaboration and communication skills are part of students' professional skills. Seto's study (2018) shows that it was feasible to assess collaboration skills and reflect on them afterwards with students. For content knowledge, review studies on educational escape rooms show that the evaluation is usually absent, disputable, or indicates no gain (Veldkamp et al., 2020b; Fortaris & Mastoras, 2019). The discrepancy between perceived and actual learning of content knowledge is in line with other findings in pioneer studies on educational games (Garris et al., 2002), practical work (Abrahams & Millar, 2008), and inquiry-based science instruction (Minner et al., 2010). These and similar studies showed that the interventions appeared not to be effective without active linking of knowledge during the intervention or reflection afterwards. A plenary reflection or debriefing, after the gameplay, is implemented in 40% of all educational escape rooms (Fortaris & Mastoras, 2019) and in half of the physical ones (Veldkamp et al., 2020b).

A current trend in educational escape rooms is upscaling the game with the use of technology in order to play the game with a whole class or course at the same time (Blankenship et al., 2021; Shvalb & Harshoshanim, 2020; Strippel et al., 2021). Technology is mostly implemented to structure the game, validate answers (Ross, 2019), supply pre-set hints (Veldkamp et al., 2020a), and/or immerse students in outside world contexts which are out of reach or potentially dangerous (Cheng & Annetta, 2012).

4.1.2 Theoretical grounding of educational escape rooms

Teachers develop escape rooms based on their experiences with recreational escape rooms and/or video escape games, and/or refer in their game design decisions to pedagogical or game principles, such as autonomy and immersion (Veldkamp et al., 2020b). Due to the game-like properties of escape rooms, we may resort to educational game theories. The potential for game-based learning in science education is to bring authentic science-related environments in the classroom, promote collaborative problem solving, and provide an effective learning environment, according to Li and Tsai's review (2013). For example, Cheng and Annetta developed a game to let students 'experience' the effects of drugs in a virtual authentic environment. Students' knowledge improved and their attitude to drugs changed (2012). In the game design, it appears important to integrate learning and playing, without losing what is enjoyable about games (Ke, 2016; Vandercruysse & Elen, 2017): simulations, role play, humour, surprise, puzzles, storytelling, and mystery (Whitton, 2018). Essential aspects of educational games for engaging and learning are the players' identity and role during gameplay, immersion & discovery-oriented experience, interactivity (including collaboration, autonomy, and ownership), progression & increasing complexity, scaffolding learning (including repetition, feedback, rewards, and debriefing) and alignment with the curriculum (Annetta, 2010; Ávila-Pesántez et al., 2017; Ke, 2016; Lameras et al., 2017). A review showed that although most GBL research is related to digital games, physical or hybrid educational escape rooms can address the above-mentioned aspects (Veldkamp et al., 2020b).

GBL reviews stress an understanding of the relations between educational and game design aspects for engagement (Connolly et al., 2012; Jabbar & Felicia, 2015) and learning (Ke, 2016; Van der Linden et al., 2019). A review study on common practices in educational escape rooms regarding specific educational and game design aspects draws the same conclusions (Veldkamp et al., 2020b). An educational design framework was used to understand the data on the synthesized practices in educational escape rooms, see Figure 4.1.

The framework addresses the different alignments needed in a successful educational game. Van der Linden et al. (2019) emphasize that the learning goal should be leading in the design of an educational game, and it needs to be ensured that the game goal can only be reached when the desired learning goal is reached. Additionally, a learning goal can only be achieved when supported with an adequate pedagogical approach, and the game goal by adequate game mechanics. Moreover, during iterations of the design process the focus should be on aligning the pedagogical approach with the game mechanics, as it appears the most essential and difficult step.

Applying this to, for example, medical escape rooms, the alignment is strong as the game goal and learning goal both comprise rescuing patients by setting the right diagnoses and administer the right interventions (Veldkamp et al., 2020b). Less aligned are goals on mathematics skills and unlock handcuffs, as one can try brute force when running out of time. In addition, it was concluded that pedagogics such as collaborative learning do not align with game mechanics like a sequential puzzle organisation in combination with a team size of six or more. Students were more active and collaborative when the used puzzle organisation created positive social interdependence.

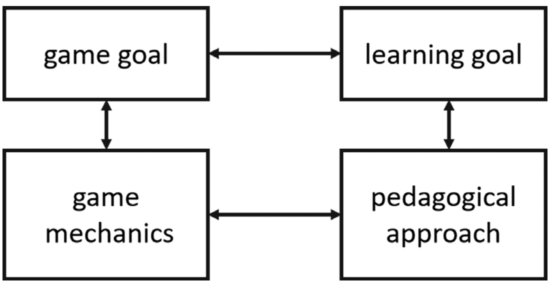


Figure 4.1 Design framework on alignment between game goal, learning goal, pedagogical approach and game mechanics (Van der Linden et al., 2019).

For the design of educational escape rooms, the available models comprise step-by-step procedures (Botturi & Babazadeh, 2020; Clarke et al., 2017; Eukel, & Morrell, 2020; Guigon et al., 2018). However, design challenges for educational games are not considered. Veldkamp et al. (2021b[1]) described in a framework the three challenges that inform the design of an educational escape room. Additional to aligning game and educational aspects, the challenges are the participants' transition from the real world into the game world and the transfer from experiences and knowledge obtained within the game world back into the real world. These two challenges are addressed by Visch and colleagues (2013) in their persuasive game model. Persuasive game theory presumes that participants' beliefs, attitudes, and behaviour in the real world can be transformed by a game. The enjoyable and immersive game world can persuade and help players to behave in ways they experience as difficult or unsafe in the real world. Acquired beliefs, attitudes, and/or behaviour can then be applied in the real world; the ultimate goal of persuasive games (Jacobs et al., 2017). However, an explicit transfer to the real world is needed and often neglected in game design (Visch et al., 2013). Other than Van der Linden's framework, this model does not focus on the gameplay as such but describes the participants' transition from the real world into the game world and back. Hence, Veldkamp et al. (2021b) combined the frameworks covering all three design challenges in one framework for educational escape rooms, see Figure 4.2. In the context of this escape room, the expected outcome was a persuasive goal, it can be assumed that a similar structure applies to learning goals.

In secondary education, the students' transit from the science class into the game world, is not as voluntary as in a recreational game. To persuade students, immersion is important. Immersion is the process where someone is lured into a story or problem (Douglas & Hargadon, 2001), gets engaged, solves challenges, and finishes the game (Hamari et al., 2016). Immersion correlates with improved learning outcomes in science GBL. However, more immersion in the game leads only to higher game scores, but not to higher learning outcomes (Cheng et al., 2015). Ermi and Mäyrä (2005) distinguish sensory immersion, challenge-based immersion, and imaginative immersion. Sensory immersion implies the audio-visual properties of a game, the extent to which the surface features of a game have a perceptual impact on the player. Challenge-based immersion entails immersion in the cognitive and motor aspects of the game that are required to meet the presented challenges. Finally, imaginative immersion refers to the immersion within the imaginary world created through the game and depends on the richness of the narrative structure of the game. However, in a classroom, the possibilities for scenery and props, which are important for immersion are limited. So, which immersive design elements are crucial for luring students into STEM game tasks?

STEM escape rooms aim at collaborative learning. In collaborative learning environments learners are engaged; working together to formulate questions, discuss ideas, explore solutions, complete tasks and reflect on them (Srinivas, 2011; Kozlov & Groβe, 2016). Learners interact to reach a shared goal (Dillenbourg, 1999). The environment needs to provide students with the opportunity to discuss and to bear responsibility for their learning and participation (Laal & Laal, 2012; Yücel & Usluel, 2016). In STEM escape rooms collaborative learning is fostered with supportive game mechanics fostering

1 This article is provided in the Appendix of this book.

collaboration, such as adequate puzzle organisations and team sizes (Veldkamp et al., 2020b). However, is unknown to what extent collaborative learning is fostered during escape room gameplay.

To improve the transfer of the acquired knowledge and skills from the game world to the real world, debriefing is needed (Sanchez & Plumattez, 2018; Watson et al., 2011). Watson et al. (2011) see teachers as agents bridging the game world and the real world. The debriefing after an educational game is a complex process as the experience and knowledge need to be decontextualised and institutionalised for future contexts. Therefore, teachers need to discuss the game experience and puzzles, link puzzles to learning goals and content, and discuss the learning for broader application (Sanchez & Plumattez, 2018).

A systematic review on escape rooms in STEM education urges to research which game elements exactly influences students' science learning in a positive way (Lathwesen & Belova, 2021). In our study, it is researched to what extent the game elements immersion, collaboration, and debriefing foster learning in educational escape rooms. These game elements address the main challenges in designing effective escape rooms. So, for an escape room activity in secondary science education the following research questions (RQs) were explored:

1. to what extent are the learning goals achieved?
2. how do the educational game design elements influence the learning process?

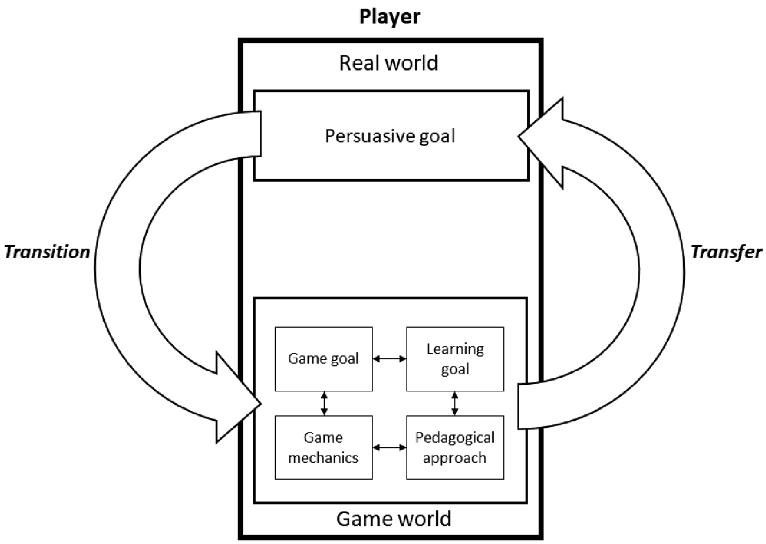


Figure 4.2 An educational game design framework for escape rooms, focussing on the three main challenges 1) the participants' transition from the real world to the game world, 2) the alignment of game design aspects and educational aspects, and 3) the transfer from attained experiences and knowledge back into the real world (Veldkamp et al., 2021b). The framework is developed in a persuasive game context, in our context this will be replaced by a learning goal.

4.2 Method

4.2.1 Study design and data collection

A mixed-method study was carried out. The activity was played in two Dutch secondary schools reacting to an announcement in a newsletter; one school with collaborative learning as the driving pedagogy and one regular school. The six classes had a total of 126 pre-A-level students grade 10-12, aged 16-20 yrs. A pre-test/post-test was deployed to study to what extent the students achieved the intended learning goals (RQ1). The pre-knowledge test was administered just before the students played the escape game and the post-knowledge test was administered after the debriefing.

To study how the game design elements immersion, collaboration, and debriefing influence learning in a physical escape room (RQ2), various data sources were used: experience questionnaires, interviews with students and teachers, and classroom observations (see Table 4.1).

The statements for the experience questionnaire were either adopted or adapted from other studies or developed by the authors (see Appendix B, Table 5). A 5-point Likert scale was used, ranging from 'totally disagree' to 'totally agree'. The pre-test/post-tests, the experience questionnaire, and interview questions (see Appendix A, B, C) were pretested on two students using a think-aloud protocol (Jääskeläinen, 2010). Consequently, a few questions in the experience questionnaire were rephrased.

Table 4.1 The various data sources and numbers

Data source	Number female, male, other	RQ
Students - pre-test/post-test	126 68, 57, 1	1
Students - experience questionnaire	126 68, 57, 1	2
Students - interviews	14	2
Teachers - interviews	5	2
Classroom - observations	6	2

Note: RQ research question.

Before the start of the class, the researcher randomly chose one of the five escape boxes to observe. During gameplay, every student standing around the box was observed once a minute, using a predefined coding scheme (see Table 4.4). Another researcher performed the role of game master (GM) monitoring and guiding the teams who got stuck, due to technical or cognitive difficulties. The teacher had no described role and observed all teams informally. For the semi-structured interviews, a non-random sampling strategy was used, since the teachers and students participated on a voluntary basis. From each class, students were interviewed in small groups, with a total of fourteen students.

4.2.2 Data analysis

Answers given by the students on the pre- and post-knowledge tests were graded; one point for every correctly answered question and zero points for every incorrect or 'I don't know' answer. To determine the reliability of the pre- and post-knowledge test, the calculated Cronbach's alpha was respectively 0.78 and 0.72. Without question T13 (see Appendix A), which showed no correlation with other questions, the post-knowledge test Cronbach's alpha increased to 0.74. A Wilcoxon signed-rank test was used to determine whether the content knowledge of the students had increased on the test average.

In the experience questionnaire, 18 out of 21 items addressed the design elements, with a Cronbach's alpha of 0,81. Data were analysed using descriptive statistics and Spearman's rank correlation test. On the classroom observations, descriptive statistics were used.

All interviews were recorded, transcribed verbatim, and analysed independently by two researchers following Boeije (2010), using immersion, collaboration, collaborative learning, debriefing, and learning outcomes as sensitising concepts in NVivo 12. For the students' interviews, the inter-rater reliability testing showed for the students' interviews 96.6% agreement, with a Cohen's kappa for the elements immersion of 0.92, collaboration 0.90, and debriefing 0.94. For the teachers' interviews, the inter-rater reliability testing showed 98.6% agreement, with Cohen's kappa's for immersion of 0.80, collaboration 0.67, collaborative learning 0.89, and debriefing 0.91.

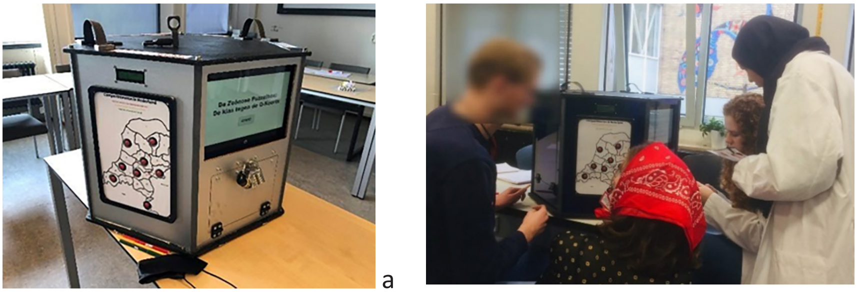
4.2.3. Description of the escape box design and narrative

The learning goals addressed immunology for grade 11, involving concepts and mechanisms on immunisation, B and T cells, antibiotics, and the differences between bacteria and viruses. Extracurricular goals covered knowledge of the approach One Health, which recognises that the health of people and animals are interconnected, and a multidisciplinary approach is needed to defeat zoonoses, like Q-fever.

The escape room activity was developed from scratch in three design cycles using design-based research (Bakker, 2018). The resulting escape boxes were co-created with students, who were close to the target group's real world and game world (Veldkamp et al., 2020a).

The escape box has changeable fronts, see Figure 4.3. An educator can choose six out 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. Puzzles placed on each side of the fronts put players face to face with each other and stimulate them to collaborate. The storyboard option in Microsoft PowerPoint was used to structure the game, support the narrative and supply authentic movie clips. In addition, it revealed pre-set hints for teams lagging and teams could continue their game, while others finished.

The storyline covers the rise and fall of a Q-fever epidemic in goats caused by the bacteria Coxiella burnetii. The main character is an animated bacterium. The staged newscasts with authentic material of a Q-fever epidemic in the Netherlands (2007-2011) inform the team on the epidemic and its course as a result of the team's actions. In the 'multidisciplinary' team, students wear clothing according to their unique role in the narrative, such as a livestock farmer, veterinarian, general practitioner, government, or civilian, see Figure 4.3b. The game started plenary, presenting game rules and a newscast introducing the epidemic with the students as a multidisciplinary rescue team. The game ended when students achieved the game's goal, or after 45 minutes.



a b

Figure 4.3 a. The escape box featuring on the left front buttons linked to an embedded microchip, and an LCD screen for the question and feedback. The right front shows the laptop screen with an interactive PowerPoint. b. Students dressed according to their role, playing the game.

Addressing the three design challenges

1. Alignment of goals, game mechanics, and pedagogy. The game goal is the team's defeat of the epidemic, by adequate anamnesis, culling measures, and the development of a human vaccine. To achieve this game goal, knowledge on immunology needs to be applied to puzzles supporting the game goal and covering the learning goals (for more details, see Appendix D). Laal & Laal (2012) researched fundamental elements of collaborative learning: positive interdependence, face-to-face interaction, individual accountability, social skills, and group processing. The social dependence needed is scaffolded by game mechanics, such as the organisation of the puzzles (see Appendix E), as in some phases multiple puzzles need to be solved at the same time, the time restriction, and resource dependence as some information is related to a specific role.
2. For the transition to the game world, the following immersive elements were implemented: a narrative with a call for action to the students in distinct roles, appropriate clothing, authentic video material and a sound design. The escape box, featuring a hexagonal shape, was designed to stimulate students to gather around with consequently less distraction by their surroundings.
3. To improve the transfer of learning from the game world to the real world, a debrief was designed based on research of Sanchez & Plumattez on debriefing in educational escape rooms (2018). The teachers guided the debriefs, as they could link the topics to previous and coming lessons and knew their students best.

4.3 Results

4.3.1 Results on the intended learning goals (RQ 1)

The means of the scores are Mpre =7.8, SD = 3.5; Mpost = 15.0 (14.95), SD = 2.8, showed a significant increase in scores (Wilcoxon's Z= -9,8, $p < 0.0001$). In the experience questionnaire, students answered positively on the question on the appreciation for the game (Q1), on average 4.5 out of 5-point Likert scale. The question on future escape rooms (Q2) averaged to 4.3. Additional analysis (Mann-Whitney U testing) showed no gender preferences.

Table 4.2 Descriptive statistics for the perceived immersion, collaboration and debriefing items in the post-activity survey

Category	Mean	SD	Mode
Immersion	3.9	0.5	
T3	3.42		4
T4	3.66		4
T5	4.17		5
T6	4.28		5
T7	4.40		5
T8	3.48		4
T9	4.14		5
Collaboration	3.9	0.6	
T10	4.50		5
T11	4.35		5
T12	4.50		5
T13	3.87		4
T14	2.98		3
T15	3.33		4
Debriefing	3.7	0.7	
T16	3.70		4
T18	3.29		3
T19	3.92		4
T20	3.76		4
T21	3.66		4

Note: Q Question, SD standard deviation

Spearman's rank correlations show a small positive correlation between the knowledge gain during the activity and the student's appreciation of the activity, see Table 4.3. In addition, a negative correlation exist between the students' pre-test knowledge and the knowledge gain during the activity ($R = -0{,}642$, $p < 0.01$). This suggests that students who know less learned more during the activity.

4.3.2 Results on the influence of educational design elements on the learning outcomes (RQ 2)

To study the influence of perceived immersion, collaboration, and debriefing on the learning of students with an escape room activity, an experience questionnaire, classroom observations, student interviews, and teacher interviews were conducted (see Table 4.1).

Results from the experience questionnaire

Table 4.2 shows the results from the experience questionnaire. The high means (3.9 out of 5) for the items on immersion and collaboration indicating that students felt very immersed and perceived that had worked very well together. The mean for the debriefing items is slightly lower (3.7 out of 5).

Table 4.3 The Spearman's correlation coefficients on relations between the students' appreciation of the activity (Q1), willingness for this type of activities in the future (Q2), their experiences on immersion, collaboration, debriefing and their knowledge gain.

	Appreciation	Future	Immersion	Collaboration	Debriefing
Future	0.650**				
Immersion	0.457**	0.459**			
Collaboration	0.424**	0.506**	0.348**		
Debriefing	0.480**	0.402**	0.487**	0.337**	
Knowledge gain	0.203*	0.108	0.180*	0.088	0.108

Note: * Correlation is significant at the 0.05 level (2-tailed) ** Correlation is significant at the 0.01 level (2-tailed)

The Spearman's rank correlation coefficients showed that students who experienced strong immersion, also experienced strong collaboration and scored high on the appreciation of debriefing ($p < 0.01$), see Table 4.3. The appreciation of the activity was even more strongly related to experiences of immersion, collaboration, and appreciation of debriefing. Additional analysis (Mann-Whitney U testing) showed no gender preferences for any of the studied variables.

Immersion. The questions Q5-7 and 9 from the experience questionnaire, show the highest means (4.2 - 4.4) and modes (all five), meaning that students felt not distracted by teammates or the surroundings and focussed on the game by means of the box, see Table 4.2. The score on elements of sensory immersion (Q8 'videoclips, clothing and props') was lower (3.5). The elements related to imaginative immersion (Q3), and challenge-based immersion (Q4) were lower (3.4-3.7) than the scores on the role of the box (4.2 - 4.4), but still indicating a positive influence on immersion. The Spearman's rank correlation test indicates that students' experience of immersion shows a positive small correlation with the knowledge gain during the activity ($p < 0.05$), see Table 4.3. This means that students' experience of immersion influences learning, although the influence is small.

Collaboration. The questions Q10-12 show the highest means (4.5, 4.4, 4.5) and modes (all five), demonstrating an experienced high degree of communication and collaboration in the teams. The means of the questions (Q14, 15) indicating the perception of collaborative learning, were the lowest of all items, respectively 3.0 and 3.3, both with a standard deviation of 1.0. This indicates that a few students perceived they had learned from getting explanations and even fewer students perceived they had learned by giving explanations. This is not due to a lack of the perceived collaboration as the scores on these items were high.

Debriefing. The means for the debriefing items are between (3.7 and 3.9) and the mode is 4 for all items, except for Q18 which has a mode of 3. The students appreciated the debriefing (Q16) in helping to understand concepts on immunology (Q19) and to apply these concepts in real-world situations (Q21). The scores on Q18 seem to indicate that the students' questions were not sufficiently answered during the debriefing. However, none of the students who were not satisfied posed a question during the debrief as asked in Q17. Classroom observations during the debriefing showed that there was room to ask questions, but only a few students used that opportunity. In addition, Spearman's rank correlation tests showed that students with perceived higher knowledge at the start thought they profited less from the debriefing.

Classroom observations

One of the criteria of immersion is that one is not easily distracted (Ermi & Mäyrä, 2005), therefore off and on-task behaviour was scored. None of the students observed were off-task during the activity (Table 4.4). This alone is not enough to state that the students were immersed. However, it does support the self-evaluation by the students. Students were communicating verbally 28.8% of the observed time, next to looking at and possibly thinking about how to solve the escape box (32.7%), and physically trying to solve the puzzles (15.2%). Although most time is spent on-task on the content knowledge (76.8%), the time spent on explaining or discussing content knowledge is only 3.1%. Additional notes on the classroom observation schemes showed that students laughed about the videos with the animated bacterium and the news reporter. Some students started to hum the news theme music along at the start or the end of each news item, others tried to skip it. Additional notes showed that at the regular school, in all teams observed, students addressed each other or themselves according to their role, for example: 'Doc, do you know?' or 'Heee! I'm not a stupid farmer.'

Student interviews

All students indicated they would like escape game activities more often, although not every lesson.

Immersion. The implemented elements addressing sensory and imaginative immersion were 1) a narrative supported by videoclips, 2) sound design, and 3) roles and clothing for the players. The content-based puzzles addressed challenge-based immersion. Students mentioned noticing their surroundings only after finishing the game, or when they were visited by players who had already finished the game. In their explanation, students mention competition, time restriction, the novelty factor, and their focus on the box. As a student (S8) explained: 'the weird box, shiny, with buttons and puzzles, you want to touch and try'. In addition, students mentioned that the shape of the box helped them to focus on their part in the game, on 'their' puzzle. Some added that later on while walking around the box, they were still faced on the centre, and not on their surroundings (S9, S13, S14).

Most students considered the puzzles challenging but doable, and informative with a fun or puzzle twist, as it was not always clear how to solve a puzzle. This last aspect was appreciated but also confusing for those who were not familiar with escape rooms. Two students mentioned that although the content-based puzzles Word Search and the anagram, were not congruent with the zoonosis context, they added a fun element.

According to the students, the authentic video clips made the narrative credible and contributed to immersion as it made the terrible consequences for the live-stock and farmers visible.

> *S14: 'It showed the consequences for people, for example, the farmer who lost all his goats, that is quite intense. With those images, it is easier to empathize with them.'*

Table 4.4 Observed student behaviour in six groups (total of 28 students) during classroom observations

Frequency of codes	Percentage of total	Code	Student behaviour	Description of behaviour
			On-task	
136	15.2%	CP	Content - physical play	Physically involved in the games' content
229	25.7%	CC	Content - communication	Communication with team member(s)
28	3.1%	CE	Content-explanation	Team member explaining or discussing content
292	32.7%	CO	Content - observation	Observing content puzzles
0	0	CQ	Content - question	Posing question to GM* or teacher on content
5	0.6%	GQ	Game - question	Posing question to GM* or teacher not on content
202	22.6%	GO	Game - other	Busy with the game, other than content
			Off task	
0	0	OI	Off-task individually	Off task behaviour by themselves
0	0	OT	Off-task team	Off task behaviour in relation to team member(s)
0	0	OS	Off-task surroundings	Off task behaviour by something outside the team
892	100%			Total

Note: GM game master.

Although the newsreader and the animated bacterium were referred to as 'fake' and adding humour, some students in their final high school year, considered the animated bacterium too childish and the announcement of the newscasts too long, as the players' time was restricted. The sound design during the gameplay was only noticed by two of the fourteen interviewees and appreciated in supporting the narrative. The applause after finishing the game was mentioned by more students and appreciated. All students mentioned that the roles in the narrative immersed them in the game, although they did not adhere to their roles for the full length of the activity.

> *S8: 'I was engaged immediately. You are standing around that box and the first thing you think is 'I want that bandana, that jacket, or that prop'. Consequently, you enrol and it is more fun to do the puzzles because you are in that role.'*

Four students wondered whether the roles were crucial for immersion. Eight of the fourteen students added that it showed them the multidisciplinary approach in the battle of zoonoses. Half of the interviewed groups from the regular school mentioned that the roles also structured the initial division of tasks.

> *S12: 'I think that if you are in a group without roles, everyone will cluster on each topic. If you have a role assigned, you are more eager to find out your stuff.'*

Collaboration & collaborative learning. Students formed their own teams. All interviewed students stated that their teams functioned well, adding that teams should not be greater than five for a game with this number of puzzles. All groups mentioned that the (hexagonal) shape of the box allocated each student to a side, made them feel the owner of the puzzle(s) on that side, but also allowed them to see on their neighbours' side and optionally help them.

> *S8: '[..] there is a kind of separation with each role on each side, but you can get to the other sides, [..] you can observe that the person with the role often takes the lead; the first one who will turn the lock, press the buttons or enter the code.'*

As learning outcomes, five of the seven groups of interviewees mentioned the refreshing of known concepts and knowledge. In addition, the students from the regular school named aspects on collaboration, such as that various talents or insights are needed to solve a problem, awareness of the role of communication in collaboration, and the balance between task allocation and dare to outsource your problem. This in contrast to the students from the school with collaborative learning as pedagogy. They only mentioned that you need various disciplines to beat a zoonosis and its stepwise procedure.

On the question how they learned during gameplay, students mentioned group exchange of information or checking each other's answers. This was limited to a certain extent, as 'you only hear the answer, but you don't know what the question is' (S6). 'You haven't learned the meaning of the concepts. So, you learn it superficial, and not in detail' (S5).

Some students from the regular school mentioned that the activity does not equal the usual amount of content knowledge covered in a lesson. However, the efficiency in terms of remembering is perceived higher by students. Students indicated to be less distracted in the escape game, due to the level of participation needed, the diversity in activities, the authentic context refreshing and extending knowledge, the urgency to succeed in time, and it is said to be more fun.

The role of debriefing. According to most students, debriefing is essential in the learning process as it wraps up the most important information from the puzzles and relates the main concepts. Students mention that they only solved a selection of the puzzles, due to the division of tasks. The debrief took away doubts on given answers and some teachers addressed student ideas on concepts. In addition, some teachers made connections with previous lessons, addressed other zoonoses and their consequences for society, and the societal debate on vaccination. Interviewed students from teachers who had not made these additions, advised incorporating such additions in the debriefing to make it more interesting than 'just a wrap up'.

Teachers' informal observations

Two out of five teachers had experiences with commercial escape rooms. Three out of five teachers, all from the regular school, had experiences with developing and implementing educational escape rooms. The goal of the escape box activity was to refresh students' knowledge on immunology; a formative assessment in an authentic context.

All teachers concluded that students were enthusiastic and more engaged than in their regular classes. However, in two out of the six classes, one or two students were not active, for no outstanding reason.

Three teachers observed that a few boys wanted to crack the locks without doing the content-based puzzles. One teacher added that the element of competition makes the game vulnerable for non-functioning parts, as students feel wronged if they must wait for the non-functioning parts to be repaired.

Teacher interviews

For each of the implemented immersive elements, escape boxes, narrative, and students' unique roles, we questioned their effects on the immersion and engagement of students, the collaboration of students, and the collaborative learning of students during the gameplay. In addition, we asked teachers about the role of debriefing in the activity.

The escape boxes. In relation to immersion and engagement, teachers observed that students entering the classroom curiously walked around the box 'which looked swanky and had devices incorporated' (T4). All teachers mentioned that standing around the box made students focus on the box and on each other. It facilitates ownership for the side of the box in front of them and they can also see their neighbours' sides. No involvement with other groups or mobile phones was noticed by the teachers. Teachers who had played educational escape rooms before indicated that in these escape rooms with loose puzzles and materials, students moved more and worked more separately from each other. According to teachers, escape boxes centralize students' attention and foster immersion and engagement.

In relation to collaboration, all teachers mentioned that the box shape invites to collaborate, as students see and hear each other while working. In addition, students displayed their puzzles on the boxes and could be seen and discussed by all. In only a few groups, all students within a team explored each puzzle together. One teacher wondered if the boxes make it difficult to withdraw and think awhile for yourself.

Collaborative learning was only recognised by three teachers as they heard discussion and exchange of concepts. Two others saw no signs of collaborative learning at all. They assumed that due to the competition there is no time nor need to explain answers. T4: 'They are not going to ask: How did you arrive at this answer? An escape game sends you forward, not backwards.'

The narrative. The narrative was communicated to the students by a display on one side of the box. In relation to immersion and engagement, teachers observed that from the start students appreciated the narrative; it was intriguing and funny. The context was new, authentic and realistic due to the use of genuine footage. Some teachers thought at first that the use of an animated bacterium as a protagonist would be too childish for A-level students. However, they observed that students laughed and appreciated it. One teacher suggested that it might soften the dramatic realistic footage. Teachers observed that students perceived the enfolding of new parts of the narrative by the movie clips as a reward.

In relation to collaboration, teachers observed that students waited till everyone was gathered around the display and watched the movie clips together. They interpreted that it bonded the students and focused them on a new phase in the narrative and related assignments, as tactics and task divisions were discussed after watching the movie clips together.

Students' roles in the narrative. In relation to immersion and engagement, teachers observed that as soon as students entered the classroom the clothing triggered discussion and division of the roles. Subsequently, students put on clothing before the class had started, apparently lured into the activity. All teachers from the regular school mentioned that students referred to each other's roles during the gameplay. Teachers from the collaborative learning-based school had not heard students referring to roles and observed no added value of the roles, clothing, or props for students. Although, 'the various professions involved deepened the problem of zoonoses' (T1).

In relation to collaboration, teachers from the regular school observed that the start of the game with each player at a side made the player responsible for this side with the related assignments. It was more difficult to withdraw and easier to address team members in their roles rather than personally. This task allocation effect became less during the game.

In relation to collaborative learning, it was mentioned that the roles helped to experience and understand the mean message of the game, that collaboration of disciplines is needed to defeat zoonoses. One teacher wondered if the roles and subsequent individual task allocation might have negative effects on collaborative learning.

Debriefing. Teachers declared that debriefing is essential. They observed that due to the division of tasks and time pressure, students do not address all puzzles or read badly. Debriefing is perceived necessary to discuss common misunderstandings, to make connections between the topics in various puzzles, and to add more content, depending on the level of the classes.

4.4 Discussion

Students enjoyed the escape box activity and no gender preferences were found in line with previous studies (Veldkamp et al., 2021a; López-Pernas et al., 2019). The pre-test/post-test results showed an increase of knowledge gain in contrast to outcomes of studies in a systematic review which showed no, or a disputable knowledge gain (Veldkamp et al., 2020b). However, like the studies in the review, no long-term retention has been tested and the test items addressed lower-order knowledge objectives (Anderson & Krathwohl, 2001). Future research needs to address these limitations. The Spearman's rank correlation test indicated a small positive correlation between the knowledge gain during the activity and the student's appreciation of the activity (see Table 4.3). However, does this mean that the more the student liked the activity, the more their knowledge gain was, or the other way around?

Previous research has shown that students who knew more, learned more during activities (Ausubel, 1986; Kole & Healy, 2007; Vosniadou, 1994). Our data suggest that students who knew less, learned more during the activity. This can be caused by a ceiling effect of the test, as items addressed only lower-order knowledge objectives. In addition, correlation tests indicate that the appreciation of the activity correlates positively with the appreciation of each of the game design elements. This indicates that the appreciation does not depend on one of the design elements, but all contribute. In the next sections, the results from all data sources on each of the elements will be synthesized and discussed.

4.4.1 Immersion

In this study, students felt immersed. The perceived immersion shows a positive correlation with the knowledge gain of students. The elements related to imaginative immersion (narrative and roles), sensory immersion (such as clothing, props), and the challenge-based immersion (puzzles) scored lower than the escape box itself (Table 4.2). Students felt not distracted by their surroundings or teammates and focused on the box. This is confirmed by all other sources, mentioning the sensory aspects of the box, and its shape centring all students' attention to each other and the game. Before the start, available clothing provoked discussion on the roles. Whether this is due to sensory immersion, imaginative immersion or both, cannot be decided on the available data.

Sound design connected to phases or events in the narrative is an important part of sensory immersion in (educational) games (Cuadrado et al., 2020; Grimshaw, 2012). In this study, players differed in their awareness and appreciation of the sound design. Compared to other immersive elements, it has less common ground. Another study showed that tempo and pitch changes in sound design has no impact on learning outcomes in educational games (Richards et al., 2008). Based on their and our results, we doubt that sound design is important in physical educational games, especially when played by multiple teams in the same classroom.

Some students tried to crack physical locks without solving the puzzles. So physical locks seem part of challenge-based or sensory immersion of physical escape rooms. We suggest including them in questionnaires on immersion and research their type of immersion. These students tried to reach the game goal circumventing the underlying tasks aligned with the learning goal. In relation to the game design framework (Figure 4.2), it can be concluded that the game goal and learning goals need to be more aligned. In relation to imaginative immersion, an authentic context with a combination of authentic footage and an animated bacterium seems to be a good balance between addressing serious problems and the playfulness of an educational game (Ke, 2016).

The two schools enrolled in the research were not selected on their different pedagogies. Various data sources showed that this aspect determined their experiences with the roles. In the school with collaborative learning pedagogy, the distinct roles fostered individual immersion and visualized the multidisciplinary approach in beating zoonoses. At the regular school, it also played a positive role in collaboration.

4.4.2 Collaboration

In studies on educational escape rooms collaboration and collaborative learning are mentioned in the same breath. The assumption is that the team-based games supports collaboration and automatically collaborative learning (Arnal et al., 2019; Gordon, 2017; Brady & Andersen, 2019; Peleg et al., 2019; Vergne et al., 2019; Wu et al., 2018). Various data sources (experience questionnaires, interviews students and teachers) indicate a high degree of collaboration. In regular classes, the roles fostered task allocation too, although it lessened during the gameplay. However, collaborative learning scarcely takes place, as only 3,1% of the time is spent on explaining and discussing the content knowledge, the scores on perceived collaborative learning are neutral and only three teachers observed signs of collaborative learning. Teachers observed that time restriction and competition conflict with explaining and discussing findings. Discussion and reflection on tasks are important for learning according to theories on collaborative learning (Gerlach, 1994; Golub, et al., 1988). Thus, although the game successfully scaffolded collaboration, it hardly led to collaborative learning.

4.4.3 Debriefing

The experience questionnaire and interviews showed that students appreciated the debriefing. It is essential according to them and the teachers, to cover the important information from all puzzles, interrelating the main concepts, and take away doubts and incorrect ideas. Results showed that students with more prior knowledge gained less knowledge during the game. In order to give students more than a wrap-up, relations to societal issues can be added conform Sanchez and Plumettaz-Sieber (2019). Additionally, some students advised that new information should be given as part of the debrief, to keep it interesting for some students. This is complementary to Sanchez and Plumettaz-Sieber's components of a debrief (2019).

4.5 Conclusion

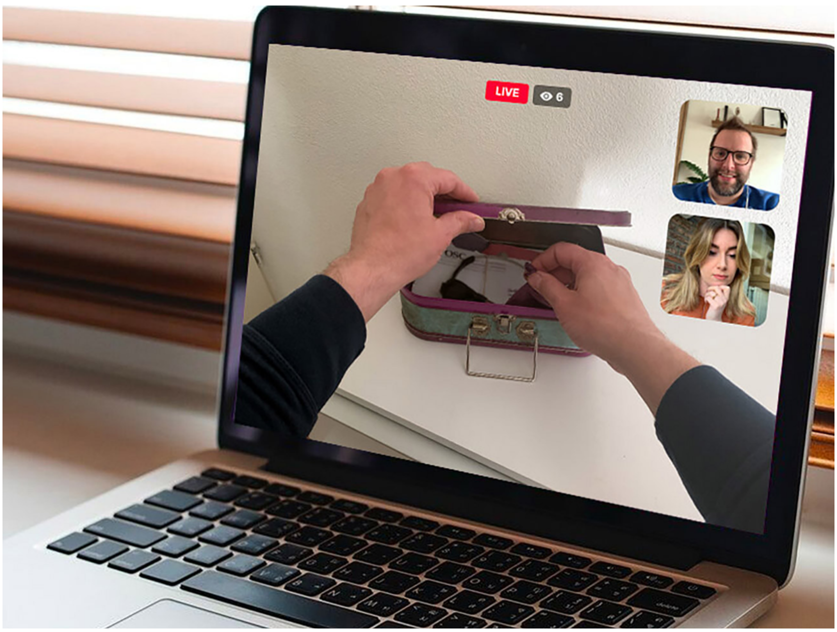
In this study on an escape game for immunology, we used an educational game design framework for escape rooms, focusing on the three main challenges, the participants' transition to the game world, the alignment of game design aspects and educational aspects in the game world, and the transfer from attained experiences and knowledge within the game world back into the real world. This framework led to research the important design elements related to each of these challenges: immersion, collaboration, and debriefing. The appreciation of the activity correlates positively with the scores of each of the design elements and the actual knowledge gain after the gameplay. Although students' collaboration was successfully fostered, with 76% of the time spent on the content knowledge, it scarcely led to collaborative learning during gameplay, due to lack of discussion and reflection needed for deeper understanding, the so-called reflection-in-action (Lavoué et al., 2015).

Based on the results, most accountable for the knowledge gain during gameplay is immersion, scaffolded by the roles and boxes, resulting in a constant focus on tasks. Based on current data it might be possible that immersion is a threshold element of the learning process, fostering mostly individual learning during gameplay, but not unlimited. More immersion in the game leads only to higher game scores, but not to higher science learning outcomes (Cheng et al., 2015). In addition, we found that the roles fostered task allocation and collaboration in the regular school, but not in the collaborative learning-based school.

In educational game frameworks on immersion, as they are based on digital game research, the notion of escape boxes to scaffold collaboration or physical objects fostering immersion is lacking. In addition, the use of sound in escape games in a classroom seems overrated. We advise adapting game experience questionnaires on these forementioned aspects for physical or hybrid educational games. Finally, the educational escape game framework would help educators and researchers develop and evaluate escape games in science education, creating immersive games which not only confront learners with science-related real-world contexts or socio-scientific issues but also give learning gains.

Chapter 5

The state of escape
General conclusions, reflections, and recommendations



5.1 The educational potential of educational science escape rooms

The main motive to start this research project was academic curiosity regarding the spontaneous phenomenon of escape rooms in education. This was initiated by teachers investing a lot of time and effort on its development and implementation. This led to two research aims that were addressed in four studies presented in Chapters 1 to 4. The chapter numbers correspond with numbers of the study.

The first aim was to explore this phenomenon, characterise it, and unravel the educational potential of escape rooms for secondary science education. The second aim was to develop guidelines for an adequate design of escape rooms in secondary science education.

In the four studies, with varying research designs and methods, the following two overarching research questions were leading:

1. What is the educational potential of escape rooms for secondary science education?
2. What are adequate principles and guidelines for designing and implementing escape rooms in secondary science education?

In the first two studies, Chapter 1 and 2, we explored what secondary science education could gain by employing escape rooms. The goal of the first study was to get insight in the educational potential according to Dutch teachers and secondary students. For this we surveyed and interviewed students and teachers who participated in a nation-wide escape room challenge. The second study had a broader scope. The goal was to get insights in common practices and considerations on the development and implementation of educational escape rooms on an international scale. We approached this by performing a systematic review study.

In Chapter 1, we used a phenomenological approach and triangulation of several data sources to describe 1) how teachers and students experience escape rooms, 2) what their perceptions are of the usability of escape rooms for science education in terms of goals and learning outcomes, and 3) what they experience or foresee as boundary conditions and barriers for teachers in implementing escape rooms in their classroom. In total 270 Dutch lower secondary science students and 50 teachers were involved, participating in the same biology escape room. In the second study we broadened our scope. Chapter 2 we reviewed 39 publications on physical escape rooms developed all over the world. Common practices and theoretical considerations regarding specific educational and game design aspects were synthesized. Thereafter, the relations between educational and game design aspects were studied. Finally, it was determined to what extent the educational goals of the educational escape rooms were achieved.

5.1.1 Exploration and characterisation

Results from Chapters 1 and 2 show that escape rooms as a science learning environment appeal to teachers of diverse types of educational institutions, disciplines, ages, gender, and teaching experiences. The teachers, early adopters and beyond, appreciated the diversity of content-based activities, the need for multiple skills related to the content knowledge, the need for general skills like communication and collaboration skills, and the high engagement of the students. The opportunity to implement these activities in authentic science contexts, makes the activity more meaningful for science teachers.

Student engagement in escape rooms comprises of cognitive, behavioural and affective engagement (Chapter 1). Addressing all types of engagement is rare for school activities in general (Fredricks et al., 2004), but seem more common in serious games (Hookham & Nesbitt, 2019). The different types of engagement relate to different aspects of academic achievement: willingness to do work, prevention of dropping out, development of basic skills and deeper understanding of knowledge (Fredricks et al., 2004). This strengthens the educational potential of escape rooms and makes them more interesting for teachers.

In addition, no gender differences in the engagement or appreciation of escape rooms were found, unlike some other types of educational games (Kinzie & Joseph, 2008). The most appreciated aspects were diversity of puzzles with a problem-solving and discovery nature, the need for physical objects and cooperation (Chapter 1). Physical objects (props), such as vaults, locks, codes, black light etc. were associated with the game-like character and challenges of escape rooms. Surprisingly, also non-functional props were mentioned. The props were non-functional in relation to solving the content-based puzzles. This made us sensible for the power of immersive physical elements in an educational environment. The above mentioned most appreciated aspects of escape rooms are characteristics of exploratory and problem-based play (Kinzie & Joseph, 2008). Kinzie and Joseph (2008) showed that in order to attract all gender in the underlying science content and skills, educational games need to use both types of play.

In addition, students appreciated the feeling of autonomy, ownership and mastery during gameplay. The students' perceived feeling of autonomy and mastery during the gameplay is interesting, as an escape room setup is very strict. It has few degrees of freedom, due to its common design involving codes and locks. In this respect, the escape room is an example of Trninic's proposed integration of guided repetition and discovery by students (Trninic, 2018), with the opportunity to scaffold learning processes without losing the students' feeling of ownership, discovery and victory.

With respect to learning goals, both studies seem to indicate that escape rooms are mostly suitable for fostering, rehearsing and formative assessment of content knowledge and skills, while using communication and teamwork skills. In relation to escape rooms that aimed at acquiring new content knowledge, the conclusions of both studies were similar. Escape rooms can create interest and wonder, however, for deeper understanding of new topics additional instruction is required (Giang et al., 2018; Mills & King, 2019; Vörös & Sárközi, 2017). Student interviews in Chapter 1 suggest why, as students pointed out that acquisition of knowledge calls for tranquillity and reflection. Science teachers reasoned that development of science knowledge comprises understanding of concepts and carefully relating these concepts (conform e.g., Wardekker, 1998). Acquiring unknown knowledge in an unstructured environment, with uncertainties about what to do and how to proceed, seems to ask too much from most students.

In the science escape room in Chapter 1, students felt mutually dependent, more than in other teamwork activities. This was due to the time constraints and the diversity of the puzzles that need to be done at the same time. Based on Chapter 1 and 2, we conclude that, with a design creating mutual dependency (see Section 5.2), teamwork is conditional to finish an escape room in time. An escape room might be a suitable environment to foster communication and collaboration skills, if initial instructions, coaching and debriefing are provided, as shown in a study by Seto (2018).

Students experienced ‘the need to think hard’ using multiple thinking skills (Chapter 1). What were the learning outcomes on content knowledge after playing and educational escape room? Unfortunately, review studies on educational escape rooms showed that systematic testing of learning goals is usually absent or showed disputable or no gain (Fortaris & Mastoras, 2019; Chapter 2). Both studies, Chapter 1 and 2, show discrepancy in perceived and actual learning of content knowledge by students. The discrepancy is in line with other findings in pioneer studies on educational games (Garris et al., 2002), practical work (Abrahams & Millar, 2008) and inquiry-based science instruction (Minner et al., 2010). These studies have similar conclusions: with active linking of knowledge during the intervention and reflection afterwards, the interventions will be more effective in fostering content knowledge.

5.1.2 The educational niche and potential of escape rooms

With escape rooms, science teachers can create authentic science environments with meaningful activities requiring students’ content knowledge and related skills. The team-based activities usually have an overarching goal which need to be achieved in a limited time. For education, each of the characteristics is not unique on its own. The combination, however, seems unique and appealing for science teachers.

Based on the studies in Chapters 1 and 2, we argue that educational potential of the escape rooms consists of various aspects. The authentic science contexts give logic and meaning to the content knowledge and skills, especially when the content knowledge is considered abstract by students. In addition, students can immerse in fictional realities, such as outer world contexts which are out of reach or potentially dangerous. In an escape room there is room for experiment and failure, with immediate feedback. The diverse content-based activities stimulate diverse forms of talents. Escape rooms create feelings of mastery, ownership, and mutual dependence, resulting in high student engagement (regardless of age or gender). The engagement is cognitive, behavioural and affective.

This description of the niche and educational potential of escape rooms might picture you a magical maze where no teacher is needed. However, the teachers’ role during the gameplay is diverse and delicate; too much or the lack of guidance appears to disrupt the students’ feeling of immersion and autonomy (Chapter 2). Beside guiding, teachers monitor the safety, the equipment, students’ progression and some teachers also assess students’ skills. In none of the reviewed studies in Chapter 2, nor any other studies, indications were found that students felt less immersed when the teacher was physically in the same room. Though in some escape rooms teachers played a role in the narrative enhancing the immersion. The teacher’s role after the escape room, during the debriefing appears crucial in students’ learning, as Chapter 4 shows. The described teacher roles in escape rooms are similar to the teacher’s pedagogical activities as synthesized in a systematic review of educational games (Kangas et al., 2017).

To unlock the escape rooms’ full potential as a learning activity, the game requires an adequate design with debriefing afterwards.

5.2 A design for escape rooms in secondary science education

This section starts with results and reflections in relation to the second overarching question on a design for escape rooms in science education. Then practical recommendations and guidelines on designing and implementing educational escape rooms will follow.

This section is based on the Chapters 2 to 4. In relation to Chapter 2, this section only focusses on the synthesized common practices and theoretical considerations regarding specific educational and game design aspects of educational escape rooms. Chapter 3 describes design-based research on the adaptation of the escape room concept to education. In three design cycles in co-participation with students, it resulted in a proof of concept. In the fourth and last study, Chapter 4, an escape game is evaluated. The escape game was developed based on previous studies and a design approach for educational escape rooms (Veldkamp et al., 2021b[1]). In addition, we studied how educational game design elements immersion, collaboration and debriefing influenced the learning process. A total of 126 upper-secondary science students and five science teachers were involved in the pre-test/post-tests, experience questionnaires, interviews and classroom observations.

5.2.1 Research and design challenges

Teachers develop their escape rooms inspired by escape video games, and/or their experiences in recreational escape rooms (Chapter 2). We analysed the relations between the common practices in educational and game design elements. Apparently, the function of an escape room in the learning trajectory and the specific learning goals appears to be decisive for its design. For example, sequential puzzle pathways were implemented when learning goals comprised a sequential process which students had to follow, or when students needed to be assessed individually. Path-based and specific hybrid structures were implemented ensuring that all participants are active and interdependent, to scaffold active and collaborative learning. An exemption were medical escape rooms in relation to the used puzzle path. These pathways were all sequential, assumingly based on the practice in simulation-based medical education (Anderson et al., 2021). However, their evaluations of medical escape rooms only mention that not all students were active, collaborative and/or felt needed.

Escape rooms with learning goals solely on introducing a subject, general skills or affective goals, are all stand-alone activities. Escape rooms that are intended to foster content knowledge and related skills are embedded in a course curriculum, usually positioned in addition to lectures. Escape rooms with formative assessment goals are positioned either mid-term or just before the final exams. Whether or not students are assessed during game play has consequences for the role and amount of staff, the group size of students, and the (fair) delivery of hints. The use of hint systems prevailed more in escape rooms with an assessment goal. In science escape rooms, the implementation of technology is often related to the learning goals. Technology is also used to monitor safety and progression, to support narrative and enhance immersion and mostly to structure the gameplay by verifying answers and unfolding the narrative with new puzzles. Technology gives teachers the possibility to scale up for large enrolment. The playtime with a median and mean of 60 minutes, appeared independent of any studied aspect. The playtime seems more determined by available time slots and the assumed practice in recreational escape rooms.

1 This article is provided in the Appendix of this book.

We also studied the considerations on choices made in relation to specific educational and game design aspects (Chapter 2). When these considerations are mentioned, they refer to theories on collaborative learning, game-based learning or game theories, to common practices in recreational escape rooms and /or seem based on classroom practice, such as in simulation-based medical education. The students' supposed feeling of immersion and autonomy is regularly mentioned in these considerations.

The outcomes of the review study showed that teachers decisions on escape room design are a complex of set of interrelations, which need to be aligned in order to achieve the desired students' behaviour and outcomes. While interpretating the data, we used an educational design framework describing crucial alignments, between game goal, learning goal(s), pedagogical approach and game mechanics (Van der Linden et al., 2019). It emphasizes that the learning goal should be leading in the design of an educational game and it needs to be ensured that the game goal can only be reached when the desired learning goal is reached. Additionally, a learning goal can only be achieved when supported with an adequate pedagogical approach, and the game goal by adequate game mechanics. Van der Linden et al. (2019) showed that during the iterations of the design process the focus should be on aligning the pedagogical approach with the game mechanics, as it appears the most essential and difficult step, which was confirmed by our systematic review.

Chapter 3 describes our own exploration of the adaptation of the escape room concept into escape rooms for science classes. We started with outlining the differences between recreational and educational escape rooms, ensuing boundary conditions for educational escape rooms, partly derived from Chapter 1. The boundary conditions resulted in the following design criteria: align learning goals and puzzles, ensure active participation within teams, create confined learning spaces within the larger room, enable fast and easy handling of escape game, develop sustainable materials, foster immersion within the class context, foster autonomy. In three design cycles, in co-participation with respectively secondary students, undergraduate and graduate students, so-called escape boxes were developed: a proof-of-concept. The technology-enhanced boxes can be reused for various subjects due to the adaptable fronts and separate reusable content. 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 organisation and discussions. However, the resulting escape boxes appeared to be unique and innovative compared to current educational escape rooms. In total 134 secondary students evaluated the escape box games, apart from the numerous play testers with different expertise.

The escape boxes succeed in putting learners in direct contact with each other, stimulating them to collaborate in a physical world as a result of the shape of the boxes and the organisation and design of the puzzles. The puzzles required combining information uncovered by different subgroups and were developed so that learners recognised the knowledge and skills needed to solve the puzzles. Structuring of the escape 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 for all students appeared complex.

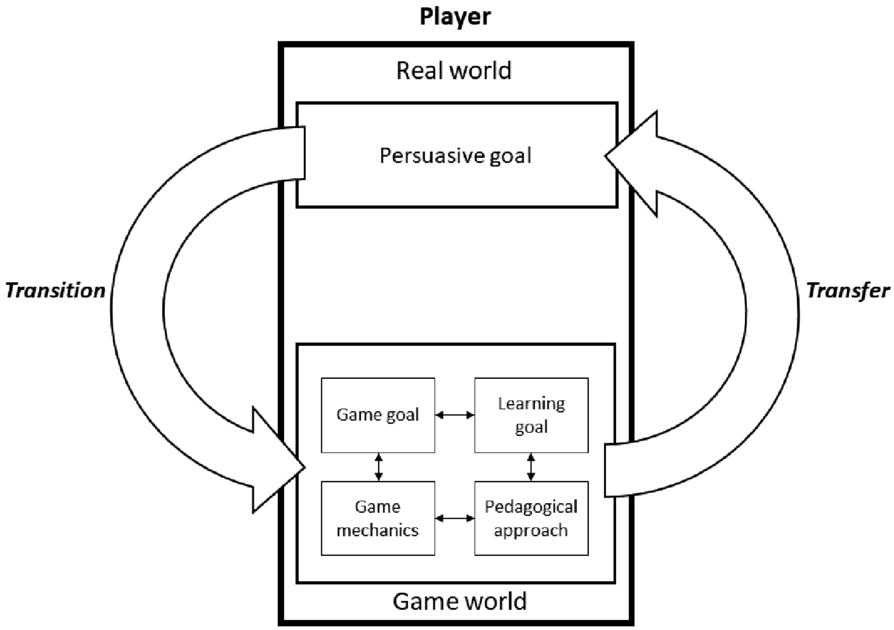


Figure 5.1 An educational game design framework for escape rooms, focussing on the three main challenges 1) the participants' transition from the real world to the game world, 2) the alignment of game design aspects and educational aspects in the game world, and 3) the transfer from attained experiences and knowledge within the game world back into the real world (Veldkamp et al., 2021b).

A follow-up study was grounded in an educational game design framework for escape rooms which was developed in the meantime (Veldkamp et al., 2021b). The framework acknowledges three challenges in relation to the design process of educational escape rooms: 1) the participants' transition from the real world to the game world; 2) the alignment of game design aspects and educational aspects in the game world; and 3) the transfer from experiences and knowledge obtained within the game world back into the real world, see Figure 5.1.

In secondary education, the students' transit from the science class into the game world, is not as voluntary as in a recreational game. To persuade students, immersion is important. Immersion is the process where someone is lured into a story or problem (Douglas & Hargadon, 2001), gets engaged, solves challenges, and finishes the game (Hamari et al., 2016). Immersion correlates with improved learning outcomes in science game-based learning (Cheng et al., 2015). To improve transfer of the acquired knowledge and skills from the game world to the real world, a debriefing on the experience and the decontextualization of content knowledge is needed (Sanchez & Plumattez, 2018).

Chapter 4 describes to which extent the game design elements immersion, collaboration, and debriefing foster learning in educational escape rooms. We focussed on immersion and debriefing as these are related to design challenges, as described above. As collaborative learning is said to be the pedagogical approach in learning with an escape room, we focused also on collaboration during the escape game.

A total of 126 upper-secondary science students and five science teachers were involved in the pre-test/post-tests, experience questionnaires, interviews, and classroom observations.

Correlational analysis indicated that the appreciation of the activity varies positively with the appreciation of each of the game design elements. This indicates that the appreciation does not depend on one of the design elements, but that all elements contribute. Based on the results, most accountable for the knowledge gain during gameplay is immersion, mainly created by the roles and boxes, resulting in a constant focus on the tasks. Cheng et al. (2015) showed that immersion correlates with improved learning outcomes in science game-based learning. In addition, they concluded that more immersion in the game leads only to higher game scores, but not to higher learning outcomes. Thus, it might be possible that immersion is a threshold element of the learning process, fostering mostly individual learning during gameplay, but not unlimited. In addition, we found that the immersive element of students having a role in the narrative also fostered task allocation and collaboration in the regular school, but not in the collaborative learning-based school. As discussed in Section 5.1, although collaboration was successfully fostered by the design, it scarcely led to collaborative learning during gameplay.

With a summary of the outcomes on debriefing, we will conclude this section. As concluded in Chapter 1, the time pressure during the gameplay urges the need for a thorough reflection on the content knowledge afterwards. In Chapter 2, we researched the debriefs in the reviewed escape rooms. Only half of the studies mentioned a debrief after the gameplay. The debriefs varied in components and duration (5-120 min.), due to the assigned educational value of debriefing. The mentioned components cover the elements of Lederman's model on debriefing as a systematic evaluation of theory and practice (Sanchez & Plumattez, 2018). We used Lederman's model as described by Sanchez and Plumattez (2018) to structure the debrief for the escape box activity in Chapter 4. This worked well for teachers and students. To keep the debrief interesting for all, some students suggested to extent the debrief with added information. This extension of knowledge was also practiced in some reviewed studies (Chapter 2) and is an extension of Lederman's model (1992).

5.2.2 Principles and guidelines for designing science escape rooms

The following guidelines are based on the studies 2-4 and the educational game design framework for escape rooms, focussing on the three main challenges in designing escape rooms: 1) the participants' transition from the real world to the game world, 2) the alignment of game design aspects and educational aspects in the game world, and 3) the transfer from attained experiences and knowledge within the game world back into the real world (Veldkamp et al., 2021b). The principles and guidelines are categorized in: the design of the activity, the process, and the organisation in the class.

The design of the escape activity

Dare to 'leave' the room. When adapting escape rooms for whole classes at the same time, the option of abandoning the 'room' aspect of escape rooms is worth considering. Options are to create station-based tasks in more rooms, or to use one box that includes all puzzles and equipment for each team. The implementation of freely available technology can structure puzzle paths, validate answers linked to unlocking new information, present pre-set hints for teams lagging, and enhance immersion in and out of the classroom context.

Create alignment. We recommend aligning of learning goals, game goal, pedagogy, and game mechanics in the design of educational escape rooms (see Figure 5.1). When choosing pedagogical approaches in support of the learning goals, alignment with game aspects, such as puzzle structure, type of puzzles and team size, is important to achieve the educational goals. When choosing approaches such as team-based or collaborative learning, an aligned puzzle structure can be path-based or hybrid, creating interdependence between the players. When using a hybrid structure, a degree of linearity is advised, as it will help guide the players and it is easier to monitor for staff. Individual puzzles can also create mutual interdependence when various skills are required or when information is divided amongst players.

Strive for high success rates. To increase the students' learning experiences and achieve the learning goals embedded in all puzzles, strive for a high success rate, by adjusting and testing for an adequate level of difficulty of the puzzles in the escape room.

Allow all groups to finish the escape game. It was observed that the escape game and thereby the learning process during gameplay stopped for all students once the first team opens the only end vault. Offering an end goal or vault for every team can tackle this problem. Thus, the teams play against time, and not against each other.

Design the role of the teacher. Teachers and staff have a better view on the players' behaviour guiding in the same room than with monitoring from an adjacent room. The players' immersion seems not to suffer from the presence or intervention of staff balancing the need of students and their feelings of immersion and autonomy. Consequently, the organisation of monitoring devices is not needed and the game organisation less complicated. The role of the teacher and staff during the gameplay is delicate and challenging as students' immersion and feeling of autonomy can be disrupted. Giving the teachers and staff a role in the narrative in which they can be questioned by the students, might prevent this.

Design specific for grading. When players are assessed on performance during gameplay, small team sizes (4-5 players) and a sequential puzzle path are recommended. Let who are graded (teams or individuals) and what is graded (solely the gameplay or the preparation and/or reflection of the student) be decided in relation to the intended learning goals. The precautionary measure to grade students to activate them, seems unnecessary as participants of all ages are highly engaged by the escape rooms as learning activity. The need for grading to prevent teams exchanging codes or answers might be related to the age of the target group.

Consider hybrid learning spaces. Hybrid learning spaces can foster immersion and so the learners' transfer from the school context to the game context, preferably using real world science related scenarios.

Guidelines for the design process

Co-create. Co-creating the escape game with the target group is advisable, by making them member of the design team. Gamers among them can add their expertise on game design, game mechanics and narrative structure.

Start from scratch. Starting with well-defined educational boundary conditions for the specific educational situation, will result in specific design criteria. The design criteria combined with a serious game design framework (like Figure 5.1), used in design-based research, will lead to a protype more adequate meeting the specific students' needs.

Playtest from different perspectives. Plan a series of playtests with multiple perspectives important in educational game design: learner, gamer, and educator, and, if involved in the project, stakeholders.

Guidelines for the implementation in the classroom

Heterogenous teams. As the activity usually asks for multiple talents and skills, heterogenous groups are preferable. In addition, as escape rooms ask an escape-room-way of logic and thinking, it is advisable that at least one team member has experiences with escape rooms.

Implement a debrief. The implementation of a debrief is advised with components such as questions of participants, discussion of puzzles and the content knowledge needed to solve the puzzles and relating them to learning goals, extension of information, feedback on performances, reflection on learning process and goals for the future (Chapter 2). The components are conform Lederman's components of a debriefing (1992), with addition of the component 'extension of information'. To finish an escape room in time, teamwork and communication skills are conditional. When fostering of teamwork and communication skills is a goal of the escape room, a specific debrief or an escape room solely on these social skills is advised, as reflection on these goals is usually lost in a reflection on other educational goals.

5.3 Claims on educational escape rooms

In this section, we look at claims for educational escape rooms considering the outcomes of our four studies.

Claim 1. Educational escape rooms foster the four C's

> *"A major theme in current education is called the Four C's: Critical Thinking and Problem Solving; Communication; Collaboration; Creativity and Innovation. An Escape Room encapsulates all four of these skills into one activity that will engage even the most reluctant learners." (Hourglass escapes, 2021).*
>
> *"Our games help students practice 4C [….] while working together to solve academic puzzles." (Breakout EDU, 2021).*

The educational aims and conclusions in the reviewed studied of Chapter 2, align with the quotes. To summarize the claims, in educational escape rooms students work actively together on a diversity of content-based puzzles, triggered in diverse ways and intrinsically motivated, while developing the four C's: *communication, collaboration, critical thinking,* and *creativity*.

All studies presented in this PhD thesis confirm that students worked together on a diversity of content-based puzzles. Students were triggered in diverse ways, felt cognitively, behaviourally, and affectively engaged and described using different thinking skills. We have a problem with the assumed increased intrinsic motivation of the students. This assumption was stated in many reviewed studies too (Chapter 2), although it was not systematically researched. In Chapter 1, none of the interviewed students named (increasing) motivation as a goal for using escape rooms in the classroom, and only two percent of the students used it as an argument to participate in future escape rooms. Literature on serious gaming (Van der Linden et al., 2019) and educational escape rooms (Frenzel, Cernusca, Marg, Schotters & Eukel, 2020) showed that students are more externally motivated by game aspects such as winning or the prize, than intrinsically by the content knowledge, i.e., most students are more driven by the game goal than the educational goal(s). In Section 5.2, this tension field in serious games and the consequence for designing educational games is addressed more in depth.

As argued in Section 5.1.1, an escape room might be a suitable environment to enhance communication and collaboration skills, if initial instructions, coaching, and debriefing are provided on these skills.

In the reviewed studies (Chapter 2), a lot of the used escape rooms were developed to foster critical thinking, although it was not systematically investigated, nor in our own studies. However, students in Chapter 1 repeatedly mentioned spontaneously the need to think critically during gameplay.

The assumed development of creativity needs to be defined in more detail. The creativity needed in escape rooms is the creativity to find the teachers' programmed answers. Students called this 'using an escape room-way of thinking' (Chapter 1). The question is to which extent this way of thinking relates to creativity, or the creative thinking needed to solve (open-ended) science problems?

Claim 2. Collaborative learning drives the learning processes during gameplay

Our systematic review (Chapter 2) shows that in medical escape rooms, the required collaboration and communication skills are part of professional skills students need to develop. For STEM escape rooms, teachers link these skills to the collaborative learning they want to foster. In the reviewed studies on educational escape rooms, collaboration and collaborative learning are mentioned in the same breath. The assumption is that the team-based game supports collaboration and automatically collaborative learning (Arnal et al., 2019; Gordon, 2017; Brady & Andersen, 2019; Peleg et al., 2019; Vergne, Simmons, & Bowen, 2019; Wu et al., 2018). In collaborative learning environments learners are engaged; working together to formulate questions, discuss ideas, explore solutions, complete tasks, and reflect on them (Srinivas, 2011; Kozlov & Groβe, 2016). Learners interact to reach a shared goal (Dillenbourg, 1999). Escape rooms meet the terms for collaborative learning, as essential elements in collaborative learning are positive goal interdependence, complementary roles, dividing information or other resources and constructive competition (Johnson & Johnson, 2009). In Chapter 4, our developed escape game, successfully fostered collaboration and scaffolded collaborative learning processes. However, based on the triangulated data, we concluded that collaborative learning hardly occurred during gameplay. The environment needs to provide students with the opportunity to discuss and to bear responsibility for their learning and participation (Laal & Laal, 2012; Yücel & Usluel, 2016). In an educational escape room, the time for discussion and reflection needed for deeper understanding of the science content seems to lack (Abrahams & Millar, 2008; Garris et al., 2002; Minner et al., 2010).

Time appears to be an ambiguous factor in science learning during the escape room gameplay (Chapter 1 and 4). Mijal et al. (2021) observed the same problem in their escape room. On one hand, it gives urgence to players' thinking, acting, and creates mutual dependency. On the other hand, it limits 'learning by explaining' and time to reflect on the content, the so-called reflection-in-action. The consequence is that reflection-on-action afterwards becomes crucial for learning with an escape room activity (Lavoué et al., 2015; Schön, 1983)

5.4 Implications and future directions of research

In this section, we discuss the practical and scientific implications of the studies, limitations, and the implications for the future research agenda.

5.4.1 Implications & future research

For the emerging research field of educational escape rooms, we defined the educational potential and niche of educational escape rooms, based on two distinct types of research (Chapters 1 and 2). As a side effect, some claims or assumptions were unintentionally demythologized, as described in Section 5.3. The systematic review (Chapter 2) gives an overview over common practices, and theoretical considerations that can be very useful for teachers, who can avoid reinventing the wheel in their own escape room design. In addition, it shows important alignments in educational and game design elements. These alignments are not only important in designing escape rooms, but they might direct future research on educational escape rooms. Study 3 provides an elaborate description of differences in recreational and educational escape rooms, the resulting boundary conditions, and the design principles for educational escape rooms. Together with the guidelines derived from Study 2, they have informed and have already been used by other teachers and researchers (e.g., Botturi & Babazadeh, 2020; Lathwesen & Belova, 2021; Moffett, 2021).

In our design of an escape room (Chapter 4), we derived guidelines from the theories on collaborative learning to design aligned game mechanics. Our research shows that successful scaffolding of teamwork does not automatically lead to collaborative learning. The game mechanics of time restriction prevents thorough discussion and reflection on the content. It would be interesting to explore alternatives in the design of the escape room which give room for reflection during gameplay and still ensures social dependence and urgency to achieve the (game) goal.

Frameworks used in game research and related experience questionnaires are mostly based on virtual games. Consequently, physical objects and props fostering immersion are lacking. When researchers use these frameworks for physical or hybrid escape rooms, they need to take this into account and design the interactions with the physical environment.

The limitations of Chapter 4, on testing content knowledge gain on lower Bloom levels and not testing sustained learning of content knowledge and content related skills, could be considered in longitudinal studies. In relation to higher order Bloom levels, the question need to be answered what sort of creativity is fostered in escape rooms and to which extent it relates to the creative thinking needed to solve open-ended science problems?

Another important focus of further research could be the balance between the teachers' scaffolding and students' feeling of mastery and ownership, which might lead to more guidelines for teachers and the prevention of students dropping out during gameplay. In relation to these aspects, the possibilities of pre-set hints in combination with teachers with a role in the narrative could be more systematically investigated.

Research designs other than case studies are rare at the time of this publication (Taraldsen et al., 2020). Some researchers plead for large randomised controlled trials to test for effectivity of educational escape rooms in medicine (Taraldsen et al., 2020). For secondary science education large randomised controlled trials (RCTs) with physical or hybrid escape rooms do not seem to be realistic. The reason is that, based on our research, debriefing is an essential part of an educational escape room. Because there may be a large variation in the way teachers perform the debriefing, a controlled experiment is not feasible. Moreover, large randomised controlled trials with physical or hybrid escape rooms are logistically complicated in secondary education.

In addition to future research, the research literature on educational escape rooms is scattered in the various subject disciplines, the field of (educational) game research, educational technology, and educational studies. It would advance the research on escape rooms to learn each other's terminology, theoretical background and appreciate its merits. This is needed as designing an educational escape game appears complex and asks for the co-participation of a multi-perspective team (Chapter 3).

5.5 The rise and fall of educational escape rooms?

5.5.1 Escape rooms: adaptive learning environments

At the start of the lockdown due to Covid-19, the tentative title for this dissertation was: No Escape: the rise and fall of educational escape rooms. However, the lockdown seemingly had no effect on publications on the topic of escape rooms in education. Two journals, Well Played and Simulation & Gaming, even dedicated a special issue to the topic. Partly, this is a lagged effect of pre-corona research, partly educators changed their projects on escape rooms to virtual ones (Ang et al., 2020; Bubar et al., 2021; Smith & Davis, 2021; Vestal, Matthias, & Thompson, 2021). Just before the lockdown, the trend in educational escape rooms was upscaling an escape room for a whole class to play at the same time using technology or technology enhanced escape boxes (Blankenship et al., 2021; Chapter 3; Shvalb & Harshoshanim, 2020; Strippel et al., 2021).

Technology was mostly implemented to structure the escape game (Chapter2). In addition, it is used to validate answers (Ross, 2019; López-Pernas et al., 2019), to supply pre-set hints (Chapter 3; López-Pernas et al., 2019), and can be used to immerse students in outside world science contexts which are out of reach or potentially dangerous (Cheng & Annetta, 2012). Covid-19 and the lockdown that followed, have boosted the development of virtual escape rooms in education (Ang, Ng, & Liew, 2020; Lópes-Pernaz, 2021b). Educators continue to adapt the escape room concept to new educational situations using available technology. In relation to the motive of avoiding danger and to enhance the playability outside traditional classroom contexts, it would be interesting to further investigate the augmented reality and virtual reality (AR/VR) possibilities for science escape rooms. The first case studies using these technologies in (science education) escape rooms seem promising (Bubar et al., 2021; Estudante & Dietrich, 2020; Janonis et al., 2020; Mystakidis, Cachafeiro, & Hatzilygeroudis, 2019; McFadden, & Porter, 2018; Zeng et al., 2020).

5.5.2 Virtual versus physical escape rooms

As discussed in 5.5.1, the pandemic has boosted the development of virtual escape rooms in education (Ang et al., 2020; Lópes-Pernaz, 2021b). In a systematic review on escape rooms in STEM education, one out of ten studies is on virtual escape rooms (Lathwesen & Belova, 2021). For the first half of 2021, this proportion raised to a quarter of the studies reviewed. Unfortunately, the review did not distinguish between these two types of escape rooms in relation to the researched aspects. In the next section, virtual and physical escape rooms will be compared in relation to aspects science teachers appreciate or strive for in relation to escape rooms:

- the need for collaboration
- activities combining content knowledge and content related skills
- the use of authentic science contexts
- implementation on a large scale
- using learning analytics

The need for collaboration

Teachers appreciated the students need for collaboration. In physical escape rooms, students have face-to-face contact. Virtual escape rooms can be played when teams work together on one or more devices in the same room or remotely when students are separated in space. In a comparative study with physical and virtual versions of the same escape game, the virtual version was experienced more stressful and difficult by students. In addition, the remote collaboration, as well as the remote tutoring, was experienced more challenging than in the physical escape room (López-Pernas et al., 2021b).

Activities combining content knowledge and content related skills

Science teachers appreciated the diversity of activities combining content knowledge and content related skills; i.e., thinking skills and/or manual skills (Chapter 1). In research and projects on simulation labs (e.g., Janonis et al., 2020), fostering manual skills is not the goal, but thinking skills. Manual skills are difficult to simulate in virtual environments, using controllers or computer mouses instead of lab equipment.

The use of authentic science contexts

The opportunity to foster learning in authentic science contexts in escape rooms, was appreciated by science teachers. Chapter 3 discussed that the opportunities in classroom to create immersive realistic environments are limited. For escape room contexts which are not available in schools, the use of technology could create graphically more realistic settings or backgrounds. Pioneering teachers in primary or secondary education have developed virtual escape rooms using technology such as Google forms (Ang et al., 2020; Vergne et al., 2020; Vestal et al., 2021), Genial.Ly (Jiménez et al., 2020), QR codes (Huang et al., 2020), URL codes (van Helden, 2020) or Microsoft PowerPoint (Seghier, 2021; Verhoeven, 2021). Due to covid-19, Ang and colleagues (2020) transformed their physical escape room to a virtual one using Google Forms. Their results showed less engagement and motivation of students with the virtual escape room. In relation to these results, we have two considerations. Firstly, accessible technology for primary and secondary teachers in terms of skills and sources are limited in relation to the creation of immersive worlds. Here, educational organisations or research institutes might step in. Secondly, students are the actors and can become hero of the game narrative, as we have seen in Chapter 4. The connection between the student and the personage (avatar) he controls when playing, is stronger in physical escape rooms than in virtual escape rooms (Nicholson, 2016). In screen-based games, there is a separation between the avatar that exists inside the game world, and the control by the player in the real world. In physical escape games the player and the avatar are the same. According to Nicholson (2016), this unique connection is distinct for physical escape game genre. So, on the one hand, tasks with a sensory motoric component and available props could be experienced less realistic in virtual escape rooms. One the other hand, virtual escape rooms using advanced technology can create authentic science settings more graphically realistic compared to a classroom environment.

Implementation on a large scale

Chapter 1 shows that in relation to the organisation, short preparation and reset times are boundary conditions for teachers in implementing educational escape rooms. Advantages of virtual escape rooms are limitless scalability, and the limited preparation and reset time needed, once they have been developed. The teachers' lesson preparation time is limited (Collinson & Cook, 2001; Hargreaves, 1990) and the development of an escape game is time-consuming and one of the major hindrances for teachers (López-Pernas et al., 2021a).

Using learning analytics

Advanced technology such as Artificial Intelligence in escape rooms also has opportunities in using learning analytics in monitoring students' answers, which can be used during the game, for example in adapting hints and puzzles to the prior knowledge or progress of the learners (Menestrina & De Angeli, 2017; Zeng et al., 2020). After the game, the students' answers can be used during the debriefing.

To wrap up, virtual escape rooms for science education have organisational and logistic advantages when compared to physical escape rooms. In addition, there are possibilities for implementing learning analytics and graphically realistic science contexts. However, the changed user interface challenges the collaboration and tutoring during gameplay. In addition, fostering of content-related motoric skills is diminished. More research is needed on the several types of escape rooms and their advantages and disadvantages.

5.5.3 Educational escape rooms and the novelty factor

Escape rooms are a recent phenomenon in science education. Will the enthusiasm of students subdue when playing educational escape games more often? According to Frenzel et al. (2020), their perception data suggests a strong impact of their escape room beyond the novelty factor of the activity based on a student evaluation scale. However, we think that such a firm conclusion should be based on more data directly related to the aspect of novelty. There are indications that secondary science students do not easily get bored playing escape games instead of regular lessons. In Singapore, a secondary school has six escape room facilities within their school. The mathematics teachers adapt the rooms with the content-based tasks to new topics in the students' curriculum (Spectra, 2019). As students in Chapter 1 explained: the way of thinking in the game is the same, however, the content differs every time. In combination with the diversity of learning activities addressing different expertise and talents of students, we expect that educational escape rooms will stay part of teachers' repertoires. We hope that multidisciplinary teams of researchers in the various disciplines of education, educational technology, and game-based learning will find grounded ways to design and research educational escape rooms. As a good example, Guigon and colleagues (2019) developed a web tool to facilitate the development of educational puzzles. In addition, the open-source web platform of López-Pernas and colleagues (2021a) facilitates logistical and educational aspects, such as student registration and team formation, management of resources, gamification elements, progress monitoring, hint management and grading. These developments are promising as they ease the design and implementation of effective educational escape rooms in science education.

5.5.4 As time goes by…

Four years ago, I started this research trajectory out of curiosity why teachers adapted the escape room concept to the classroom and invested a lot of time and effort on its development and implementation. We used research designs and methods that were novel in the emerging research field. The developed technology-enhanced, adaptable, all-inclusive escape box was a novelty, and escape box became a new concept in literature. Further, a design framework focussing on the challenges in designing an educational escape game was developed and guidelines derived to develop science escape rooms fostering science learning without losing students' feeling of ownership, discovery, and victory.

The implementation of escape rooms in education was spontaneously initiated by teachers. Educational science escape rooms found a niche in creating authentic environments with meaningful activities requiring students' content knowledge, related skills and working in teams with time restrictions. Research on educational escape rooms has started and will continue as teachers want to finetune the concept to meet their aims and students' needs in learning science. The game is on! No escape!

Samenvatting in het Nederlands

Summary in Dutch

Samen NL

Samen NL

Motivatie en doelen

Een escaperoom is een interactief spel waarbij een groep mensen samen puzzels oplost om binnen een bepaalde tijd een specifiek doel te bereiken. De naam is ontleend aan de eerste games waarbij het doel een ontsnapping uit een kamer was (Nicholson, 2016). Tegenwoordig is er een enorme variatie in doelen zoals het ontmantelen van een bom, of het oplossen van een mysterie. Geïnspireerd door de escaperoom hype in de recreatieve sector gingen docenten escaperooms ontwikkelen voor hun leerlingen, vaak met als doel de lesstof in een aantrekkelijke vorm te presenteren. In de onderwijshistorie is het bijzonder dat dit wereldwijd gebeurde in alle sectoren van het onderwijs, primair onderwijs tot hoger onderwijs en zelfs voor professionele ontwikkeling van docenten (Fortaris & Mastoras, 2019). Daarbij verschenen de escaperooms *bottom-up*, dat wil zeggen door docenten zelf geïnitieerd, niet op instigatie van curricula, pedagogische centra of andere onderwijsondersteunende instituten.

Waarom besteden zoveel docenten zoveel tijd aan het ontwikkelen, uitvoeren en evalueren van deze activiteit? Vullen escaperooms een niche in het onderwijsrepertoire of is het een alternatief voor bepaalde werkvormen? En hoe ontwikkel en implementeer je als docent een escaperoom zodat leerlingen de leerdoelen halen?

Deze dissertatie beschrijft een onderzoekstraject naar educatieve escaperooms voor het bètaonderwijs. De centrale onderzoeksvragen zijn:

1. *Wat is de educatieve potentie van escaperooms voor bètavakken in het voortgezet onderwijs?*
2. *Wat zijn adequate principes en richtlijnen voor het ontwerpen en toepassen van escaperooms in de bètavakken van het voorgezet onderwijs?*

De onderzoeksvragen gaven aanleiding tot vier studies. In de eerste studie is de educatieve potentie van escaperooms voor het voortgezet bètaonderwijs onderzocht. Vervolgens is de gangbare praktijk van educatieve escaperooms geanalyseerd op belangrijke educatieve en game-ontwerpaspecten. In de derde studie stond het ontwerpen en evalueren van een educatieve escaperoom voor bètaonderwijs centraal: een *proof-of-concept*. In de laatste studie is onderzocht welke rol *immersion*, samenwerking en nabespreking hebben op het leren met behulp van een educatieve escaperoom. Immersion is het proces dat een lezer of speler in een game wordt gezogen of ondergedompeld (Douglas & Hargadon, 2001), betrokken raakt en de game wil afmaken (Hamari et al., 2016). Er is geen Nederlands woord dat immersion in één term adequaat vertaalt; daarom blijven we het hier gebruiken.

Studie 1: De educatieve potentie van escaperooms voor het bètaonderwijs in het voortgezet onderwijs

In de eerste studie (**Hoofdstuk 1**), werd vanuit een fenomenologisch perspectief (Creswell, 2013) de inzet van escaperooms in bètaonderwijs in het voortgezet onderwijs onderzocht. We wilden weten

- *hoe docenten en leerlingen de escaperoom als leeractiviteit ervaren,*
- *hoe zij de bruikbaarheid van escaperooms voor bètaonderwijs inschatten met betrekking tot onderwijsdoelen en de leeruitkomsten,*
- *welke voorwaarden en beperkingen docenten ervaren of voorzien met betrekking tot de implementatie van escaperooms in hun onderwijs.*

In deze studie is een *mixed-method* design gebruikt. Naast semigestructureerde interviews met 11 docenten, 68 leerlingen en observaties in 14 klassen, zijn vragenlijsten van 39 docenten en 202 leerlingen verwerkt en filmpjes die leerlingen uit 17 klassen over hun ervaringen maakten.

Het perspectief van docenten

Als onderwijsactiviteit spreken escaperooms bètadocenten van verschillende leeftijden, gender en onderwijservaring aan. Docenten zien betrokken leerlingen die met focus en enthousiasme aan het werk zijn. Voor docenten zijn de succesfactoren van escaperooms: de diversiteit aan op leerstof gebaseerde puzzels, toepassing van verschillende soorten kennis en vaardigheden, de noodzaak tot samenwerking, escaperoom-aspecten als competitie en de prijs. Bijna alle docenten gaven aan dat ze escaperooms geschikt vinden als onderwijsactiviteit voor leerlingen van alle leeftijden en schooltypen. De docenten vinden escaperooms het meest geschikt voor het ontwikkelen van samenwerkingsvaardigheden, het verwerken, oefenen en toetsen van domeinspecifieke lesstof en vaardigheden. Docenten waren sceptischer met betrekking tot het aanleren van nieuwe stof, omdat de daarvoor benodigde rust, reflectie en zorgvuldigheid met betrekking tot het relateren van belangrijke concepten ontbreekt.

Samen NL

Het perspectief van leerlingen

Met betrekking tot de bovengenoemde toepassingen kwamen de leerlingenpercepties overeen met die van docenten. Daarnaast waren leerlingen kritisch met betrekking tot de toetsmogelijkheden met behulp van escaperooms. Ze noemden daarbij o.a. de discrepantie tussen de oefen- en toetsomgeving en de wederzijdse afhankelijkheid binnen een team.

De meest gewaardeerde aspecten van een escaperoom voor leerlingen waren de diversiteit aan opdrachten waarbij vooral het probleemoplossend aspect, het *zelf* ontdekken, *zelf* uitzoeken en *zelf* oplossen werden vermeld. Ook hoog scoorden het samenwerken en de fysieke objecten. De door leerlingen genoemde aspecten zijn onderdeel van zgn. *exploratory* en *problem-based play* (Kinzie & Joseph, 2008). Kinzie en Joseph toonden aan dat beide soorten spel moeten worden toegepast om games in bètaonderwijs aantrekkelijk te maken voor alle genders. In onze onderzoeksresultaten zijn inderdaad geen genderverschillen geconstateerd.

In de getrianguleerde data doken twee onderwerpen voortdurend op waar niet naar gevraagd was: **samenwerking** en **betrokkenheid van leerlingen bij de activiteit** (*engagement*). Leerlingen bleken cognitief, gedragsmatig èn affectief betrokken in de escaperoom. Elk type betrokkenheid is op een andere manier gerelateerd aan leren (Fredricks et al., 2004). De review van Fredricks et al. (2004) laat zien dat onderwijsactiviteiten die *al* deze aspecten van betrokkenheid triggeren zeldzaam zijn. Dat educatieve escaperooms alle typen betrokkenheid kunnen triggeren maakt de activiteit voor docenten interessanter en versterkt de educatieve potentie.

Leerlingen ervoeren gedurende de escaperoom: eigenaarschap, autonomie en competentie. Dat leerlingen ervaren dat ze *zelf* ontdekken, *zelf* alles moeten uitzoeken en kennis ontwikkelen is interessant omdat een escaperoom qua opzet weinig of geen vrijheidsgraden kent. Hiermee lijkt een escaperoom een goed voorbeeld van Trninic's voorgestelde integratie van begeleide herhaling en vrijheid geven voor zelf ontdekken (Trninic, 2018).

Een escaperoom heeft een tijdslimiet. Deze beperking creëert volgens leerlingen een grotere sociale afhankelijkheid dan reguliere samenwerkingsopdrachten. Enerzijds geeft de tijdslimiet urgentie aan het handelen van de leerlingen, anderzijds beperkt de tijdslimiet het uitwisselen en uitleggen van domeinspecifieke kennis.

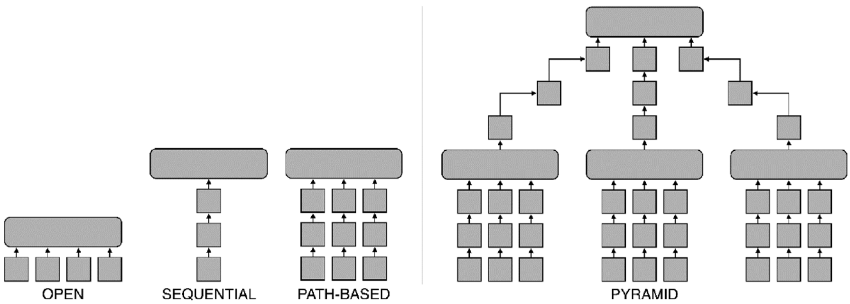
Tijd is ook het hoofdthema in barrières en voorwaarden die docenten noemen met betrekking tot het ontwikkelen en implementeren van escaperooms. Naast de genoemde beperking zijn de voorwaarden gelijk aan die voor elke onderwijsleeractiviteit (bijvoorbeeld voldoen aan het curriculum). Desondanks hadden 42 van de 50 docenten het voornemen om een escaperoom te implementeren. Acht docenten twijfelden, daarbij verwijzend naar hun beschikbare tijd voor ontwikkelen en implementeren van escape rooms.

Studie 2: De gangbare praktijk van educatieve escaperooms met betrekking tot ontwerpelementen en de toepassing in de klas

Hoofdstuk 2 beschrijft een reviewstudie naar adequate ontwerpprincipes en richtlijnen voor het ontwerpen en toepassen van escaperooms in de klas. Daarvoor is bij 39 escaperooms onderzocht hoe bepaalde educatieve aspecten, zoals leerdoelen en de rol van de docent, zijn ingevuld. Ook belangrijke game-ontwerpaspecten zijn onderzocht, zoals de typen puzzels en hun organisatie. Het in hoofdstuk 1 geschetste beeld met betrekking tot de educatieve potentie van escaperooms werd in de reviewstudie bevestigd en op één punt aangevuld. Bètadocenten kiezen voor hun escaperooms bijna altijd authentieke contexten, zodat de relevantie van de domeinspecifieke kennis zichtbaar en levendig wordt voor leerlingen.

Educatieve aspecten

De onderzochten escaperooms werden toegepast in voortgezet onderwijs, hoger onderwijs en voor de professionalisering van personeel. **De leerdoelen** van de onderzochte escaperooms beschreven domeinspecifieke kennis en vaardigheden en affectieve doelen in combinatie met algemene vaardigheden zoals communicatie en samenwerking. **De positie van de escaperoom in het leertraject** was verschillend afhankelijk van het doel van de docent met de escaperoom. De escaperooms werden in formele educatie geïmplementeerd aan de start van een nieuw onderwerp, na de theorielessen of voor het examen als een formatieve evaluatie. Bij formatieve evaluatie werden naast de prestatie ook de voorbereiding en/of reflectie van deelnemers beoordeeld, individueel of als team. **De docentrol** werd zeer verschillend ingevuld: monitoren en/of begeleiden en/of nabespreken. Reacties van leerlingen laten zien dat begeleiden gedurende de escaperoom een delicaat proces is. Interveniëren kan de immersion en het gevoel van autonomie van leerlingen bedreigen. Immersion en autonomie blijken ook leidend in de keuzes die docenten maken met betrekking tot ontwerpaspecten, zoals de aanwezigheid van begeleiders in de spelruimte, een rol voor begeleiders in het verhaal en het al dan niet verstrekken van hints. Slechts de helft van de escaperooms werd gevolgd door een nabespreking door de docent. De nabesprekingen verschilden met betrekking tot het aantal onderdelen, zoals het bespreken van vragen of reflectie op eigen leerproces. Alle genoemde onderdelen samen kwamen overeen met de geadviseerde onderdelen in het nabesprekingsmodel van Lederman (Lederman, 1992).



Figuur 6.1 Puzzelstructuren in escaperooms: a) basis structuren: open, lineair en path-based; b) een complexe, hybride structuur. De vierkanten symboliseren puzzels en de rechthoeken zijn meta-puzzels (aangepast van Nicholson, 2015)

Samen NL

Educatieve aspecten

De organisatie van de puzzels blijkt afhankelijk van de specifieke leerdoelen voor leerlingen en het doel van de docent met de escaperoom in het leertraject. Als de onderwijsinhoud lineair van aard is of leerlingen individueel beoordeeld moeten worden, is de puzzelstructuur lineair, zie Figuur 6.1. Als docenten noemen dat ze sociale afhankelijkheid of samenwerkend leren willen stimuleren dan is de gekozen puzzelstructuur *path-based*, of *hybride,* zie Figuur 6.1. Hiervoor blijkt **een groepsgrootte** van 4-6 personen het meest geschikt. De maximale **speeltijd** varieerde van 20-120 minuten, met een mediaan en modus van 60.

Tot slot is onderzocht met welk doel **technologie** wordt toegepast in escaperooms. Doelen zijn: monitoren, oefenen van gerelateerde leerdoelen, ondersteunen van het verhaal, verifiëren van antwoorden en ontsluiten van nieuwe puzzels en informatie. De technologische mogelijkheden met betrekking tot het verifiëren van antwoorden en ontsluiten van nieuwe puzzels en informatie, willen de docenten verder onderzoeken. Deze toepassingen kunnen namelijk het gevoel van autonomie en eigenaarschap van deelnemers vergroten. Daarnaast wordt het opschaling van een escaperoom voor een hele klas of cursus vergemakkelijkt.

Twee modellen voor het ontwerpen van educatieve escaperooms zijn van Clarke et al. (2017) en Guigon et al. (2018). De modellen geven een stap-voor-stap routeplan voor het ontwerpen van een escaperoom. Onze reviewstudie laat een complexer ontwerpproces zien waarbij de onderzochte elementen gerelateerd blijken te zijn. Alleen de game-ontwerp elementen **teamgrootte** en **maximale speeltijd** blijken onafhankelijk van de andere onderzochte elementen te worden bepaald.

In 36 van de 39 studies willen de docenten een escaperoom implementeren met als doelen 1) de exploratie van een activerende leeromgeving, 2) die de motivatie en betrokkenheid van studenten verhoogd, 3) vakspecifieke kennis en vaardigheden vergroot, 4) terwijl algemene vaardigheden, zoals communicatie en samenwerken, worden ontwikkeld.

De reviewstudie laat zien dat de doelen 1 en 2 bereikt kunnen worden met educatieve escaperooms. Met betrekking tot het derde doel, vergroting van de domeinspecifieke kennis en vaardigheden, was in alle studies een ruime meerderheid van de participanten positief over hun mogelijke leeruitkomsten. Helaas zijn de vakspecifieke vaardigheden niet of te beperkt systematisch onderzocht om deze percepties te kunnen bevestigen. Met betrekking tot cognitieve doelen zijn er vier studies die dit systematisch hebben onderzocht met voor- en nametingen en/of vergelijkend onderzoek. Slechts één studie laat een toename zien, die volgens ons ook op een andere manier verklaard kan worden. Met betrekking tot het ontwikkelen of bevorderen van communicatie en samenwerkingsvaardigheden, is er slechts één studie die dit doel voldoende systematisch heeft onderzocht en kan bevestigen (Seto, 2018). Hierbij is wel de voorwaarde dat docenten gedurende de escaperoom deze vaardigheden systematisch evalueren en nabespreken.

Studie 3: Het ontwerpen van een educatieve escaperoom voor bètaonderwijs: een *proof-of-concept*

Hoofdstuk 3 beschrijft op welke manier het escaperoomconcept kan worden aangepast en toegepast in het voortgezet onderwijs**.** Als eerste zijn belangrijke verschillen tussen recreatieve en educatieve escaperooms beschreven. Op basis hiervan werden voorwaarden voor implementatie en daaraan gekoppelde ontwerpcriteria opgesteld. Ontwerpcriteria zoals: afstemming leerdoelen en puzzels, participatie alle teamleden, werkruimtes teams, snel opzetten en resetten game, herbruikbare lesmaterialen, immersion, autonomie leerlingen.

In drie ontwerpcycli, en in co-participatie met leerlingen en studenten als medeontwikkelaars, resulteerde dit in zogenaamde *escape boxen*, zie Figuur 6.2. De ontwikkelde escape boxen zijn vak en inhoud onafhankelijk. De zijkanten hebben een of meer van de volgende opties: een laptopdisplay, een LCD gekoppeld aan drukknopen, magnetische vlakken en/of deksels van verschillende groottes. De posities van de zijkanten kunnen verwisseld worden. Op deze manier heeft de docent veel mogelijkheden in het ontwerpen van een game.

Een zogenaamd *participatory design* met verschillende partijen zoals, leerlingen, studenten, opleiders, domeinspecifieke inhoudsexperts en ingenieurs bleek organisatorisch complex. De resulterende escape boxen zijn uniek en innovatief. De escape boxen zijn getest door playtesters met verschillende expertises op gebied van inhoud, onderwijs en games. Tot slot hebben 134 leerlingen uit het voortgezet onderwijs de escape box activiteit geëvalueerd.

Figuur 6.2 a. Ontwerptekening escape box, opengewerkte bovenkant, b. Escape box klaar voor de start, en c. Box inhoud op tafel na afloop van de escape game.

De escape boxen zetten leerlingen oog-in-oog met elkaar, hierdoor worden de communicatie en samenwerking gestimuleerd. Met ingebouwde technologie werd de fasering van de game gestructureerd. De digitale controle van de antwoorden en het geven van pre-set hints verminderde de druk op de rol van de docent. Het ontwikkelen en timen van pre-set hints voor leerlingen met verschillende behoeftes blijkt complex en behoeft nader onderzoek.

Studie 4: De rol van immersion, samenwerking en nabespreking op het leren met een educatieve escaperoom

In **Hoofdstuk 4** is gebruikgemaakt van een inmiddels ontwikkeld ontwerpmodel voor educatieve escaperooms (Veldkamp et al., 2021b[1]). Dit ontwerpmodel adresseert drie belangrijke uitdagingen voor het ontwerp en gebruik van educatieve games in het onderwijs, zie Figuur 6.3. Deze uitdagingen zijn, 1) de transitie van leerlingen van de werkelijkheid (het klaslokaal) naar een andere realiteit (de spelomgeving), 2) de afstemming tussen educatieve en game-ontwerpaspecten in het ontwerp, en 3) de overdracht van de ervaringen, en verkregen kennis en vaardigheden vanuit de spelomgeving terug naar de werkelijkheid; het uiteindelijke doel van de escaperoom. In deze laatste studie is met betrekking tot elk van deze uitdagingen bij het ontwerpen van een educatieve escaperoom, een element onderzocht dat daarin een belangrijke rol speelt. Dit zijn respectievelijk immersion, samenwerking en nabespreking.

De escaperoom over het onderwerp Q-koorts (een zoönose) is gespeeld met 126 leerlingen uit 5 havo en 6 vwo. Van de twee betrokken scholen had één school samenwerkend leren als didactische pijler en de ander had een reguliere opzet. De studieopzet was *mixed-method,* met kennistesten voor en na de activiteit, een vragenlijst, interviews met leerlingen en docenten en observaties.

In lijn met de vorige studies waardeerden de leerlingen de escaperoom als onderwijsactiviteit en werden er geen genderverschillen gevonden. De resultaten van de kennistesten lieten een toename in kennis zien.

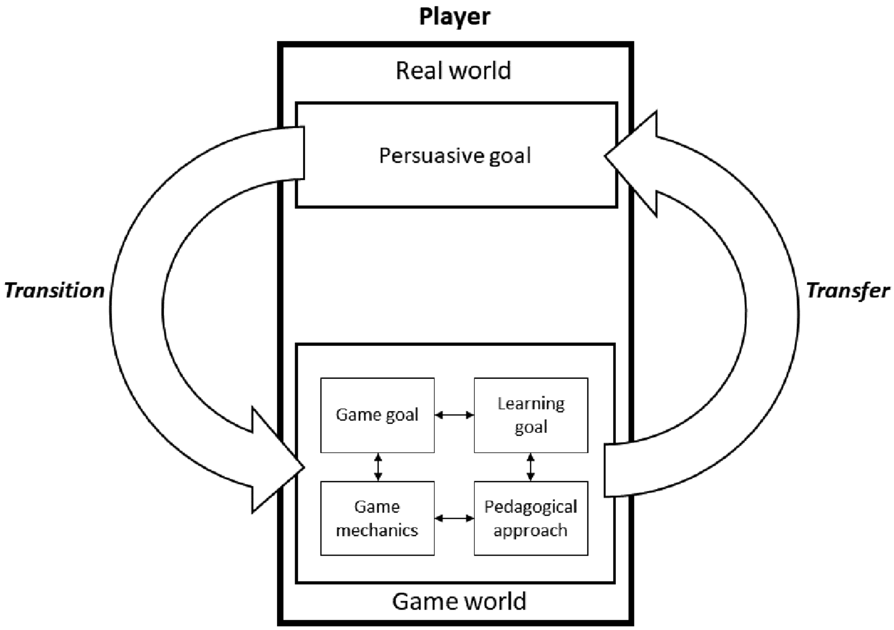
Daarnaast werden er positieve correlaties gevonden tussen:

- de waardering voor de activiteit en elk van de onderzochte elementen
- de mate van kennistoename en de waardering voor de activiteit
- de mate van kennistoename en de mate van immersion

De bijdrage van de vorm van de boxen aan de immersion was groter dan aspecten zoals de puzzels of de rollen die leerlingen hadden in het verhaal. Andere databronnen bevestigen dat leerlingen dankzij de box niet afgeleid werden door hun omgeving en gericht bleven op teamgenoten en de opdrachten.

De leerlingen binnen een team hadden verschillende rollen in het verhaal (boer, dierenarts, arts, burger of ambtenaar). Dit hielp de multidisciplinaire aanpak van een zoönose visualiseren. Daarnaast hadden de rollen op de reguliere school een positief effect op de samenwerking bij de start van de game, zoals de taakverdeling en individuele aansprakelijkheid.

1 This article is provided in the Appendix of this book.



Figuur 6.3 Ontwerpmodel voor educatieve escaperooms, 1) de transitie van leerlingen van de werkelijkheid (het klaslokaal) naar een fictieve realiteit (de spelomgeving), 2) de afstemming tussen educatieve en game-ontwerpaspecten in het ontwerp, en 3) de overdracht van de ervaringen, en verkregen kennis en vaardigheden vanuit de spelomgeving terug naar de werkelijkheid; het uiteindelijke doel van de escaperoom (Veldkamp et al., 2021b).

Ondanks de tevredenheid over de samenwerking van leerlingen, blijkt samenwerkend leren nauwelijks plaats te vinden op basis van de vragenlijsten, interviews met leerlingen, docenten en de resultaten van de observaties. Volgens docenten conflicteren de tijdslimiet en het competitie-element met het uitleggen en bediscussiëren van de benodigde domeinspecifieke inhoud.

Meer tijd is er bij een nabespreking. Deze is volgens leerlingen en docenten cruciaal voor leren met een escaperoom. Gewaardeerde onderdelen zijn: het bespreken van de domeinspecifieke kennis die nodig is voor de puzzels, vragen en incomplete ideeën van leerlingen bespreken. Enkele docenten bespraken gerelateerde maatschappelijke dilemma's, zoals de vaccinatieplicht voor mensen. Alle genoemde onderdelen samen waren conform het nabesprekingsmodel van Lederman (2009). In aanvulling daarop noemden enkele leerlingen de behoefte aan nieuwe informatie tijdens een nabespreking. Dit kan ondervangen dat leerlingen met meer voorkennis minder geleerd hadden, zoals de correlatieberekeningen aantoonden.

Terug naar de hoofdvragen:

1. *Wat is de educatieve potentie van escaperooms voor bètaonderwijs in het voortgezet onderwijs?*

Educatieve escaperooms bieden een variatie aan opdrachten aan die domeinspecifieke kennis en vaardigheden vragen, binnen een wetenschappelijke context. Het werken in teams vereist een goede communicatie en samenwerking van leerlingen onderling. De opdrachten leiden tot een overkoepelend gamedoel en moeten binnen een beperkte tijd uitgevoerd zijn. Elk van de onderdelen in deze beschrijving van een escaperoom is niet uniek voor het onderwijs. De combinatie is dat wel en spreekt docenten aan.

Op basis van hoofdstuk 1-4 zien we de volgende educatieve potentie van escaperooms. De wetenschappelijke context maakt de opdrachten met de daarvoor benodigde kennis en vaardigheden relevant en logisch. Dit is vooral van belang voor contexten of onderwerpen die door leerlingen als abstract worden ervaren, te gevaarlijk zijn of buiten bereik. In een escaperoom is er ruimte om dingen uit te proberen en er is onmiddellijk feedback. Door de variatie aan opdrachten worden verschillende type kennis en expertise aangesproken. In escaperooms ervaren leerlingen eigenaarschap, verantwoordelijkheid en wederzijdse afhankelijkheid gedurende de activiteit. Dit resulteert in een grote betrokkenheid die cognitief, gedragsmatig en affectief van aard is. Deze betrokkenheid blijkt niet afhankelijk van leeftijd of gender van de leerling.

Een escaperoom is geen magisch doolhof waarbij geen docent nodig is. Een docent is nodig voor de monitoring van de veiligheid en progressie, en daarop gebaseerde begeleiding. Bij het leren met een escaperoom blijkt *wanneer* en *hoe* de docent intervenieert gevoelig te liggen vanwege de door leerlingen ervaren immersion, autonomie en eigenaarschap (Hoofdstuk 2). De nabespreking door de docent lijkt bepalend voor het behalen van leerresultaten (Hoofdstuk 4). Het onderzoeken van de educatieve potentie heeft ook bijgedragen aan het ontmythologiseren van de mogelijkheden van de huidige escaperooms voor onderwijs (Hoofdstuk 5).

2. *Wat zijn adequate principes en richtlijnen voor het ontwerpen en toepassen van escaperooms in de bètavakken van het voorgezet onderwijs?*

Docenten hebben hun escaperoom ontwikkeld op basis van hun ervaringen met recreatieve escaperooms en/of met zogenaamde point-and-click home escape games (Hoofdstuk 2). De studies 2-4 (zie overeenkomstige hoofdstukken), hebben principes en richtlijnen opgeleverd voor de toekomstige ontwikkeling van educatieve escaperooms. Deze principes en richtlijnen relateren aan het ontwerpkader voor educatieve escaperooms dat door Veldkamp et al. (2021) is ontwikkeld, zie paragraaf Studie 4. Hieronder staan de principes en richtlijnen gecategoriseerd in: het ontwerpen van een escaperoom, het ontwerpproces en de organisatie in de klas.

Het ontwerpen van een escaperoom

Zorg voor afstemming tussen de onderdelen. Zorg dat de leerdoelen, gamedoel(en), gehanteerde didactiek en game-ontwerpaspecten onderling zijn afgestemd.

Streef naar succes voor zoveel mogelijk leerlingen. Voor een goede leerervaring en het behalen van de leerdoelen is het belangrijk dat zoveel mogelijk leerlingen alle kennis-gerelateerde puzzels maken.

Zorg dat alle groepen een eindstreep kunnen halen. Met één einddoel voor de hele klas, stopt de game en het leerproces wanneer het eerste team wint. Met een einddoel voor elk team, spelen leerlingen ‘alleen’ tegen de tijd.

Durf het room**-aspect los te laten.** Probeer los te komen van het gamedoel ‘ontsnappen uit het klaslokaal’. Een ander doel geeft meer didactische mogelijkheden binnen of buiten de klas en schooldeuren.

Denk na over de rol van de docent. De door leerlingen ervaren immersion en autonomie in een escaperoom hoeft niet doorbroken te worden door de aanwezigheid van docenten. Docenten moeten wel een balans vinden tussen leerlingen zelf laten ontdekken en ingrijpen. Daarnaast kan de docent zichzelf een rol in het verhaal geven zodat de interactie tussen docent en leerlingen binnen het verhaal past.

Ontwerp specifiek voor toetsing. Als gedurende het spelverloop prestaties beoordeeld moeten worden, is een lineaire organisatie van de puzzels en een kleine teamgrootte (maximaal 4) aan te raden. Afhankelijk van de door de docent gestelde doelen met de escaperoom, kan of het hele team of elk individu beoordeeld worden. Deze doelen bepalen ook *wat* er beoordeeld wordt, alleen de prestaties in de escaperoom of ook de voorbereiding en de reflectie op het leren.

Overweeg hybrid learning spaces. De mogelijkheden die hybrid learning spaces bieden, kunnen immersion versterken en zo de transitie vergemakkelijken van het klaslokaal naar de spelomgeving. Afhankelijk van de geïmplementeerde technologie kunnen ook aspecten zoals het verhaal, de puzzels, feedback en hints gereguleerd worden.

Het ontwerpproces

Start from scratch. Start met het vaststellen van randvoorwaarden voor de specifieke onderwijssetting. Formuleer gerelateerde ontwerpcriteria. Een design-based onderzoek gebaseerd op deze ontwerpcriteria en een *educatieve game framework* zoals Figuur 6.3, zal leiden tot een prototype dat toegespitst is op de specifieke onderwijssituatie.

Ontwerp samen met de doelgroep. Onze ervaring is dat ontwikkelaars uit de doelgroep een goed gevoel hebben voor doelgroep aansprekende verhaallijnen en humor. De gamers onder hen brengen hun ervaring in met betrekking tot spelontwerp en *immersive* aspecten.

Test met spelers van verschillende expertise. Plan een serie van testen met spelers die verschillende expertise en perspectieven hebben met betrekking tot een educatieve game: leerlingen, gamers, docenten, andere vakinhoudelijke experts en indien van toepassing de stakeholders in het project.

De organisatie in de klas

Heterogene teams. Een escaperoom vraagt verschillende soorten kennis en vaardigheden, heterogene groepen zijn om die reden aan te raden. Daarnaast vraagt een escape-room een specifieke soort logica, een teamlid met escaperoomervaring is om die reden te overwegen.

Maak tijd voor een nabespreking. Voor de leeropbrengst met een escaperoom is het cruciaal om de activiteit na te bespreken. Geadviseerde onderdelen zijn: 1) ruimte voor vragen van leerlingen, wegnemen twijfels, en bespreken van misvattingen van leerlingen, 2) het bespreken van de puzzels in relatie met de benodigde leerstof en doelen, 3) een koppeling aan gerelateerde onderwerpen en/of maatschappelijke discussies, 4) feedback op leerprestaties en doelen voor de toekomst. Daarnaast hebben leerlingen met een hoge startkennis behoefte aan nieuwe informatie.

Implicaties & toekomstig onderzoek

De beschrijving van de verschillen tussen recreatieve en educatieve escaperooms, daarop gebaseerde ontwerpcriteria, de ontdekte principes en richtlijnen worden gebruikt door docenten en educatieve onderzoekers (e.g., Botturi & Babazadeh, 2020; Lathwesen & Belova, 2021; Moffett, 2021). Hoofdstuk 4 laat zien dat samenwerkend leren beperkt plaatsvindt in huidige escaperooms met een tijdlimiet. Het is interessant om te onderzoeken of er mogelijkheden zijn om de ruimte voor discussie en/of *learning-by-explaining* tijdens een escaperoom te vergroten. Ook de leerwinst op langere termijn en het testen van leerwinst op hogere orde niveaus van Bloom is nog niet onderzocht (Bloom et al., 1956).

Ontwerpkaders en vragenlijsten die in gameresearch worden gebruikt, lijken gebaseerd op, en enkel voor virtuele games. De immersion door fysieke objecten en props ontbreekt en moet op dit punt aangevuld worden. Onderzoek naar educatieve escaperooms vindt plaats in verschillende *vak*disciplines, en disciplines zoals game research, educatieve game research, educatieve technologie en onderwijskunde. De oproep tot één vaktaal lijkt me onrealistisch (Anderson et al., 2021). Wel zou onderzoek naar educatieve escaperooms baat hebben bij het leren en begrijpen van elkaars terminologie, werkwijze en theoretische kaders. Het ontwikkelen van een educatieve escaperoom vraagt verschillende expertises en perspectieven (leerling, docent, gamer) en daardoor co-participatie binnen een ontwikkelteam.

Escaperooms: adaptieve leeromgevingen

De lockdown met de behoefte aan online leeromgevingen heeft de ontwikkeling van virtuele escaperooms gekatalyseerd (Ang et al., 2020; Hoven, 2021; Moffett, 2021; Smith & Davis, 2021). In Hoofdstuk 5 worden de voor- en nadelen van de verschillende typen escaperooms voor het bètaonderwijs besproken. De voorlopige conclusie is dat virtuele escaperooms organisatorische en logistieke voordelen bieden. Daarnaast geeft het mogelijkheden voor het analyseren van prestaties van leerlingen en aanpassen van de escaperoom daarop. Maar de communicatie en samenwerking van leerlingen onderling en de begeleiding door docenten blijkt lastiger. Daarnaast worden voor bètaonderwijs belangrijke motorische vaardigheden (zoals labvaardigheden) slecht gesimuleerd in een virtuele omgeving.

Het is uniek in de onderwijshistorie dat escaperooms bottom-up, door docenten, zijn geïnitieerd. Het escaperoomconcept is adaptief gebleken en zal in de toekomst aangepast worden aan veranderende doelen van docenten, de behoeftes van leerlingen met betrekking tot bètaonderwijs, en de uitkomsten van onderzoek naar educatieve escaperooms. Want dat is nu op gang gekomen: *the game is on*. No escape!

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Appendix

Educational escape rooms:
Challenges in aligning game and education

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Abstract

This article analyzes in a post-mortem reflection, the design of MasterMind, an escape room that served as a means of professional development in the use and implementation of online educational tools in academic teaching. Escape rooms have inspired educators all over the world to adapt the popular entertainment activity for education. The time-constrained and problem-based games require active and collaborative participants, which makes an escape room an interesting setting for educators. As there are differences in the settings and goals of educational and recreational escape rooms, there is a need for description of the design process, taking into account both game design and educational aspects. MasterMind was developed by a multidisciplinary team of educators, educational researchers and game researchers. The design analysis of MasterMind focuses on three related challenges that have informed the design process: 1) the participants' transition from the real world to the game world; 2) the alignment of game design aspects and educational aspects in the game world; and 3) the transfer from experiences and knowledge obtained within the game world back into the real world. The description and analysis is guided by frameworks on persuasive games and the alignment of game goals and learning goals. The analysis gives insights in how to balance game and educational aspects in the design, in order for players to reach both persuasive and learning goals. We recommend an integrated approach of the different design challenges. Therefore, we propose a design model combining and aligning the used frameworks, leading to an integrated approach in tackling design challenges in persuasive, serious games.

Introduction

Escape rooms have inspired educators all over the world to adapt this popular entertainment activity for education purposes. This article discusses the design and design philosophy of MasterMind, an escape room developed at Utrecht University by a multidisciplinary team of educators, educational researchers and game researchers. MasterMind served as a means of professional development in the use and implementation of online educational tools in academic teaching. Its aim was to playfully introduce university teachers to digital educational tools and help them make informed decisions about employing these tools in their educational contexts. It targeted early majority and late majority adopters of digital technologies in education (cf. Rogers, 1962). A majority of the participants perceived that the experience of playing MasterMind made them more inclined to use digital tools in their own teaching, and that it was an enjoyable and meaningful time investment.[1]

This article analyzes in a post-mortem reflection, the design of MasterMind. Post-mortem reflections are also referred to as post-mortem evaluations, post-project audits, debriefs or retrospectives. Project members identify and analyze elements of a project, product or meeting that were successful and unsuccessful, and articulate lessons learned (Kasi, Keil, Mathiassen, & Pedersen, 2008; Myllyaho, Salo, Kääriäinen, Hyysalo, & Koskela, 2004). MasterMind project members based their analysis on formal evaluations by questionnaires[1], observations as game masters, and informal contact with participants after the game. The design of MasterMind is analyzed from the perspective of three design challenges that have informed the design process: 1) the participants' transition from the real world to the game world; 2) the alignment of game design and educational aspects within the game world; and 3) the transfer from experiences and knowledge obtained within the game world back into the real world. We argue that educational escape rooms, such as MasterMind, can be positioned in a context of both serious and persuasive gaming and thus need to take into account the design challenges that are particular to both forms of games. Drawing on a general theoretical model for persuasive game design (Visch, Vegt, Anderiesen, & van der Kooij, 2013) and a design framework for the alignment between game goals and learning goals (Van der Linden, Van Joolingen, & Meulenbroeks, 2019), the article reflects on how we engaged with the aforementioned challenges in the design of MasterMind. We appoint successful and less successful design elements of this persuasive game, and describe encountered dilemmas and lessons learned. With this, we hope to contribute to the discourse on serious gaming and help foster the dialogue between serious game designers and educators.

Escape rooms in education

Escape rooms are live-action team-based games in which players encounter challenges that are part of a quest that needs to be completed in a limited amount of time (Nicholson, 2015). Parallel to their immense popularity in the entertainment industry worldwide, escape rooms are gaining popularity as educational environments. Both students and teachers perceive that while participating in escape rooms, students are more engaged and active compared to regular classes (Cain, 2019). The time-constrained and problem-based games

1 A post-activity survey was sent to 196 participants. It questioned their experience in the escape room in relation to the goals and their intentions with digital educational tools in their future practice. 127 participants worked as teachers and 38 teachers responded to the survey.

require active and collaborative participants, which makes an escape room an interesting setting for educators.

The development of educational escape rooms started spontaneously with enthusiastic teachers. They share materials on platforms, such as Breakout EDU, which has about 40.000 members (Breakout EDU, 2018; Sanchez & Plumettaz-Sieber, 2019). Educational escape rooms have been developed for a variety of age groups and for various educational purposes: to recruit students (Connelly, Burbach, Kennedy, & Walters, 2018) or for students to get to know institutional services (Guo & Goh, 2016). Other case studies describe students developing escape rooms in order to foster design skills (e.g. Li, Chou, Chen, & Chiu, 2018). Most escape rooms have been designed to foster domain specific skills and knowledge, or to support the development of generic skills and affective goals. Despite increasing scholarly interest in educational escape rooms, there is a paucity of literature on their use in the context of professional development (Fotaris & Mastoras, 2019; Veldkamp, van de Grint, Knippels, & van Joolingen, 2020). This article aims to address that gap.

Serious games and persuasive games

As the development of educational escape rooms started spontaneously with enthusiastic teachers, no academic literature was found on the development of (educational) escape rooms at the start of the MasterMind project. However, educational escape rooms can be considered a form of serious gaming. Serious game design combines educational design with game design (Lameras et al., 2017; Whitton, 2018). Most research on serious games comprises digital games in educational settings (Ávila-Pesántez, Rivera, & Alban, 2017; Lameras et al., 2017). Systematic reviews on serious games show a wide diversity in definitions of serious games foregrounding different 'essential' characteristics, such as the role of ICT (Ke, 2016; Lameras et al., 2017). Moreover, authors differ on whether serious games are "games primarily focused on education rather than entertainment" (Miller et al. 2011, p. 1425) or that entertainment and fun come first, as these aspects are considered conditional for learning with serious games (Prenski, 2001; Zyda, 2005). We bypass these differences by following Cook (2005), who offers a broader description of serious games:

> "(...) the application of gaming technology, process, and design to the solution of problems faced by businesses and other organizations. Serious games promote the transfer and cross fertilization of game development knowledge and techniques in traditionally non-game markets such as training, product design, sales, marketing, etc."

There are different reasons why non-game markets, of which education is an example, turn to games to solve problems within their organization. In the case of Utrecht University, games are used to resolve the low acceptance of digital educational tools among staff. The enjoyable and immersive game world can help, motivate, and persuade users to behave in ways they experience as difficult in the real world (Visch et al., 2015). Players experience games as not only enjoyable but also protective worlds where actions have fewer consequences than in the real world and can be practiced over and over again (Whitton, 2018). Games can change behavior in the game world and subsequently in the real world. This is the assumption and ultimate aim of persuasive games, a subset of serious games aimed at creating a user experienced game world that changes the user behavior or attitude in the real world (Jacobs, Jansz, & de la Hera Conde-Pumpido, 2017; Visch et al., 2013). Motivating game elements, such as challenges, draw the player into a game world where equivalents of real world tasks are carried out. The transfer of effects from the game world to the real world can be actively designed, but is often neglected (Visch et al, 2013). How to successfully design this transfer is one of the challenges for developers of persuasive games.

In a review study on digital serious games, Ke (2016) notes that the effectiveness of games created for educational purposes depends on various aspects: 1) the nature of learning to be fostered (skills or conceptual knowledge); 2) how specific game aspects, such as feedback to players, are implemented; and 3) the way games are used in education, for example as a micro-world to embody a situated practice or an interactive, multimodal representation of conceptual knowledge. Ke's findings imply that the specific nature of the knowledge to be obtained and the educational goals to be achieved should primarily drive the design of learning games. Carefully mapping learning actions onto play actions seems to be a necessary and core mechanism for successful learning-play integration, whereas the narrative that structures and frames learning interactions can be considered supplementary. A systematic review on educational escape rooms draws the same conclusion and showed how specific educational and game design aspects are related (Veldkamp, van de Grint, Knippels, & van Joolingen, 2020). Ideally, the game is designed in a way that players can reach the game goal only by achieving educational goals (Van der Linden et al., 2019). An extra challenge for serious games is to integrate learning and playing without losing what is enjoyable about games (Ke, 2016). In games with poorly developed player experiences, the message is ineffective (Ferrara, 2013). Elements that can help create an enjoyable playful learning environment are puzzles, simulations, role play, humor, surprise, storytelling, and mystery (Whitton, 2018).

In addition, given all these aspects that need to be taken into account, it comes as no surprise that educators "are overwhelmed by the plethora of design choices and level of complexity entailed in integrating, combining and balancing learning with game features" (Lameras et al., 2017, p.990). Lameras et al. (2017) plead that more dialogue is needed between educators and serious game designers to improve the process of amalgamating learning with gaming. For the design of escape rooms in education, such a dialogue would benefit from more qualitative research that helps understand the concrete considerations and decisions made by developers of educational escape rooms.

MasterMind: a brief description

In spite of considerable university investments in technological innovation in education (e.g. licenses, hardware, software, and workshops), a significant part of lecturers at Utrecht University has not yet implemented technological tools in their teaching. These early and late majorities (cf. Rogers, 1962) need to be personally convinced of the value of an innovative technology before investing time in exploring it (Moore, 1991). Moreover, research indicates that this exploration should happen in collaboration with other colleagues and with enough opportunities for reflection (Ertmer, 1999). MasterMind aimed to address this issue with a mobile, pop-up escape room that allows university teachers to experience and engage hands-on with educational technologies in a playful and safe environment, together with others. A post-game debriefing aimed to help participants to reflect on their experiences and make informed decisions about using (or not using) these tools in their own educational setting. Ideally, the positive experience of playing MasterMind contributes to active implementation of digital educational tools in teaching. This is the persuasive goal of MasterMind. MasterMind can be considered an example of persuasive gaming, as it aims to create a user experienced game world to change the teachers' attitudes and behavior in the real world.

MasterMind consisted of two main parts that each lasted one hour: an escape room and a debriefing. The escape room can host 4 to 6 players who sign up as a team. The narrative setting of the escape room is within the fictive tech start-up company MasterMind, founded by student-entrepreneur Tim Turner. Tim has developed 4D Virtual Reality and creates experiences where people can see, taste, feel and smell alternative realities. While waiting for Tim's presentation about MasterMind, the participants are shown a short promo video of the company. Suddenly, Tim breaks into the video signal with an emergency call that he is stuck in his own virtual world. Players will need to get him out, by solving puzzles based on digital educational tools available for teachers at Utrecht University (see figure 1). The puzzles typically consist of a combination of digital and physical actions. Playing the escape room is followed by a one hour debriefing in which a moderator discusses with the team which digital educational tools they have encountered in the game and how these might contribute to the team's teaching practice. The design process of MasterMind was an iterative process, including multiple rounds of play tests with game specialists, educators and the target audience which provided the input for the further development of the escape room.

Figure 1 Players in MasterMind working on a puzzle that requires both physical and digital activities.

Design challenges in MasterMind

In line with our previous discussion on serious games, one of the main challenges in designing the MasterMind escape room was to strike the right balance between game design aspects and educational aspects. More specifically, to design the gameplay in such a way that the game goal (liberate Tim) and learning goal (experience specific digital educational tools) were aligned, without losing the fun and pleasure of the game. Another challenge, in line with MasterMind's persuasive nature, was to successfully transit the participant from the real world (teaching environment) into the game world (Tim's start-up presentation at the university), and finally, to support the transfer of knowledge and experience of the tools obtained within the escape room to the participant's practice of teaching: the persuasive goal. In the next section, we will discuss how these three challenges concretely informed the design and design principles of MasterMind, after we have introduced the analytical perspective that frames our analysis and takes into account these design challenges.

Figure 2 depicts a design framework that foregrounds the different alignments that need to be taken into account to design a successful educational game (Van der Linden et al., 2019). The framework is developed in line with the intrinsic integration theory, which suggests that the learning goal and game goal should be aligned in an educational game.

Van der Linden et al. (2019) emphasize that the learning goal should be leading in the design of an educational game and that game developers in designing the gameplay need to ensure that the game goal can only be reached when the desired learning goal is reached. Additionally, according to the logic of alignment, both learning goal and game goal can only be achieved if they are pursued within a matching structure and logic, meaning that the learning goal needs to be supported by the proper pedagogical approach and the game goal by the proper game mechanics. Which pedagogical approach to adopt or which game mechanics to use should be informed by the learning goal and game goal respectively. Moreover, Van der Linden et al. (2019) propose that during the iterations of the design process the focus should be on aligning the pedagogical approach with the game mechanics.

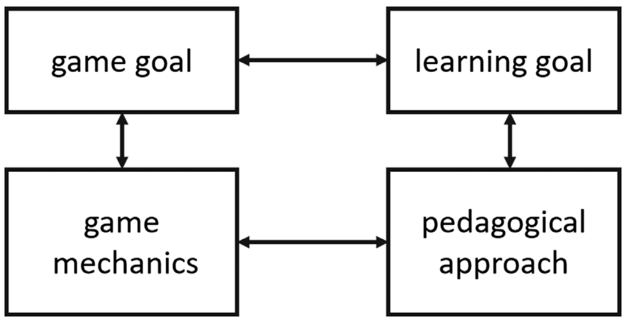

Figure 2 Design framework on alignment between game goal, learning goal, pedagogical approach and game mechanics (Van der Linden et al., 2019).

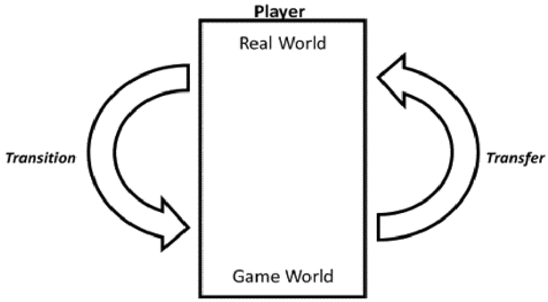

Figure 3 Persuasive game model (adapted from Visch et al., 2013).

In case of the MasterMind escape room gameplay, the learning goal is for teachers with moderate to low technology acceptance to use a set of digital educational tools and to become aware of the functionalities from the both perspectives of the teacher and learners. To align with this learning goal, MasterMind adopted playful learning as its pedagogical approaches, since this aims at an enjoyable, safe environment that offers a positive response to failure and support for learners to immerse themselves in the spirit of play (Whitton, 2018). Within such a safe environment, the pedagogics experiential and collaborative learning can support the learning goal of Mastermind. For the game mechanics to align with this pedagogical approach of playful, experiential and collaborative learning, an integration of the educational tools into the game puzzles and activities is necessary. These puzzles, then, need to steer towards working in a team and having fun. Finally, the gameplay has to be such that only when the tool-based puzzles are solved within time, the game goal can be reached: to liberate Tim from the virtual world.

Figure 3 shows a Persuasive Game Design Model adapted from Visch et al. (2013). The original model is based on three central concepts related to persuasive gaming: gamification, game world and behavioral change design. Persuasive games assume that user behavior and motivations in the real world can be transformed through a process of gamification. In MasterMind the real world is the environment of a university teacher, and the game world is a kick-off meeting for staff at Tim's enterprise. Other than the previous framework, this model does not focus on the game world and game play as much, but describes the players' movement from the real world into the game world and back.

In order to address specific behavior and attitude in the game world, it is important that behavioral and motivational aspects from the real world become part of the 'safe' game world; a gamified real world context (Visch et al., 2013). In the game world, these behavioral and motivational aspects can be changed towards the desired behavior or motivation.

If the desired behavior is addressed and realized in the game world, Visch et al. (2013) suggest, it can be transferred to the real world and produce a so-called transfer effect: 'the effect of the user experienced game world on forming, altering, or reinforcing user-compliance, -behavior, or -attitude, in the real world' (Visch et al., 2013). In order for this effect to take place, the transition from the game world to the real world needs to be designed. This 'transfer design,' the authors claim, is often neglected and formed yet another design challenge for MasterMind. A one hour debriefing session was developed to structure and catalyze this transfer, which included a reflection on the experiences and educational content as conditional for learning with escape rooms (Sanchez & Plumettaz-Sieber, 2019).

In the following analysis, we describe each part of the Mastermind escape room - pre-game, in-game and post-game - followed by the design considerations in relation to the design challenges. We look into how aspects (behavior, motivation, attributes) of the real world of the participants have been translated into game elements that have been incorporated in the design of the game world (challenge one). We also reflect in more detail on how specific game aspects and educational aspects have been aligned in the design of the MasterMind escape room (challenge two). Additionally, we describe which design strategies MasterMind developed and employed to facilitate a meaningful transfer of experiences, knowledge and ideas obtained within the game world back into the real world (challenge three).

Pre-game: mailing and welcome

The aim of the pre-game experience was to facilitate the transition from the real world to the game world by creating tension and preparing players for the game play.

One week prior to the game, all players in a team (N= 4-6), received an email from the (fictive) protagonist of the game: student/entrepreneur Tim Turner. He thanks the participant for signing up to the kick-off presentation of his new company MasterMind, shares time and location details and asks participants to be present 10 minutes early. In all communication with the participants, the emphasis was on the narrative, not on the educational goal or pedagogical approach.

On the day of the game, players were welcomed by a game master in a separate informal reception room. The reception room was equipped with game attributes such as the classic boardgame mastermind and playfully hidden game rules. Meanwhile, the game master walked back and forth between the actual escape room and the reception room, checking if Tim has arrived yet. After a few minutes, the game master invited the players to take a seat in the escape room. The game master told them that Tim went away to fix a technical issue, but that he is expected to return swiftly. Hereafter, the game master guided the players to the actual escape room, and started a promo-video of Tim's company MasterMind.

Design considerations

The preparation of mental settings is important for this target group, because the game will require them to perform actions and behaviors they do not perform in the real world, namely the hands-on engagement with innovative educational tools.

The in-narrative mailing allows players to relate to the protagonist, student Tim before the game starts. The contrast of Tim's request to arrive early and him being late is designed to create a tension that might enhance the urge to take action as soon as the game begins. The reception room serves as a transition space, between the real world and the game world. Here, players have the opportunity to leave behind their day-to-day work and get into a playful mood with their team, a familiar strategy in the design of escape rooms

(Clare, 2016). The provided rules and tips for how to play an escape room help to boost playfulness and anticipation for gameplay. This is again designed to increase the urge to take action once the game starts. But more importantly, these tips make implicit game rules and mechanics explicit, preparing players for the game mechanics that will be used. Players that have never played an escape room before will for instance not search the room for clues, unless they understand that this is a regular activity in the game world. Making rules and mechanics explicit might allow for an easier transition from the real world to the game world.

Evaluation

The participants' immersion succeeded. After the game master invited players to the presentation without Tim, some players indicated they preferred to wait or to look for Tim. This indicate the realistic narrative, setting and players' expectations regarding the presentation of the student start-up. On the other hand, other players entering the reception room, recognized escape room elements, concluded that an escape room had begun, and directly showed behavior accordingly. It is questionable whether the playful way the information on gameplay (rules and tips) was presented to the players, was the most effective.

We wonder whether or not to explicate in the pre-game mailing that participants will enter a real life escape game. On the one hand, this would increase clarity for the participants about what to expect, on the other hand this might affect the level of immersion.

In-Game: setting and narrative

To reach our persuasive goal, a balance had to be struck between a setting in the game world that would be out of the ordinary enough for the participants to show out of the ordinary behavior, and a setting that would allow for easy transfer of game attitudes and skills to the professional practice of the participants in the real world.

The setting of the escape room was within the fictive tech start-up company MasterMind. There was a lot of equipment with a 1980's look and feel present in the room. The call to action is Tim's cry for help to reset the system to liberate him from the virtual world, which was the game goal.

Design considerations

Given the learning goals on specific digital educational tools, the escape room needed to be a technology-rich environment. However, the target group was unlikely to be intrinsically interested in technology and may even be deterred by it. Therefore, the technology that was presented in the narrative (4D virtual reality) is obviously science fiction. Through their 1980's look and feel, all the physical equipment made it obvious that this is not something the players have to worry about in daily life while it created an acceptable environment to work with technology.

Tim, a student was chosen as protagonist, introducing him in the mailing and promo video as someone teachers can relate to. The call to action is urgent, confronting teachers with a challenge they have never had at hand before, making it sensible that new types of solutions and behaviors are needed to solve this problem. On the other hand, helping a student with a problem does align well with the professional practice and real world roles of the players, allowing for an easier transfer. This is in line with the situated learning theory, which states that learning should take place in a practice in which it would normally be applied (Lave & Wenger, 1991).

Evaluation

The design of the game setting appeared an area of tension following the projects' various goals. The learning goal for teachers was to experience and learn about educational tools, which asks for a technology-rich environment. The persuasive goal was to persuade technology 'laggers' or avoiders to perform behavior they are unfamiliar with in their professional practice. Our solution was to design a setting which is obviously fiction, with the digital tool based puzzles in a *physical* form with a *1980's look* and a narrative on *4D reality*. However, this interferes with the situated learning theory requiring the exercise setting to be congruent with the professional practice (Lave & Wenger, 1991). In balancing these goals and their consequences in terms of design elements, the play tests with the target group had a crucial role. In the final setting, players easily touched and managed the digital tasks using physical equipment with *1980's look*. Physical attributes seemed to give players more feeling over control of technology. These observations are interesting to research in more detail in the future.

In-Game: pedagogical approaches

Ertmer (1999) identifies collaboration as an important strategy to address teachers' reluctance to use technology in education, this was part of our pedagogical approach. Collaborative learning requires all members of a team to be active. This was created by the amount of puzzles available at the same time for players in combination with the time restriction, which lowers the threshold to start with the technology-based puzzles.

The escape room aimed at facilitating teacher teams. Players share the same experience during the start and the end of the game. In mid-game, several puzzles were open to work on synchronously. Most teams split up to work in pairs on these puzzles, with pairs helping each other when needed.

Design considerations

The puzzles were organized and individually designed in a way, that collaboration between players was needed, mirroring the help teachers can get within their own immediate working environment. In addition the puzzles were constructed in a way players experienced the student, and were possible the teacher perspective. This is also in line with the situated learning theory, which states that learning should take place in a practice in which it would normally be applied (Lave & Wenger, 1991).

Evaluation

There were no differences observed regarding communication or degree of collaboration in teams with members who knew each other or not. The participants felt social dependence and started to work together. A mentioned drawback in the questionnaire results and debriefing, is that not everyone had hands-on experienced all tools, which might be important for technology avoiders. At the same time, the omission of the experience gave urgency for a discussion of the tools during the reflection on the tools afterwards. The amount of team members (3-5) and the degree of communication in a team seem boundary conditions for solving the puzzles.

In-Game: puzzles

The escape room aim was to introduce teachers to six digital educational tools[2] they could use in their own teaching. Therefore current tool versions were used in the puzzles, no simulations or mockup versions. Puzzles typically consisted of a combination of digital and physical activities. The physical activities were most of the time primarily designed for fun and engagement while the digital activities addressed the learning goal of the escape room (to use a set of digital tools and become aware of their functionalities).

Design considerations

The selection of the tools was informed by their availability within the real world. All tools were supported by Utrecht University. Moreover they were selected to cover a variety of educational functions. Implementing the actual tools in the game design allowed players to experience the real product, but this limited possibilities in designing the puzzles. Practical matters were also taken into account, such as the possibility to adapt the tool to design puzzles and the ability to quickly reset the tool for the next group of players. Puzzles were constructed in a way players experienced the student perspective and, if possible, the teacher perspective on the tool, this strengthens situated learning. Although most tools required only digital activities to engage with their functionalities, physical actions with a puzzle twist were added in the design for a number of reasons: to appeal to this specific target group of teachers belonging to the early and late majority, to link the digital activities in the narrative, to stimulate interaction between players, and to stimulate fun, immersion and diversity in activities.

One puzzle, for instance, was aimed at engaging with a tool for practicing communication skills, using video assignments, called Traintool. First, players needed to find a spoken password in a physical puzzle, then they received instructions in the educational tool on how to speak to convincingly to people and machines. The next step was to practice this skill by recording a video in the educational tool. After doing this, they received feedback on their performance within the tool, just as students would. They subsequently had to apply this feedback on the found password and unlock a physical machine by saying a piece of text in a specific manner in a microphone. Then, a physical reward in the form of a code is unlocked. Altogether, this puzzle allowed teachers to experience how students can receive instruction, practice communication skills, and receive feedback in this platform and then apply the learned skills in practice. So, in order to reach the game sub-goal (the unlocked code), players should also meet the learning sub-goal (using the specific educational tool and discovering its functionalities).

The last puzzle of the escape room was designed as a team activity with all players standing around a table. Because it was the last puzzle and not all teams would be able to finish it, this puzzle was not directly linked to one of the learning goals for the escape room. However, it did contribute to the escape room being a shared experience and facilitated group discussions during the post-game debriefing.

Evaluation

According to van der Linden et al. (2019), the game goal and learning goal need to be aligned. This was easy to achieve for designers, as the puzzles which needed to be solved to liberate Tim (game goal), were digital educational tool

2 Selected tools: Augmented Reality application: HP Reveal, Virtual Reality application Rico Theta, Traintool, Scalable Learning, Feedback Fruits, and assessment tool Remindo.

based (learning goal). In the selection of the tools, next time we would take into consideration the length of the tools university license contract. After the selection of tools, the designer's dilemma is to use current tool versions or mock-up versions. Use of the current versions increases the game world mirroring the real world, however it limits the creation of tool-based puzzles as the current versions are usually robust to user manipulation. In addition, current tool versions are sensitive to manufacturer's maintenance or availability of the tool.

The designed puzzles were based on regular student tasks or teacher handling of the tools in combination with a puzzle twist to increase the playfulness. The puzzle twist for some assignments took more time in a lot of groups than expected. We would lower this puzzle aspect in a future escape room puzzles, to balance the players' time spent more on learn the tool than on the puzzle aspect. In relation to the evaluation in the previous section on team size and communication, we would advise smaller teams and easier puzzles for an escape room with such a persuasive goal and learning goal.

The success rate of about 60% of the teams finishing in time, does not seem successful in the effort to achieve all learning goals. However, the last puzzle did not have goals in terms of educational tools, but was successfully designed to finish the game collaboratively as literally all hands were needed to solve the puzzle. The puzzle had three rounds creating a collective feeling of success in between the rounds and made it possible to anticipate in differences in progression and success in the teams. Another possibility for future escape rooms, to anticipate on the teams differences in progression during gameplay, would be for game masters to differentiate the degree of guiding. Guiding in educational escape rooms appear to be delicate balancing between the players feeling of autonomy and ownership and teachers' wish players to achieve all learning goals (Veldkamp, van de Grint, Knippels, & van Joolingen, 2020).

Post-Game

The first moments after gameplay were designed to reduce the adrenaline and evoke positive emotions to increase players' openness to reflection with regards to their own teaching practices during the debriefing.

The game ended when Tim had been liberated from the virtual world or when 60 minutes had passed. The success rate of players was about 60%. A specific video started, depending on the outcome (i.e. whether Tim was released or not). When the teachers succeeded in their mission, Tim showed his gratitude. When players did not succeed, Tim is set on a tropical island, saying that life in virtual reality is not so bad after all. Then it was time for the team photo, taken with a cardboard version of Tim.

After some time to cool down and share game play experiences, the debriefing took place in the reception room, linking the player experiences to teacher experiences. For each puzzle, the players who were most involved in that part of the escape room explained the puzzle (gameplay) and what they thought was the educational potential of the tool for their teaching practice. The facilitator could add his expertise and experience with the tools to the discussion. After all tools had been discussed, participants brainstormed about applying the tools for their own teaching. Technical and educational support were offered to teachers who liked to implement some tools or practices, and follow-up actions were able to be planned.

Design considerations

For most players, the escape room was a challenging activity, leading to a sense of fulfillment and joy when they succeeded in their mission to rescue Tim. However, when players fail, these positive emotions were not triggered. As a solution, we chose to offer comic relief by illustrating that Tim is happy in his new surroundings in the virtual world. For both endings, the cardboard version of Tim had a different function. For the successful teams, it functioned as a reward to be able to take a picture with Tim, the student they saved. For players that failed, again this is an object for comic relief: “Since Tim is virtualized, he couldn’t make it to take a picture with you, but we did print a cardboard version for you.” The team photo is an almost ritualistic part of most escape rooms. It makes explicit that - whether successful or not - the endeavor was a team effort, emphasizing the shared experience.

After a few minutes, all players moved over to the reception room for the debriefing. Again, the reception room functioned as a transition space, this time between the game world and the real world. The debriefing was designed to facilitate a shared reflection on the experiences with educational tools during gameplay, considering reflection is a key strategy for technology acceptance among teachers (Ertmer, 1999). During the debriefing, the individual player experiences of different puzzles were shared. The conversation was steered from player experience to teacher practice by the facilitator for each puzzle and thereby each tool. The debriefing ended with focusing entirely on applications in the real world and follow-up actions to support teachers in their practice.

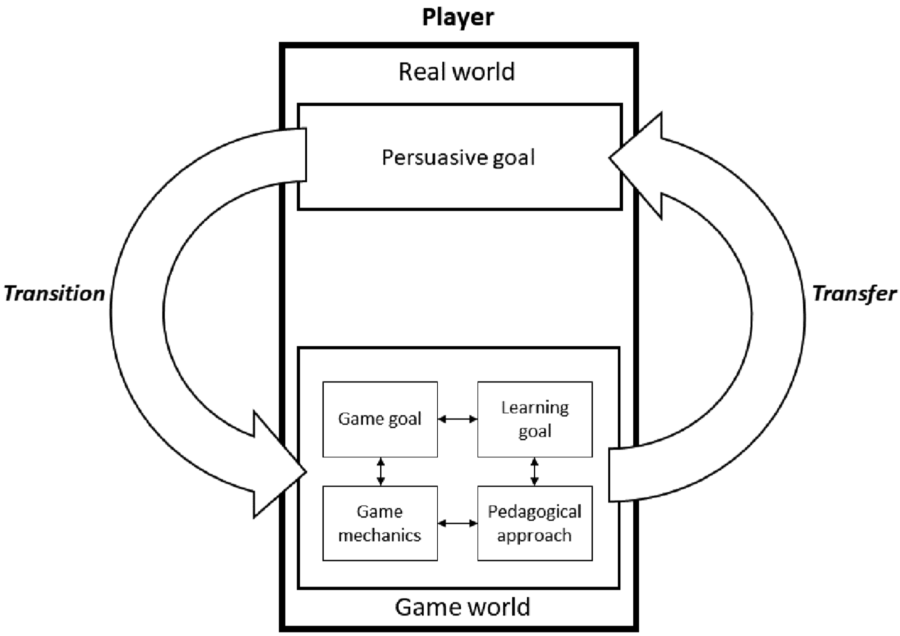

Figure 4 Integrated design approach for educational escape rooms

Evaluation

The players appreciated both videoclips, as it reduce the feeling of failure for the teams who did not achieve Tim's liberation in time. The comic relief of the clips and the photo shoot with the cardboard Tim regulated successfully the transition to the adrenaline-high activity to the reflection on the experiences with the tools and their functionality. This lasted nearly an hour. Hereafter, the transfer to their own teaching practices was guided. So, this started after two hours mentally intense activities. Some participants were at that point mentally too exhausted for an adequate reflection on the implementation in their professional practice. In future, we would start sooner with the implementation in teachers practice. The thorough exchange of the tools can be shortened by delivering a hand-out with the main point of the tools' functionality, and shortly address the players' experiences. As this part doubles with the discussion of the implementation in teaching practice, when participants also relate and discuss their experiences with the tools.

Conclusion

In this article we analyzed the design of the educational escape room MasterMind with a specific focus on three challenges that have informed the design process: 1) the participants' transition from the real world to the game world; 2) the alignment of game design aspects and educational aspects in the game world; and 3) the transfer from experiences and knowledge obtained within the game world back into the real world. In our analysis of the design, we have demonstrated that these challenges are inextricably linked to one another and call for an integrated design approach, especially when the educational escape room does not only aim for learning goals, but a persuasive goal as well. This is even more crucial if the target group are early and late majorities in professional development, who need to be personally convinced of the value of an innovative technology before adopting it. This article adds to the studies on educational escape rooms in that it shows the importance of paying as much attention to the design of the game play - making sure that the learning goal during gameplay is achieved - as to pregame, and to the transfer of the learned behavior into the real world to achieve persuasive goals. We propose an integrated framework (see figure 4) that can help designers to focus on alignment in tackling the main design challenges in persuasive games. The overarching persuasive goal starts the loop, steering the alignment of the design processes of gamification, gameplay and transfer.

For the design of educational escape rooms, available models comprise step-by-step procedures (Botturi, & Babazadeh, 2020; Clarke et al., 2016; Eukel, & Morrell, 2020; Guigon, Humeau, & Vermeulen, 2018). However, these models do not take into account design challenges for educational games, as described in the previous section. We believe that future educational escape rooms will be more persuasive in attaining their goal, when pre-game, gameplay, as well as post-game design are all driven by the same persuasive goal and learning goal and game goal are properly aligned within the game design.

Curriculum Vitae of a professional life

Alice Veldkamp was born on 6 July 1970 in Rotterdam. She completed her secondary education in 1988 at the GSR (Reformed School of Rotterdam) and graduated Biology in 1993. During her teacher training at IVLOS (Centre for Teacher Education, Utrecht University), she won a scholarship which allowed her to research the assessment of competences in the Swedish education in collaboration with the Malmö University in 1994.

In 1995, she started as a curriculum developer for the development of a new science subject, Science in a Historical and Cultural context (Algemene Natuurwetenschappen), as part of big national curriculum reform. As Alice wanted also to be part of the implementation of the reform, she started as a teacher in Biology and ANW at Christelijk Lyceum Veenendaal and later on at Bonifatius College Utrecht.

Alice as guest researcher at a primary school

During her teaching career Alice combined teaching at secondary schools with other educational projects. Examples are developing educational materials, for example for the National Cancer Trust (KWF), developing and teaching courses in teacher professionalization at the National Pedagogical Centre for science (APS), and editing for NVOX (journal of the national union of science teachers). In 2005, she was part of the teaching staff of the Life Science Centre Newcastle upon Tyne and discovered a passion for coaching junior colleagues.

In 2007, with colleagues, she set up BEST, a Science Support Centre at Utrecht University, to professionalize and empower teachers in the new science subjects. Alice's specialization was the subject Nature, Life and technology (NLT). As of 2009, Alice has been a teacher educator and school subject specialist for Biology at the Graduate school of Teaching and the Freudenthal Institute, at Utrecht University. She was involved in the development of ECENT: the expertise centre for teacher educators in science and technology, nowadays ECENT/ELWIER.

From 2017 on, she started to research the upcoming phenomenon of escape rooms in education. Nowadays, she is an acknowledged adviser and reviewer on this subject for academic journals, such as *Computers & Education* and *Technology, Knowledge and Learning*.

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Bedankt dat je in mijn proefschrift hebt gelezen. Of heb je direct naar dit hoofdstuk gebladerd om te kijken of je werd bedankt? Dat is vast terecht! Er staat één naam op de voorkant van dit boek, maar zonder jullie steun was het niet tot stand gekomen. Het is een wetenschappelijk werk, dus ik houd het bedanken hier zakelijk en ik hoop je binnenkort persoonlijk en live te bedanken.

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112. F. Kamphorst (2021). *Introducing Special Relativity in Secondary Education.*
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