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Beyond the Early Adopters: Escape Rooms in Science Education

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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.

Keywords: science education, escape rooms, student engagement, educational games, game-based learning

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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 and 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 and 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 and Fairfurst, 2019) and science disciplines (Vörös and 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 (Glavaš and Stašcik, 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 and Hendrix, 2013; Vlachopoulos and 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 and 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 sub-questions:

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.

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

TABLE 1 | The various data sources.

Data source	*N*
Classroom—observations	14
Classroom—movie clips	17
Students—online questionnaires	202
Students—interviews[a]	68
Teachers—online questionnaires	39
Teachers—interviews	11

[a]*In groups of 4–6 students.*

and 270 students participated, in the context of a national 'Escape the Classroom' Challenge, that was organized by the Dutch national organization 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 organization, 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 organization, '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 enroll. 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.

Data Collection

Table 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 behavior 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.

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 2** lists the main characteristics of the teachers and the students.

TABLE 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)

R *range.*
[a]*Age unknown.*

TABLE 3 | Most and least appreciated aspects of the Escape the Classroom Challenge according to students and 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).

Aspects	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	
	N_Q = 202	N_I = 55	N_Q = 200	N_I = 50	N_Q = 38	N_I = 11	N_Q = 37	N_I = 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 and 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 and 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

N_Q *Number of questionnaires;* N_I *Number of interviewed participants.*
It was possible for participants to skip a question or give more than one answer.

Data Analysis

Interviews with students and teachers were transcribed verbatim and analyzed per question, except for the open-ended questions. Answers to open-ended questions in the interviews and on the questionnaires were categorized, counted and analyzed by one researcher, using a process of open coding with the main concepts from the questions as sensitizing concepts (Boeije, 2010). Results were discussed with two researchers. A total of four coders analyzed the video clips. For each video clip, the visual content was described and the audio transcribed verbatim. Two coders independently analyzed the clips using a coding scheme, in relation to students' view on the experience, student behavior, teacher behavior 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.

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.

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 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.,

TABLE 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		

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.*

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 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 behaviorally 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 behavior, 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 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 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 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

N_Q *Number of questionnaires;* N_I *Number of interviewes.*

Previous Experiences with Escape Rooms

Teachers and students were asked for previous experiences with escape rooms. As seen in **Table 4**, only 8 out of the 39 teachers in the questionnaires, had already experienced recreational 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 4**); the reasoning in their explanations was alike: in escape rooms, the required way of thinking is the same, while the content can vary.

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.

TABLE 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.

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
Organizational aspects	*22*	*12*
Time: curriculum, development, preparation, reset etc.	12	7
Other: finances, availability of material, suitable classrooms etc.	10	5
Total	44	57

N_O = *Number of questionnaires;* N_I = *Number of interviewed participants.*
It was possible for participants to skip the question.

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 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, 40% 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 mostly frequently mentioned by teachers and students (see **Table 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; afterward 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 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 tranquility 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.

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) organizational aspects of implementing escape rooms and 3) required personal qualities of teachers and students (see **Table 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 organizational 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 afterward 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 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 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.

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.

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 and 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 and 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.

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 tranquility 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 and 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 afterward.

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 and Sárközi, 2017; Boysen-Osborn et al., 2018; Guigon et al., 2018; Mosley et al., 2018; Franco and DeLuca, 2019; Järveläinen and Paavilainen-Mäntymäki, 2019; Morrell and 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 centers develop escape rooms, schools can visit or borrow (Peleg et al., 2019; Science Centre Delft, 2020).

Emerging Themes in Overall Data

After qualitative analysis, the triangulated data shows the following recurring (sub)themes: engagement (cognitive, behavioral and affective) and teamwork. A review study on serious games also distinguishes these aspects of engagement (Hookham and Nesbitt, 2019). A meta-study on engagement in education showed that engagement positively influences academic achievement (Fredricks et al., 2004). Behavioral 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, behavioral 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.

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.

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 and Millar, 2008; Minner et al., 2010). These studies conclude that without active linking of knowledge during the intervention or reflection afterward, 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 afterward. 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 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, behavioral 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.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

Ethical review and approval were not required for the study on human participants in accordance with the local legislation and institutional requirements. When required, in accordance with the national legislation and the institutional requirements, informed consent was acquired.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2021.622860/full#supplementary-material.

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