The contribution of game design elements to the educational potential of Escape Rooms in secondary biology education

Masterthesis

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Abstract

In this research we investigated the educational potential of Escape Rooms in secondary biology education and which game design elements contribute to this educational potential, since secondary school teachers are using Escape Rooms in their teaching practice without scientific foundation.

Based on literature findings, we found that a well-designed Escape Room covers all of the most important SEG design elements and thus has a great educational potential. We then selected 3 SEG design elements (immersion, collaboration and a debriefing) and enhanced those in our own portable Escape Room (escape box). The escape box was then tested on 6 biology classes on 2 secondary schools in the Netherlands with students' ages ranging from 16-20 years old in order to determine the learning gains of the students and to what extent the 3 selected SEG design elements contributed to this. The students filled in a pre- and post-knowledge test and a post-activity survey. Next to those we used observation schemes and semi-structured interviews with students. We found high learning gains (an increase of 93% on content knowledge test scores) and found that a debriefing is essential for the learning gains of the students. A high degree of collaboration was also contributing to those learning gains and to a lesser – but still positive – extent, immersion. Our findings confirmed that Escape Rooms have great educational potential, but educators who want to design an Escape Room should pay particular attention to the debriefing and collaboration elements.

Key words and concepts

Educational Escape Room design, secondary biology education, gamification, game-based learning (GBL), serious games

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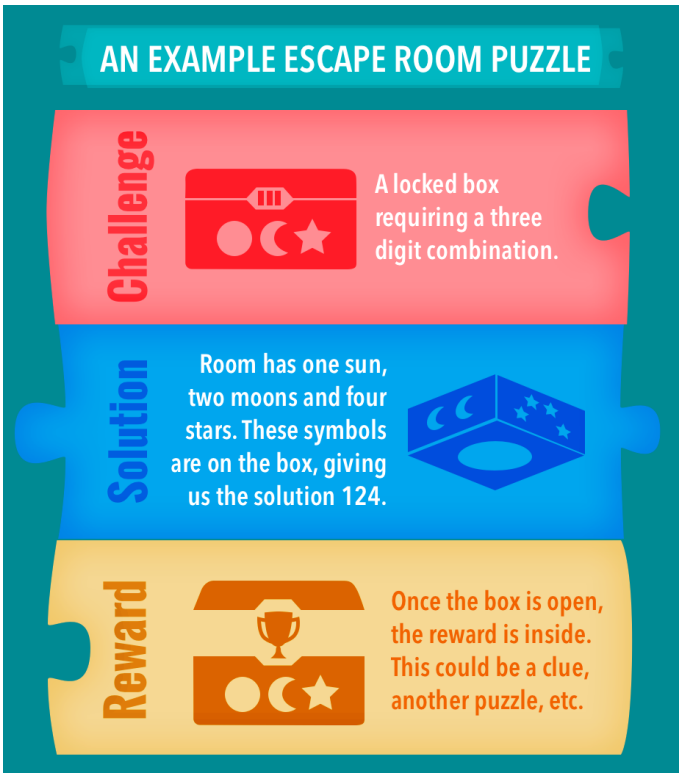
Introduction

In the past decade Escape Rooms have popped up all over the world. This new phenomenon succeeded in challenging and entertaining people at the same time and people of all ages and genders were actively looking to participate all around the globe. What started as a single Escape Room in Kyoto, Japan in 2007 was soon booming in their entertainment industry and was quickly embraced by the rest of Asia, followed by Eastern-Europe, North- and West-Europe, Australia, Canada and last but not least the USA (Nicholson, 2015; Nightingale, 2018). At the start of this research project the Escape Room Directory has listed roughly 3400 Escape Rooms worldwide (personal communication, June 28, 2018), but indicated that their list is far from complete.

The goal of Escape Rooms is to find the key to escape from a locked room. In an Escape Room the players are confronted with multiple puzzles (some obvious, other well hidden) they need to solve. Solved puzzles lead to clues for solving other puzzles, ultimately leading to a final puzzle that provides the solution, the conclusion of the story, the key to escape the room (figure 1). Varieties on this theme are also possible, players do not have to be physically locked up (the door is closed but unlocked at all times) and the Escape Room does not even have to be a room, it can also be a box with locks that the players need to crack in order to get a key to solve a mystery or problem (Vörös & Sárközi, 2017).

Figure 1

A generalized example of Escape Room puzzles



Note. Reprinted from "Escape Room Games", by Wiemker, M., Elumir, E. and Clare, A., 2015 (https://thecodex.ca/wp-content/uploads/2016/08/00511Wiemker-et-al-Paper-Escape-Room-Games.pdf).

Since Escape Rooms require cooperation, knowledge, a various skillset among the players and since they provide variety and fun, numerous teachers are already exploring the usage of Escape Rooms as educational strategy in their teaching practices. However, the scientific fundament for the usage of Escape Rooms in education is still small. Even less is known about what elements an Escape Room should contain when deployed as an educational strategy in secondary school education.

In other words, there is a paucity of research on Escape Rooms, especially in Science, Technology, Engineering and Mathematics education in secondary education (Veldkamp, van de Grint, Knippels & van Joolingen, 2020). There is more research to be found about game design elements in game-based learning (GBL) settings and about which game design elements are responsible for higher learning outcomes among students. Therefore, the aim of this research project would be to find game design elements that enhance learning in game-based learning settings and to embed those elements in an Escape Room used in secondary biology education in order to enhance its educational potential. By doing this we hope to be able to provide guidelines for educational Escape Room designers. Hence our research question: which game design elements can enhance the educational potential of Escape Rooms within secondary biology education? To answer this research question we have formulated the following subquestions:

1. to what extent did secondary biology students achieve the intended learning goals by playing an Escape Room based on game design elements which foster learning?
2. to what extent did the embedded game design elements foster students' learning?

To be able to answer these questions in the empirical part of our research project we will first comb through existing literature to find game design elements which enhance learning and then we will compare those with the design elements already present in Escape Rooms, before we embed or enhance those design elements in our own Escape Room.

Theoretical background

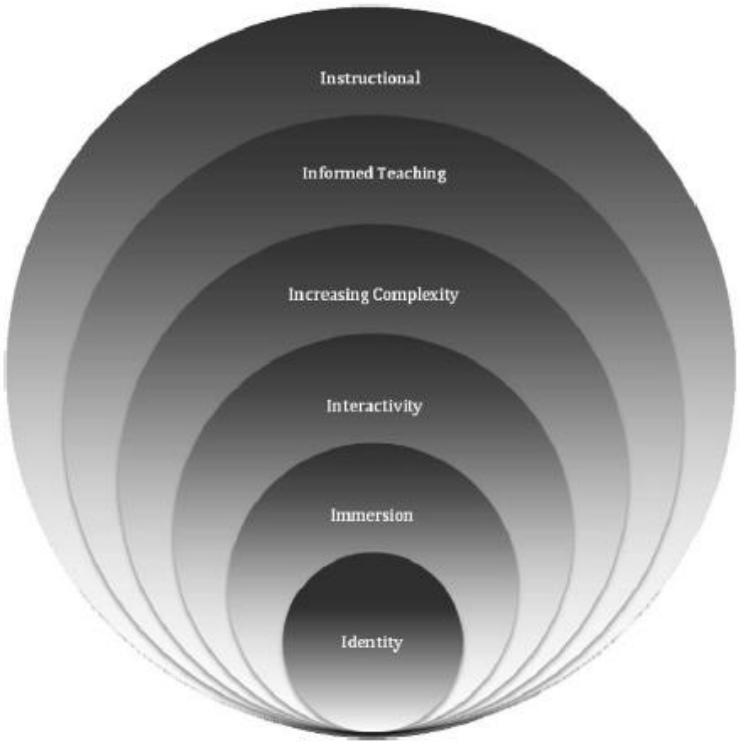
Games exist in many forms and differ in their purposes. Entertainment games are games which are made to entertain people, whereas serious games (Stapleton, 2004; Susi, Johannesson, & Backlund, 2007) are games which are made for a more serious goal than entertaining people, for example for education or team-bonding purposes. When serious games are applied in the educational sector, another concept being used in the literature is serious educational games (SEGs) (Michael & Chen, 2005).

Important elements of serious educational game design

Since we would like to know which important game design elements enhance learning and since SEGs are games designed for learning purposes, we expect SEGs to contain the most elements which enhance learning. Annetta (2010) has been researching the subject of SEG design for over a decade and defines six elements that are essential when designing a SEG, see figure 2 below.

Figure 2

Nested elements of educational game design



Note. Reprinted from "The "I's" have it: A framework for serious educational game design", by Annetta, L. A., 2010, *Review of General Psychology*, *14*(2), p. 106.

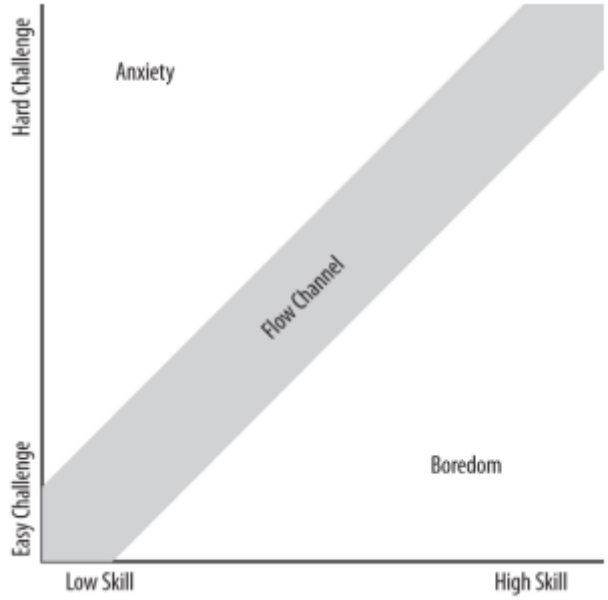
Identity stands for the ability of the SEG to capture the player's mind and trick him into believing he is a unique individual in the environment. *Immersion* means that players are engaged in the content and because they identify themselves with the main character, they become intrinsically motivated to proceed through the game's obstacles and objectives to reach a certain goal. *Interactivity* is about the players interacting with each other and where teamwork and communication are key. The most difficult part of SEG design stated by Annetta is where the designer tries to implement *increasing complexity* of content and concepts. *Informed teaching* is about the ability to monitor the students' progression through the SEG's data collection in order to give immediate feedback. *Instructional* in

this model means that a SEG should be seamlessly embedded in the regular curriculum. The teacher decides when and how to use the SEG in order to maximize its learning outcomes.

Another very important concept to reckon with while designing SEGs is flow. Finneran and Zhang (2005) stated that flow represents a state of consciousness, and that during flow, people are so absorbed in an activity that they show high performance without being aware of their surrounding environment. Breuer and Bente (2010) call it a 'blended learning experience' and even Annetta (2010) covertly refers to flow as 'stealth learning'. These authors describe their concepts as students not being aware that they are learning embedded content while playing a SEG. The concept of flow was defined by Csikszentmihalyi in 1990 as *"the state in which people are so involved in an activity that nothing else seems to matter; the experience is so enjoyable that people will do it even at great cost, for the sheer sake of doing it"*. Figure 3 below is a visual representation of this concept.

Figure 3

The concept of flow in game design



Note. Reprinted from "*Designing Games: A Guide to Engineering Experiences"*, by Sylvester, T., 2013, p. 40, Sebastopol: O'Reilly Media Inc.

The grey diagonal line in figure 3 represents flow. Players should always be in a flow when playing a game, meaning that the challenge presented should be perfectly balanced with the players' ability level. This means that players with low skill should have an easy challenge, whereas players with high skill need to have a hard challenge in order to be able to learn. If a player has a low skill and the challenge is too hard, then the player will get anxious or frustrated. Likewise, if a player has a high skill and the challenge is way too easy, then the player will get bored.

In 1987 Malone and Lepper already researched intrinsic elements that would enhance a learning game's educational potential. In their taxonomy of intrinsic motivations for learning they describe challenge (by implementing clear goals, variable difficulty levels and frequent, clear, constructive and encouraging feedback), fantasy, curiosity (both sensory and cognitive) and control as individual intrinsic motivators as well as cooperation, competition and recognition as interpersonal motivators for learning. Schaller (2005) complemented the elements defined by Malone and Lepper (1987) by adding iteration and reflection as additional criteria for learning games.

According to Stott and Neustaedter (2013) some elements found in game design are consistently more successful than others when applied to learning environments. These are the freedom to fail, rapid feedback, progression and storytelling. The freedom to fail encourages students to experiment and to take risks without the fear of failing. This shifts their focus from the final result to the learning process itself. Multiple studies point to this element as an effective tool to increase student engagement (Gee, 2008; Salen, 2008; Lee & Hammer, 2011; Kapp, 2012). Rapid feedback is needed to timely adjust the learning process. The more frequent and the more targeted the feedback is, the more effective the learning process becomes (Kapp, 2012). Progression, the third element Stott and Neustaedter found, is seen in the form of levels in game design. Each level teaches new skills or knowledge which should be combined to pass the level. The last element, storytelling, increases the students' recall by adding a story to the concepts being taught, which also increases the students' engagement and motivation.

Based on the previous literature findings the following SEG design elements which enhance learning have been found:

- rapid feedback
- immersion[a] (e.g. by storytelling)
- flow[a] (e.g. by challenge and progression)
- freedom to fail
- collaboration[b]
- clear goals
- reflection
- iteration

Now that we know which important elements should be considered when designing a SEG, in the next paragraph we will look into the elements that are important in designing Escape Rooms. This might give us clues about elements that should be adopted in serious escape games.

[a] Immersion and flow are not literally *design* elements of a game but are nevertheless important elements to consider when designing a SEG. These elements were incorporated in the summation for comprehensiveness and clarity reasons.
[b] Collaboration does not necessarily have to be present in a SEG.

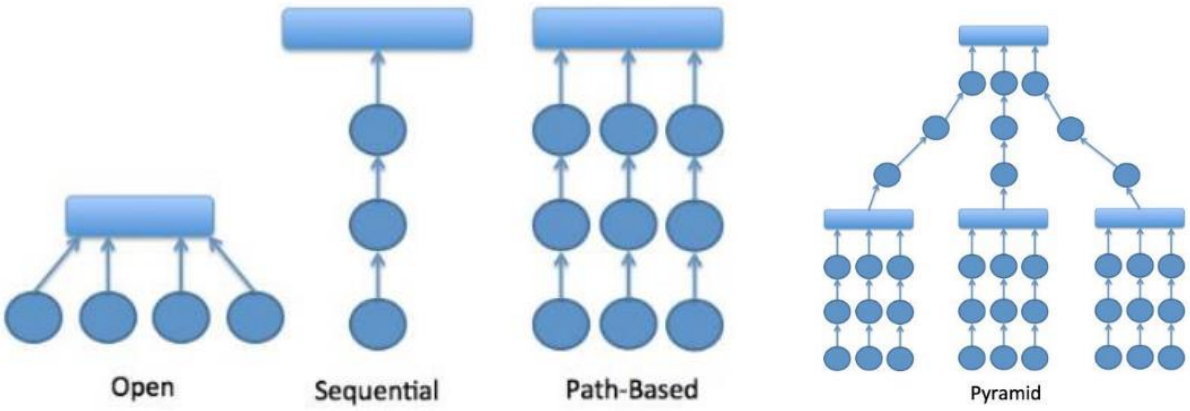
Important elements of Escape Room design

Nicholson has performed multiple studies about Escape Rooms (Nicholson, 2015, 2016a, 2016b, 2018) in order to find out what the essential components of an Escape Room are. He found out that most Escape Rooms included a mystery, a goal, opportunities for collaborative problem solving, multiple challenging puzzles, time limits, a gamemaster and a debriefing at the end. More advanced Escape Rooms included a theme, a story, immersion, role playing, a gamemaster in character and red herrings (Nicholson, 2015). Nicholson especially highlights the role of the gamemaster in Escape Rooms. The gamemaster's crucial task is monitoring the players and giving them hints when they get stuck with the puzzles; preventing frustration and interruption of flow. The gamemaster also makes sure that the puzzles are functioning, that no property is damaged, resets the room after the players have solved the puzzles or when the time is over and is available for questions (or a debrief) of players at the end of the game. The debriefing also helps in returning the players from a highly stressful emotional state back to the 'real' world and can be a useful opportunity to evaluate the Escape Room experience.

Nicholson also found multiple puzzle design patterns used in the design of Escape Rooms (figure 4).

Figure 4

Most common puzzle design patterns used in Escape Rooms worldwide



Note. Adapted from "Peeking behind the locked door: A survey of Escape Room facilities", by Nicholson, S., 2015 (http://scottnicholson.com/pubs/erfacwhite.pdf).

In figure 4 the four most common puzzle design patterns used in Escape Rooms worldwide are being shown. In an open design pattern multiple unconnected puzzles lead to a meta-puzzle. Solving the meta-puzzle (pictured by a rectangle) requires the solutions of all the previous puzzles (pictured by circles). In the sequential design pattern solving a puzzle leads to another puzzle which leads to another puzzle which leads to solving the meta-puzzle. In the path-based design pattern players can split up, solve sequential puzzles parallel and then finish the meta-puzzle together using the solutions of the previous puzzles. Hybrids of these design patterns were also found, hence the pyramid model.

In a later study by Nicholson (2018) about creating Escape Rooms for classroom usage, Nicholson evaluated three different Escape Rooms designed for classroom usage. He found that a narrative using real-world content, a goal, a time limit, a variety of challenges, cooperation and reflection afterwards were the most important elements to embed in an educational Escape Room.

Figure 5

The escapED Framework

Note. Reprinted from "escapED: a framework for creating educational escape rooms and Interactive Games for Higher/Further Education", by Clarke, S., Peel, D. J., Arnab, S., Morini, L., Keegan, H. and Wood, O., 2017, *International Journal of Serious Games*, *4*(3), p. 78.

Clarke et al. (2017) developed a framework specific for designing educational Escape Rooms, which they call the 'escapED Framework', pictured in figure 5 above. In this framework the participants, objectives, theme, puzzles, equipment and evaluation are the major elements to consider when designing an educative Escape Room. The Escape Room designer needs information about the players in order to set appropriate objectives, difficulty levels and time limits. In their paper the authors describe the need for a theme in order to enhance the engagement of the players. This can be partially accomplished by adding a story, but also by implementing props and actors. The Escape Room should have clear instructions on how to solve the puzzles and in case the players do not manage to solve a puzzle and get stuck (ruining their flow), clues or hints should have been prepared to help the players to continue. The puzzles should reflect the objectives chosen earlier in the design process. Reflection by the players on their experience with the Escape Room and evaluation of the objectives formulated is necessary to check if the players achieved said objectives.

Stasiak (2016) lists a theme, immersion, a door, a clock, a desk, paper, pens/pencils, artefacts, a soundtrack, game monitoring, a gamemaster, caskets and different puzzle paths as most common found elements of Escape Rooms. Clare (2015) found the following important elements that should be reckoned with while designing an Escape Room:

- a tutorial
- context and narrative should be suitable for the target audience
- a goal
- every puzzle should remind the players of your narrative
- a good balance between time vs. difficulty, frustration vs. boredom, resulting in flow
- easy puzzles in the start, harder puzzles later in the game
- open, sequential or linear puzzle designs
- puzzles should use logic, should be solvable and there should be clues to solve them
- level design (starting position, mood state, inventory, end goal)
- variate audio, video, contrasting colors, hidden messages

- vista moments: moments to sit back for a little bit, to enjoy huge success. It lets players recollect their thoughts

For the usage of Escape Rooms in a classroom setting, Dietrich (2018) deems a historical background, immersion in the story, a clear goal to complete in a set time, cooperation, competition and an appropriate classroom environment necessary. After the students have solved the Escape Room, a debriefing should take place to allow the students to reflect on what they have learned by playing the Escape Room and to give pointers to further resources for the students to study.

Giang et al. (2018) consider flow and debriefing as the most important elements of an Escape Room. Their statistical analysis shows that most players were in a flow during the activity and that most participants highly appreciated the debriefing at the end; according to the researchers the debriefing opened the eyes of the players, allowing for a better comprehension of the subject.

A study by Kinio, Dufresne, Brandy and Jetty (2019) assessed the impact of an Escape Room designed by them on students' motivation, learning, retention, preparation and overall satisfaction. Their Escape Room included an introduction with instruction, a theme (vascular surgery), props, hidden puzzles and clues, a challenge, knowledge- and technical skill-based problems, a limited amount of time and a debriefing. Remarkable in this study is that the researchers did not use a gamemaster in the Escape Room, the students had to find hints left in the room instead. In the discussion of their study the authors mention that they could have provided more hints to groups that got stuck, or that they could have organized the puzzles in order of incrementally increasing difficulty. Most likely this would have increased the flow of the players and thus the learning process of the students.

Comparing SEG design elements with Escape Room elements

The previous literature findings from both commercial and educational Escape Rooms show that there is a diverse set of elements to reckon with while designing Escape Rooms. All the elements that have been found in the articles throughout the previous paragraph have been collected and were categorized (see Appendix A). In table 2 below we will now compare the most important SEG design elements with the Escape Room elements which were found in the previous paragraph.

Table 2

Comparison of most important SEG design elements with Escape Room elements

Most important SEG design elements	Escape Room elements
- Rapid feedback	- Provided by a gamemaster or otherwise (via locks, audio-visual cues, etc.)
- Immersion[a] (e.g. by storytelling)	- Story, theme, narrative, dressed up actors, props, environment
- Flow[a] (e.g. by challenge and progression, occupying sensory channels)	- Flow (e.g. by challenge and progression, occupying sensory channels)
- Freedom to fail	- Limited freedom to fail due to time limit, but rapid feedback negates this partially
- Collaboration	- Collaboration
- Clear goals	- Clear goals in a set time limit
- Reflection	- Debriefing by a gamemaster
- Iteration	- Iteration can be implemented by repeating answers needed for solving puzzles

[a] Immersion and flow are not literally *design* elements of a SEG or Escape Room but are nevertheless important elements to consider when designing one. These elements were incorporated in the table for comprehensiveness and clarity reasons.

As can be seen, all of the most important SEG design elements can be linked to one or more Escape Room elements as found in the previous paragraph. A well-designed Escape Room thus has great educational potential.

Methods

To optimize the educational potential of Escape Rooms in classroom settings, we have chosen to investigate three elements from table 2 which we expected to have the greatest impact on students' learning. The elements we chose are immersion, collaboration and debriefing.

We expected immersion to be quite difficult to attain in a regular classroom setting, since no props, décor or actors are present and the financial means to buy or hire those are limited on most public schools. Immersion (Ermi & Mäyrä, 2005) is closely linked to engagement (Hamari et al., 2016) and can have a positive impact on learning outcomes (Cheng, She, & Annetta, 2015).

Collaboration is key in solving Escape Rooms (Nicholson, 2015) and since collaborative learning (Dillenbourg, 1999) has proven to have many advantages (Chandra, 2015), we expected a learning gain if the students collaborated in solving the presented puzzles of the Escape Room. Additionally, the need for collaboration between students in order to solve an Escape Room is also a motivator for teachers to employ Escape Rooms in their teaching practices (Veldkamp, van de Grint, Knippels, & van Joolingen, 2020).

The debriefing is a moment in which the students have time to gather their thoughts, reflect on what they have learned and in which they have the opportunity to ask remaining questions after playing the Escape Room (Sanchez & Plumettaz-Sieber, 2019). Reflection has proven to be very important in regular classroom activities, since it allows students to scaffold their knowledge and skills (Maybin, Mercer, & Stierer, 1992).

Implementation of enhanced game design elements in an Escape Room

Since our Escape Room was tested on secondary school students on public schools in regular classrooms, our Escape Room had to be fast and easy to assemble and disassemble. That is why we used an escape box (a portable Escape Room, see Veldkamp, Daemen, Teekens, & Koelewijn, 2019) with the three elements immersion, collaboration and debriefing embedded and enhanced.

Immersion was enhanced by a narrative around two themes (Q-fever and immunity) in which students had a role, by appropriate clothing for the roles the students fulfilled, by small props and by specifically for this purpose designed video and sound recordings. The design of the escape box featured a hexagonal shape and little height so that the students would have to gather around the escape box and would be less distracted by their environment in order to increase immersion.

Collaboration was enhanced by assigning roles (veterinarian, live-stock farmer, civilian, government, general practitioner) to the students, who needed each other to solve the puzzles presented. The puzzles were designed in a way that made it impossible to solve all puzzles individually in the given amount of time, ensuring mutual social dependency. To further encourage collaboration the escape box featured a hexagonal shape and little height, so students had to gather around it and had short physical communication lines.

The debriefing took place after all the groups of students solved their escape boxes and was done by their own teacher, who was guided by a PowerPoint developed by the authors. This PowerPoint included necessary elements for a debriefing (Sanchez & Plumettaz-Sieber, 2019), such as collecting feedback about the students' game experiences, collecting students' feedback on learning and discussing the links between concepts, the content to be learnt and the puzzles with the students.

The full development of this escape box is described in a separate study by Veldkamp et al. (2020).

Instruments

The escape box on zoonoses was then evaluated in classroom settings in Dutch secondary schools among students with an age range of 16 to 20 years old (*N* = 126). To be able to answer subquestions 1 and 2 a pre- and post-knowledge test was deployed, as well as a post-activity survey, classroom observations and semi-structured interviews.

The pre- and post-knowledge test was used to measure if the students gained content knowledge about the subject of the escape box (immunity and zoonoses). The knowledge test was developed by the authors and teachers who work regularly with secondary school students and know how to relate the content to the existing secondary school curriculum. The pre- and post-knowledge test (appendix B, p.37 and 38) consisted of statements with three answer possibilities, 'correct', 'incorrect' or 'I do not know'. Before the administration of the pre- and post-knowledge test the researchers clearly instructed the students not to randomly guess the correct answer but to answer 'I do not know' instead, in order to prevent errors in measuring the students' content knowledge as much as possible.

The post-activity survey (appendix B, p.39-41) was used to discover to what extent the enhanced game design elements which could foster learning had contributed to any potential learning gains. The questions for the post-activity survey – using a 5-point Likert scale – were either adopted or adapted from other studies or developed by the authors, see table 3 below.

Table 3

Sources used for the questions of the post-activity survey and whether the questions were adopted, adapted or developed by the authors

Questionnumber	Adopted, adapted or developed	Source
PA1	Developed	
PA2	Developed	
PA3	Developed	
PA4	Adapted	Giang, C., et al. (2018)
PA5	Adapted	Giang, C., et al. (2018)
PA6	Adapted	Jennett, C., et al. (2008)
PA7	Adopted	Jennett, C., et al. (2008)
PA8	Adapted	Jennett, C., et al. (2008)
PA9	Adopted	Veenman, S., Kenter, B., & Post, K. (2000)
PA10	Adapted	Cain, J. (2019)
PA11	Adopted	León-del-Barco, B., Mendo-Lázaro, S., Felipe-Castaño, E., Fajardo-Bullón, F., & Iglesias-Gallego, D. (2018)
PA12	Adapted	Lin, G. Y. (2004)
PA13	Developed	
PA14	Developed	
PA15	Developed	
PA16	Developed	
PA17	Developed	
PA18	Developed	
PA19	Adapted	Giang, C., et al. (2018)
PA20	Adapted	Hwang, G. J., Sung, H. Y., Hung, C. M., Huang, I., & Tsai, C. C. (2012)
PA21	Developed	
PA22	Developed	

The classroom observations (appendix C) and semi-structured interviews (appendix D) assisted in further exploration as to what the students learned and to what extent the enhanced game design elements which could foster learning contributed to this. The classroom observations (*N* = 6) were done by an external observer who used a predefined coding scheme and an observation scheme (appendix C), based on literature findings. We made a separation between students being on-task and students being off-task in the coding scheme as to determine what undermines the immersion. Furthermore, we created different categories for the on- task behavior of the students to research to what extent the students were collaborating, see table 4 below.

Table 4

Coding scheme used for classroom observations.

Abbreviation	Abbreviation written out	Description
OI	Off-task individueel	Zelf afgeleid (bijv. gebruik mobiel)
OO	Off-task omgeving	Afgeleid door iets buiten de groep
OG	Off-task binnen groep	Afgeleid door een teamlid
CF	On-task content fysiek	Fysiek aan het puzzelen
CO	On-task content overleggen	Aan het overleggen met een teamlid
CU	On-task content uitleggen	Iets aan het uitleggen aan een teamlid
CK	On-task content kijken	Kijkend naar de box, mogelijk nadenkend
CV	On-task content vraag	Vraag aan gamemaster of docent over inhoud box
GV	On-task game vraag	Vraag aan gamemaster of docent over procedure
GA	On-task game anders	Bezig met het spel, maar anders dan met de inhoud

The observer picked a random escape box (out of 5) at the start of the activity, waited for a group of students to come to the escape box and observed the group until they solved the escape box. Every 15, 12 or 10 seconds (depending on the size of the group; four, five or six students respectively) a student in a specific role was observed. This was done each minute in a sequential order of the roles available, e.g. all roles were observed once each minute. Based on the activity of the student observed, the observer wrote down the appropriate abbreviation in the observation scheme in the appropriate timeslot. Another researcher performed the role of game master (for more information about gamemasters, see the section 'important elements of Escape Room design', p.9), aiding groups of students who got stuck (whether due to technical or cognitive difficulties).

Data analysis

A non-random sampling strategy was used since the teachers and students were selected to participate on a voluntary basis. The results of the pre- and post-knowledge tests and the post-activity survey of the students were incorporated in the quantitative statistical analysis of this research. The pre- and post-knowledge tests were tested on validity and reliability. Pearson's Product Moment Correlations in SPSS version 26 was used to test the validity of the pre- and post-knowledge

tests and Cronbach's alpha in SPSS version 26 was used to test the reliability. A paired samples t-test was used to determine whether the content knowledge of the students had increased. For the analysis of the post-activity survey and the classroom observations, descriptive statistics and qualitative analysis were used.

The semi-structured interviews used to investigate how the students perceived the escape box were subject to qualitative analysis, so no statistical analysis was applied. Interviews used were semi-structured, recorded and transcribed verbatim. An open coding system (Boeije, 2010) in NVivo 12 was used to categorize the recurrent themes that were found. The interviewed students were randomly picked from the groups available.

The effect size for this study could not be determined from previous research, since almost no research has been done in this specific area. The same goes for the power analysis, since almost no research has been done in this area we were unable to determine what the minimum number of participants should have been.

Ethics

In this research project the guidelines of the Ethical Committee of the Faculty of Science (UU) were followed.

Results

In this section we will present the results of the empirical part of our research. The subquestions we hoped to answer with this empirical study were:

1. to what extent did secondary biology students achieve the intended learning goals by playing an Escape Room based on game design elements which foster learning?
2. to what extent did the embedded game design elements foster students' learning?

Achievement of intended learning goals

To answer subquestion 1 a pre- and post-knowledge test was conducted among students aged 16 – 20 years old (*N* = 126). The pre-knowledge test was administered just before the students started to work on solving the escape box and the post-knowledge test was administered after the debriefing,

which took place 40 minutes after the start. Six classes were tested on two different schools. Answers given by the students were subsequently graded by the researchers; 1 point for every correctly answered question and 0 points for every incorrectly answered question or for questions answered with 'I do not know'. No students' test results were omitted. The content validity of the pre- and post-knowledge test was determined by experts and the pre- and post-knowledge test was updated until a CVI of 1.00 was reached. Pearson's Product Moment Correlations in SPSS version 26 was used on the results of the post-knowledge test to determine if there were any questions that were misunderstood by the students. Question 13 (see appendix B) showed a mostly negative and sometimes significant correlation with the other questions and was prone to omission. To determine the reliability of the pre- and post-knowledge test Cronbach's alpha was used and was respectively 0.779 and 0.718. These values are both in the acceptable range, the first value being close to the good range. The highest reliability achievable would be a Cronbach's alpha of 0.784 for the pre-knowledge test and 0.739 for the post-knowledge test if question 13 were to be omitted. Based on these results the answers on question 13 were omitted from further data analysis.

Calculation of the means of the pre- and post-knowledge tests (*M* = 0.434, *SD* = 0.267; *M* = 0.831, *SD* = 0.104 respectively) show that the students indeed achieved the intended learning goals by playing our escape box based on game design elements which foster learning. For further proof of this a paired samples t-test was conducted, see table 6 on the next page.

Table 6

Results of the paired samples t-test

Pair		*M*	*SD*	*p* (2-tailed)
Pair 1	K1PRE - K1POST	-.889	.316	.000**
Pair 2	K2PRE - K2POST	-.841	.367	.000**
Pair 3	K3PRE - K3POST	-.738	.441	.000**
Pair 4	K4PRE - K4POST	-.587	.510	.000**
Pair 5	K5PRE - K5POST	-.778	.417	.000**
Pair 6	K6PRE - K6POST	-.429	.528	.000**
Pair 7	K7PRE - K7POST	-.492	.502	.000**
Pair 8	K8PRE - K8POST	-.175	.553	.001**
Pair 9	K9PRE - K9POST	-.119	.531	.013*
Pair 10	K10PRE - K10POST	-.040	.320	.166
Pair 11	K11PRE - K11POST	-.087	.380	.011*
Pair 12	K12PRE - K12POST	-.214	.449	.000**
Pair 13	K14PRE - K14POST	-.302	.555	.000**
Pair 14	K15PRE - K15POST	-.222	.454	.000**
Pair 15	K16PRE - K16POST	-.135	.445	.001**
Pair 16	K17PRE - K17POST	-.405	.524	.000**
Pair 17	K18PRE - K18POST	-.635	.500	.000**
Pair 18	K19PRE - K19POST	-.056	.342	.071

*$p < .05$. **$p < .01$.

As can be seen in table 6, the means of the students' scores on the post-knowledge test are all higher than the means of their scores on the pre-knowledge test. This difference in test score means is significant for all questions, except for questions 10 and 19. Bear in mind that the students' scores either have the value of 0 or 1 and that the mean difference shown in table 6 is the mean score of the pre-knowledge test compared to the mean score of the post-knowledge test. Therefore, a negative mean difference score is actually a positive result as it shows an improvement of the students' scores. The highest mean difference is observable for question 1, which is -0.889. This means 89% of the students improved their content knowledge. A small mean difference as observed for questions 10, 11 and 19 does not necessarily mean the students' content knowledge of a certain concept is weak, in contrary, their content knowledge was already high for these items (see appendix E) and only a few student's improved their content knowledge on the particular concept being questioned. The paired samples t-test clearly shows that the majority of the students have improved their content knowledge on the topic of immunity and zoonoses significantly by playing our escape box.

Contribution of enhanced game design elements to students' learning

In order to answer subquestion 2 a post-activity survey (*N* = 126), classroom observations (*N* = 6) and interviews (*N* = 14) were conducted. With the post-activity survey the students self-evaluated to what extent they were immersed, to what extent they collaborated and to what extent the debriefing helped them to understand the content knowledge. 18 out of 22 items on the post-activity survey were relevant to determine this. The reliability of these 18 items was tested with Cronbach's alpha and was 0.805, which is in the 'good' range. The survey items were divided into immersion, collaboration and debriefing items and then the means were calculated, even though the students answered on 5-point Likert scales. We are aware of the problem in the sociological field that the distances between the Likert scale points does not necessarily have to be equal and that one thus should not calculate means. However, for analysis purposes of this particular study, we presume that the distance between the Likert scale points is even. Table 7 shows the means and standard deviations for the immersion, collaboration and debriefing items in the post-activity survey.

Table 7

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

Category	*M*	*SD*	*N* of items
Immersion	3.9	0.4	7
Collaboration	3.9	0.6	6
Debriefing	3.7	0.2	5

As can be seen in table 7, the high means (3.9 out of 5) for the immersion and collaboration items show that students indicated that they were highly immersed and highly collaborative. The mean for the debriefing items is slightly lower, but also has the lowest standard deviation. This means that the students mostly agree on the usefulness of the debriefing. Further analysis (appendix F) of the immersion items shows high medians and modes for every question about immersion-related aspects, indicating that the majority of the students were not distracted by their environment and were focused on solving the escape box. High medians (5) and modes (5) were also found for PAC10, PAC11 and PAC12, demonstrating high degrees of collaboration. The means of PAC14 and PAC15 (items intended to measure collaborative learning) are the lowest of all the items, respectively 2.98 and 3.33, around the neutral point on the Likert scale. The median (4) and mode (4) of PAC15 are higher than the median (3) and mode (3) of PAC14, which means that more students have received explanations from others than there were students explaining to others. The high mode (4) of PAC15 also means that collaboration fostered learning.

The overall mean for the debriefing items is 3.7 out of 5 (see table 7), which is a bit lower than the overall means for the immersion and collaboration items, but nevertheless leaning towards the positive side of the Likert scale. The means and modes are 4 for all items (see appendix F), except for PAD18 which is 1 point lower. This indicates that the students appreciate the debriefing (PAD16) after playing the escape box in order to expand their content knowledge (PAD19) and to be able to apply this content knowledge in real-world situations (PAD21). The lower mean and mode (3) for PAD18 indicate that the students should have asked more questions, but another item on the post-activity survey reveals that most of the students did not ask questions. Observations by the researchers during the debriefing performed by the teacher also confirmed this, the students were given plenty of opportunities to ask questions during the debriefing but they did not use these opportunities.

Classroom observations

Since the post-activity survey was a self-evaluation by the students, we will now examine the classroom observations (*N* = 6) done by an external observer in order to research if the students were indeed immersed and collaborating (see the methods section for more detailed information on the codes used). Firstly, we distinguished between students being on-task and students being off-task, as one of the criteria of immersion is that one is not easily distracted when someone is immersed (Ermi & Mäyrä, 2005). Based on our observations results, none of the students were off-task during the activity (table 8). This alone is not enough to state that the students were immersed, but combined with the results from the post-activity survey it does support the self-evaluation by the students that they were highly immersed, since none of them were distracted from the task when observed. Secondly, we analyzed the students' behavior based on different predefined categories for the on- task behavior, see table 8 below.

Table 8

Observed student behavior during classroom observations

Number of acts	Percentage of total	Abbreviation	Abbreviation written out	Description
0	0	OI	Off-task individueel	Zelf afgeleid (bijv. gebruik mobiel)
0	0	OO	Off-task omgeving	Afgeleid door iets buiten de groep
0	0	OG	Off-task binnen groep	Afgeleid door een teamlid
136	15.2%	CF	On-task content fysiek	Fysiek aan het puzzelen
229	25.7%	CO	On-task content overleggen	Aan het overleggen met een teamlid
28	3.1%	CU	On-task content uitleggen	Iets aan het uitleggen aan een teamlid
292	32.7%	CK	On-task content kijken	Kijkend naar de box, mogelijk nadenkend
0	0	CV	On-task content vraag	Vraag aan gamemaster of docent over inhoud box
5	0.6%	GV	On-task game vraag	Vraag aan gamemaster of docent over procedure
202	22.6%	GA	On-task game anders	Bezig met het spel, maar anders dan met de inhoud
892	100%			Total

In table 8 we can clearly see that the 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 presented (15.2%). Again, based solely on the observation that the students communicate verbally 28.8% of the observed time does not warrant the conclusion that the students show a high degree of collaboration, but collaboration does not only consist of communication. It also consists of fulfilling your own task, whether that is done by a physical activity, a mental activity or both. If we combine those behavioral aspects together, the students were collaborating 76.8% of the observed time, which is quite high. The combination of the classroom observations and the results of the post-activity survey thus point to a high degree of collaboration.

Student interviews

And finally, to further answer subquestions 1 and 2, students (*N* = 14) were interviewed after the classroom activity had ended in order to further explore to what extent the students' immersion, collaboration and the debriefing contributed towards their learning gains and to further explore what they learned, next to the evidence of the pre- and post-knowledge tests. We will first discuss learning gains as reported by the students and then we will determine to what extent the student's immersion, collaboration and the debriefing contributed to those learning gains as well as to the learning gains found by the pre- and post-knowledge tests. See table 9 for a quick reference of the quoted students' ages, grades, education levels and genders.

Table 9

Quick reference table for quoted student's ages, grades, education levels and genders

Studentnumber	Gender	Grade	Education level
L1	f	4	VWO
L2	f	4	VWO
L3	f	6	VWO
L4	f	6	VWO
L5	m	5	HAVO
L6	f	5	HAVO
L7	m	5	HAVO
L8	m	6	VWO
L9	f	6	VWO
L10	m	6	VWO
L11	m	6	VWO
L12	f	6	VWO
L13	m	6	VWO
L14	f	6	VWO

Note. f stands for female, m stands for male.

Learning gains

During the interviews the students reported learning new content knowledge as well as recall of content knowledge which they had already learned before the activity took place. Examples of this are the difference between B- and T-immunocytes, cellular and humoral immunity, passive and active immunity, herd immunity and why an antibiotic is not effective versus a virus. The statements below substantiate some of these examples.

L8: "Niet echt iets nieuws, voornamelijk het opfrissen van de immunologielessen die we al hebben gehad. De T- en de B-cellen haal ik blijkbaar altijd door elkaar, dus dat."

L9: "Het verschil tussen bacteriën en virus met antibiotica, dat wist ik eerst niet dat dat voor bacteriën juist is maar ik dacht voor virus dus dat heb ik er ook nog uit gehaald."

L6: "Een paar dingen waar ik over twijfelde of het wel of niet zo was dat ik wel een bevestiging kreeg van het is niet zo. Bijvoorbeeld van dat virus en het antibioticum, dat wist ik nog niet zeker."

Most of the students report having learned this from either the debriefing or through communication with other group members. A single student reported having learned content knowledge by just trying to solve the puzzles of the escape box, instead of having learned content

knowledge from the debriefing or by communicating with others. Some of the students also report acquiring more knowledge about the students they worked together with, for example student L11:

"Dus je ziet wel dat sommige mensen andere sterke punten hebben denk ik.".

Students also reveal having learned about collaboration, but we will discuss that in further detail when we discuss what collaboration contributed to the learning gains of the students. In the next section we will further discover to what extent the students were immersed in order to determine if this might have fostered their learning gains.

Immersion

The post-activity survey already revealed that the students were highly immersed and the interviews conducted with the students also support this. Most notably, the students reported not being distracted at all by their environment, since they were focused on solving the escape box.

L9: "Echt totaal niet, want ook in de vragenlijst 'ben je naar andere groepjes gaan kijken', ik heb echt 0… wij zaten echt alleen maar gefocust op die box in ieder geval."

L11: "Ik heb me niet beziggehouden met de rest. Dat heb ik ook net ingevuld op dat formulier, ik heb me echt geen seconde beziggehouden met de rest. Ik had ook niet door dat er iemand anders al klaar was."

L13: "Het was interessant genoeg dat ik niet afgeleid was. Ik was druk bezig om het te proberen te halen, dus ik was niet echt afgeleid eigenlijk."

As to why the students were not distracted, they indicate that they wanted to 'win' (to be the first group of the class to solve the escape box) or that the escape box was interesting enough. The escape box also used roleplay, a narrative, audio, videos and other visual stimuli to immerse the students in the context. When asked about these aspects the students admit that the different roles (different professions) helped them become immersed in the context, although they did not adhere to their roles for the full length of the activity.

L8: "…ik merkte in elk geval dat ik er meteen bij werd betrokken. Dus je staat om die box heen en het eerste wat ik denk is 'wil ik die bandana, wil ik een jas aan of wil ik dat ding' en dan kom je gewoon in die rol en dan vind je het veel leuker om die puzzel op te lossen, want je zit in die rol."

L2: "Wij hebben ons er niet echt aan gehouden, maar je komt wel een beetje in je rol en in het spel…"

Four of the 14 interviewed students did not see the need for the roles (L3, L4, L6 and L7). The majority of the students liked the roles however and as soon as the activity started most of the students were very eager to put on the clothing associated with a role. The videos also contributed to the immersion, see the quotes below.

L1: "Je kreeg er geen antwoorden door maar door die video's werd het wel geloofwaardiger."

L14: "Ik vond dat je daardoor wel wat beter de gevolgen ook kan zien van wat het met mensen doet, bijvoorbeeld die boer die dan al zijn geiten kwijt is, dat dat best wel heftig is. En dat is misschien moeilijk voor te stellen zo, maar als je die beelden erbij hebt dan kan je je echt wat meer er inleven."

A fair share of the students found the videos too long, since they were under time pressure and were waiting for clues; a couple of students thought that the news reader lessened the immersion. Unfortunately, due to the construction of the escape box and due to the buzz in the classroom the sounds emitted from the laptop inside were barely audible, except for the applause at the end which was widely appreciated by the interviewed students. When asked about the difficulty level of the

puzzles, most of the students (*N* = 7) reported that the puzzles were at an appropriate difficulty level, some (*N* = 3) would have wanted more difficult puzzles, while others (*N* = 4) would have liked easier puzzles. The appropriate difficulty level of the puzzles is important since this increases the cognitive load of the students and thus their flow (see p.7). The hexagonal shape of the escape box might have contributed to the focus of the students as well, albeit unconsciously. The statements from the students show that they were immersed while trying to solve the escape box, though the immersion could have been stronger if the news reports were more authentic and if the students would not have been under a time constraint.

Collaboration

The next element we will discuss is to what extent the student's collaboration fostered their learning gains. The students indicate that they learned a very important lesson by collaborating, namely that it takes multiple people to solve complex problems (in the escape box context: it takes different stakeholders to combat a zoonosis successfully), which was the main take home message of the escape box. The quotes below demonstrate the student's understanding of this valuable lesson.

L2: "Dat het bij sommige dingen belangrijk is dat je het niet alleen kunt oplossen."

L8: "Zeker bij het bestrijden van zo'n epidemie dat samenwerking tussen echt iedereen daarvoor nodig is, want op het moment dat dat niet zo is dan valt het uit elkaar."

L9: "Dat als je met meerdere hersenen samen denkt dat je dan wel makkelijker tot een resultaat komt, want iedereen heeft wel op gegeven moment zijn heldere momentjes…"

L10: "Ik denk dat het ook laat zien dat het heel belangrijk is om samen te werken met elkaar. En dat elke sector wel elkaar nodig heeft."

L14: "Dat je realiseert dat er heel veel verschillende soorten mensen bij betrokken zijn, dus dierenartsen en boeren, dat je echt wel samen moet werken om zo'n probleem op te lossen."

The students also learned that they need to communicate when solving complex problems.

L12: "Hulp vragen aan elkaar."

L14: "Dat communicatie belangrijk is, dus je moet gewoon niet alles op jezelf gaan proberen maar als je het niet weet snel hulp vragen i.p.v. er heel lang mee blijven zitten."

And one student even reported collaborative learning taking place:

L11: "… door elkaar te helpen denk ik dat je juist leert, dus dat was op zich juist wel fijn…".

This single quote from student L11 is not the only one that shows that the students learned by collaborating, other students report having learned content knowledge from others.

L9: "…iemand anders wist dan wel het goede antwoord en ik wist het dan nog niet."

L13: "Overleg vooral, bijvoorbeeld met die spuitjes, als ik dan twijfel over bepaalde begrippen dan vraag ik het aan één van de anderen en dan weten die het vaak wel."

Paradoxically, when asked directly what the students learned by collaborating seven students declared that they learned 'nothing', even though they did learn by collaborating (L8, L10, L14). The other four students who said this are students from a school where they collaborate as much as possible during their school career. The quotes in this section show that the majority of the interviewed students learned valuable lessons and content knowledge by collaborating, thus collaboration fostered learning.

The debriefing

In this last section before the conclusion we will examine to what extent the debriefing contributed to the student's learning gains. 12 out of the 14 interviewed students were positive about the debriefing and indicated learning content knowledge because of the debriefing, see the quotes below.

L2: "… sommige dingen weet een ander groepje dan nog wel goed en dan dacht ik van nouja, dat was ik eigenlijk vergeten, dus dat is ook wel handig."

L1: "Zoals L2 al eerder aangaf onthoud je wel die laatste dingetjes nog wat beter."

L4: "Dat de docent het nog even herhaalde dan weet je zeker dat je overal de goede antwoorden hebt gegeven en wordt alles nog even op een rijtje gezet."

L5: "Sommige van die antistoffen had ik nog niet helemaal gezien omdat anderen daarmee bezig waren, dus aan het einde hoorde ik dat nog. Dat was wel fijn."

L7: "Het was wel nuttig want je bent aan het stressen over het spel en dan neem je niet direct alles bewust op… dat je dan denkt van 'oh ja' dat is wat er eigenlijk precies aan de hand was."

L12: "Want je hoort heel veel termen en dingen enzo in de Escape Room, maar je kunt niet per se gelijk de verbanden leggen maar dat wordt dan duidelijk in de nabespreking, dus ik denk dat het wel essentieel is."

Only two of the interviewed students (L8 and L10) deemed the debriefing unnecessary, one because he would rather read the biology textbook, the other one because he thought the usual instruction by his biology teacher was more efficient. L13 and L14 were positive about the debriefing as well, but would have liked some more broadening and deepening on the subject:

L14: "…dat je bijvoorbeeld het terugpakt op die Q-koorts epidemie die er dus wel is geweest dat je daar nog even wat gevolgen over krijgt of andere voorbeelden van zoönoses die er zijn, dat je in die zin nog wat bredere kennis erover krijgt."

None of the other students had points of improvement to recommend. The aforementioned quotes in this section clearly show that the debriefing is of great importance in learning content knowledge according to the majority (86%) of the interviewed students. The next chapter will be the conclusion of this research project, which connects the dots to a coherent answer on our research question.

Conclusion

The research question of this master thesis was 'which game design elements can enhance the educational potential of Escape Rooms within secondary biology education?'. In order to answer this research question we formulated the following subquestions:

1. to what extent did secondary biology students achieve the intended learning goals by playing an Escape Room based on game design elements which foster learning?
2. to what extent did the embedded game design elements foster students' learning?

We were looking for game design elements which could enhance learning and wanted to implement those in our own Escape Room in order to enhance its educational potential. Based on existing literature we found out that game design elements which enhance learning are mostly present in SEGs. Surprisingly, the most important elements of SEG design already correspond largely with elements that define an Escape Room, as shown in table 10 below.

Table 10

Comparison of most important SEG design elements with Escape Room elements

Most important SEG design elements	Escape Room elements
- Rapid feedback	- Provided by a gamemaster or otherwise (via locks, audio-visual cues, etc.)
- Immersion[a] (e.g. by storytelling)	- Story, theme, narrative, dressed up actors, props, environment
- Flow[a] (e.g. by challenge and progression, occupying sensory channels)	- Flow (e.g. by challenge and progression, occupying sensory channels)
- Freedom to fail	- Limited freedom to fail due to time limit, but rapid feedback negates this partially
- Collaboration	- Collaboration
- Clear goals	- Clear goals in a set time limit
- Reflection	- Debriefing by a gamemaster
- Iteration	- Iteration can be implemented by repeating answers needed for solving puzzles

[a] Immersion and flow are not literally *design* elements of a SEG or Escape Room but are nevertheless important elements to consider when designing one. These elements were incorporated in the table for comprehensiveness and clarity reasons.

Since Escape Rooms already include game design elements which foster learning, we then continued with the empirical part of this study by enhancing the educational game elements immersion, collaboration and debriefing in our own portable Escape Room (escape box) in order to find out to what extent these elements fostered students' learning. As described on page 13, we chose to select and enhance these elements since we expected the greatest impact on students' learning by these elements and, since this was a single research project with a limited time span, it was also impracticable to research the effects of all the educational game elements separately or together.

We then tested our escape box with the three aforementioned elements enhanced on six biology classes on two secondary schools in the Netherlands. After analyzing the data, it was clear that the students had shown great learning gains on content knowledge covered by the escape box; the

average score was 4.3/10 on the pre-knowledge test and 8.4/10 on the post-knowledge test. That is an increase of 93%. Beside the learning gains on content knowledge the student interviews showed that the students took the main lesson of the escape box to heart as well: collaboration is key in solving socio-scientific issues, such as zoonoses. Analysis of the post-activity survey, observation schemes and student interviews revealed that the debriefing and high degrees of collaboration played a great role in fostering those learning gains and that immersion fostered those learning gains as well, albeit to a lesser but still positive extent.

We thus conclude that a debriefing and high degrees of collaboration enhance the educational potential of Escape Rooms within secondary biology education the most and that immersion enhances the educational potential to a lesser – but still positive – extent. Based on our literature findings, we would also like to add that a well-designed Escape Room covers all of the most important SEG design elements and thus has a great educational potential, albeit resource-, time- and space-intensive.

Discussion

However, we would like to make a number of remarks to our conclusion and to our methodology, including recommendations for future research.

Due to the nature of Escape Rooms (and our escape box, which uses a hybrid puzzle path and puts the students under time pressure), it is inherent that students will miss certain parts or details of the Escape Room, since they will split up in separate sub teams in order to solve the puzzles and thus the Escape Room in time. This is not necessarily a problem, unless those details are connected to the learning goals connected to the Escape Room. This makes a debriefing essential to guarantee that every student has at least had the opportunity to achieve the learning goals aimed at in each puzzle. The quality of the debriefing strongly depends on the quality of the teacher and his interaction with the students. If the students do not let the teacher know that they do not understand certain concepts, they will learn less from the experience. In our study we had different teachers facilitating the debriefing, which might have influenced the results of our study. We chose this strategy because the teachers would be able to connect the escape box content to what they taught earlier on and the teachers know their classes best, which we hoped would encourage students to ask questions. As Dietrich (2018) and Kinio, Dufresne, Brandy, and Jetty (2019) already advised, an Escape Room should not become a substitute to regular lessons, but it should rather serve as an addition in a learning trajectory, reinforcing knowledge and skills attained in earlier lessons. Vörös and Sárközi (2017) advised that Escape Rooms are suitable for phenomenological study of a new phenomenon, but that in order to provide a deeper understanding in the subject matter additional classes are required. Whichever way teachers want to use an Escape Room, we advise teachers to be aware that educational Escape Rooms are not meant to be standalones and to always connect them to the existing curriculum or learning goals (as advised conform Coppes, Fisser, Smit and Voogt (2009)).

Another drawback of our methodology is that, due to time constraints and due to this being a master thesis, we could only test the students' knowledge on the short term instead of both on the short term and the long term. The long-term effects of playing an Escape Room would make for interesting further research; we expect that the differences in test scores between the pre- and post-knowledge test would be lower and that the effect of our intervention would diminish as time goes on. Further remarks on our pre- and post-knowledge test can also be made, we deliberately chose questions which were unambiguously to score and for concepts on immunology that are well defined within the domain of biology education. Higher order questions of Bloom's revised taxonomy (Anderson et al., 2001) to link concepts, to explain mechanisms or to create models were not included, since we

wanted to measure if there were any learning gains to be found on the level of the lower order questions first, before asking more difficult questions which would be higher on the scale of Bloom's revised taxonomy. Further research can be done with pre- and post-knowledge questions that are on a higher level of Bloom's revised taxonomy. An advantage of the simplicity of the questions used however is that students cannot deduct the correct answers from other questions in the pre- and post-knowledge test or from non-existent contexts in the pre- and post-knowledge test. Another risk in our methodology is that due to insufficient (human) resources students of different classes were not tested simultaneously and could thus communicate about the content or about what they experienced. It is our belief that the students kept this kind of communication to a minimum to not spoil their friends in different classes.

We were also a little disappointed by the smaller contribution of immersion to the learning gains of the students, even though it helped the students focus on the game and its contents. It is plausible that immersion therefore indirectly fostered the students' learning gains. Additionally, it is hard to establish and measure immersion in a regular classroom where multiple groups are solving the same escape box. The attribution of immersion, collaboration and the debriefing to the students' learning gains was tested after the debriefing, but it might be interesting to test the attribution of immersion and collaboration directly after the students solved the escape box or to test the three elements separately with control groups. In our study we cannot exclude whether the three elements were influencing each other or not, nor can we attribute a specific learning gain to a specific element. We would have been able to eliminate the attribution of an element to the students' learning gains when one of the elements would have had a very low score, but this was not the case.

The three elements immersion, collaboration and debriefing all enhanced the learning gains of the students and thus the educational potential of Escape Rooms in secondary (biology) education. High degrees of collaboration while solving the puzzles of the Escape Room and a debriefing after playing the Escape Room have proven to be very effective elements to include when designing an Escape Room for educational purposes. We hope that future researchers and educational Escape Room designers (teachers included) can use our results to improve future Escape Rooms to be used in teaching practices worldwide and, so we hope, that this will lead to students enjoying learning worldwide.

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Appendices

Appendix A – Comparison of publications with important elements of Escape Room design

	Author and year of publication ->	Nicholson, 2015	Clare, 2015	Stasiak, 2016	Clarke et al., 2017	Dietrich, 2018	Nicholson, 2018	Giang et al., 2018	Kinio, Dufresne, Brandy, & Jetty, 2019
	Type of ER ->	commercial	commercial	commercial	educational	educational	educational	educational	educational
Main element	**Sub element**								
Design		multiple puzzles							
	Puzzle design	open, sequential, path-based, pyramid, hybrid, puzzle-path	puzzle design, open, sequential or linear puzzle designs; every puzzle should remind/support the player of/to the narrative; puzzles should use logic and should be solvable; level design should consider starting position, mood state,	different puzzle paths	mode, scale				

			inventory and end goal;						
	Difficulty level	challenging puzzles, red herrings	increasing difficulty level; a single red herring quadruples the difficulty level; hidden messages	2/3 of the players should need a little help to escape the room just in time	difficulty		variety of challenges		significant but attainable challenge; hidden puzzles; knowledge- and technical skill-based problems
	Goals	goal	goal		objectives	objective to complete; clear goal	goal		
	Time limit	time limit	vista moments for players to enjoy huge success and recollect their thoughts		time	set time limit	time-limit		limited amount of time
Immersion		immersion		immersion		immersion			
	Actors	gamemaster in character							
	Environment		variation in audio, video, contrasting colors	soundtrack	location/space design	appropriate classroom environment			

	Story	mystery, theme, story	context and narrative suitable for target audience	theme	narrative design	historical background	narrative using real-world content	theme	theme
	Role-playing	role-playing							
Flow[a]			flow			changes in emotional state		flow	
Social									
	Target audience		target audience and their way of thinking		participants, user type			groups of comparable skill and knowledge levels	
	Collaboration	opportunities for collaborative problem solving				Cooperation	cooperation	cooperation and communication	collaboration and communication
	Competition					Competition			
Equipment									
	Physical props			door, clock, desk, paper, pens/pencils, artefacts, caskets	physical props	multiple different locks (key locks, number combination locks, word combination locks,			props

						directional locks), file holders, box with solution, key or prize			
	Technical props			soundtrack, game monitoring	technical props				
Gamemaster		gamemaster		gamemaster				gamemaster	no gamemaster
	Instruction		tutorial		instruction				introduction with instruction
	Providing clues/hints		clues to solve puzzles		clues/hints			short hints	clues
	Debriefing/reflection	debrief at the end			reflection	debriefing to allow students to reflect on what they have learned and to give pointers to the students for further study	reflection	debriefing afterwards to facilitate discussions about player actions and their consequence; to allow the players to ask questions about the subject; scaffolding	debriefing

[a] Flow is hard to place at the same level as the other main and sub elements, since flow partially depends on the design of the puzzles, the environment, immersion and the skill and knowledge levels of the players. To not extend this table any further, flow was placed in the list of main elements that define an ER instead of being placed on the left side as superior element.

Appendix B – Student forms: pre- and post-knowledge test & post-activity survey

Vragenlijst

Jullie gaan zo meteen een spel spelen over het onderwerp immuniteit met boxen die ontworpen zijn door studenten van de Universiteit Utrecht. Voordat het zover is vragen we je om de onderstaande gegevens in te vullen en de kennisquiz op de volgende bladzijde te maken. Vul je antwoorden met zwarte pen in.

Kleur het bolletje in dat voor jou van toepassing is.

Leeftijd:	○	○	○	○	○	○	○	○
	14	15	16	17	18	19	20	21

Geslacht:	○	○	○
	jongen	meisje	overig

Schoolniveau:	○	○
	havo	vwo

Leerjaar:	○	○	○
	4	5	6

Ik begrijp het onderwerp immuniteit:

○ ○ ○ ○ ○

Heel slecht – slecht – neutraal – goed – heel goed

Ga verder op de volgende bladzijde →

Kennisquiz voor het spelen van de box

De onderstaande vragen testen je kennis over het onderwerp immuniteit en het doen van onderzoek. Beoordeel per stelling of deze volgens jou juist of onjuist is en kleur het bijbehorende bolletje in. Als je het antwoord niet weet ga dan NIET GOKKEN, maar kruis het vakje 'weet ik niet' aan.

	Juist	Onjuist	Weet ik niet
1. Een zoönose is een ziekte die van dier op plant wordt overgebracht.	O	O	O
2. Huisdieren kunnen zoönoses krijgen.	O	O	O
3. Een zoönose is meestal dodelijk.	O	O	O
4. Q-koorts wordt veroorzaakt door een virus.	O	O	O
5. Q-koorts leidt tot miskramen bij dieren.	O	O	O
6. Een van de maatregelen bij het bestrijden van Q-koorts bij dieren is het doden van besmette dieren.	O	O	O
7. Een antibioticum werkt tegen virussen.	O	O	O
8. Bij passieve immunisatie maak je zelf geen antistoffen.	O	O	O
9. Bij actieve immunisatie maak je zelf geen antistoffen.	O	O	O
10. Bij kunstmatige immunisatie word je ingeënt door middel van een vaccin.	O	O	O
11. Bij natuurlijke immunisatie heb je een ziekteverwekker zelf opgelopen.	O	O	O
12. Kudde-immuniteit houdt in dat je beschermd bent tegen een ziekteverwekker doordat bijna iedereen in je omgeving is ingeënt.	O	O	O
13. Bij kudde-immuniteit zijn alle dieren ingeënt met een vaccin.	O	O	O
14. Voor kudde-immuniteit hoeft maar 50% van de mensen in je omgeving te zijn ingeënt.	O	O	O
15. Plasmacellen (B-cellen) maken antistoffen.	O	O	O
16. Cytotoxische T-cellen hechten aan geïnfecteerde cellen en zetten de geïnfecteerde cel aan tot celdood.	O	O	O
17. Afweer door T-cellen is een onderdeel van cellulaire afweer.	O	O	O
18. Afweer door B-cellen is een onderdeel van humorale afweer.	O	O	O
19. De volgorde van een natuurwetenschappelijk onderzoek is probleemstelling – hypothese – onderzoeksvraag – experiment – resultaten – discussie – conclusie.	O	O	O

Stop hier en wacht op instructie

Kennisquiz NA het spelen van de box

De onderstaande vragen testen je kennis over het onderwerp immuniteit en het doen van onderzoek. Beoordeel per stelling of deze volgens jou juist of onjuist is en kleur het bijbehorende bolletje in. Als je het antwoord niet weet ga dan NIET GOKKEN, maar kruis het vakje 'weet ik niet' aan.

	Juist	Onjuist	Weet ik niet
1. Een zoönose is een ziekte die van dier op plant wordt overgebracht.	O	O	O
2. Huisdieren kunnen zoönoses krijgen.	O	O	O
3. Een zoönose is meestal dodelijk.	O	O	O
4. Q-koorts wordt veroorzaakt door een virus.	O	O	O
5. Q-koorts leidt tot miskramen bij dieren.	O	O	O
6. Een van de maatregelen bij het bestrijden van Q-koorts bij dieren is het doden van besmette dieren.	O	O	O
7. Een antibioticum werkt tegen virussen.	O	O	O
8. Bij passieve immunisatie maak je zelf geen antistoffen.	O	O	O
9. Bij actieve immunisatie maak je zelf geen antistoffen.	O	O	O
10. Bij kunstmatige immunisatie word je ingeënt door middel van een vaccin.	O	O	O
11. Bij natuurlijke immunisatie heb je een ziekteverwekker zelf opgelopen.	O	O	O
12. Kudde-immuniteit houdt in dat je beschermd bent tegen een ziekteverwekker doordat bijna iedereen in je omgeving is ingeënt.	O	O	O
13. Bij kudde-immuniteit zijn alle dieren ingeënt met een vaccin.	O	O	O
14. Voor kudde-immuniteit hoeft maar 50% van de mensen in je omgeving te zijn ingeënt.	O	O	O
15. Plasmacellen (B-cellen) maken antistoffen.	O	O	O
16. Cytotoxische T-cellen hechten aan geïnfecteerde cellen en zetten de geïnfecteerde cel aan tot celdood.	O	O	O
17. Afweer door T-cellen is een onderdeel van cellulaire afweer.	O	O	O
18. Afweer door B-cellen is een onderdeel van humorale afweer.	O	O	O
19. De volgorde van een natuurwetenschappelijk onderzoek is probleemstelling – hypothese – onderzoeksvraag – experiment – resultaten – discussie – conclusie.	O	O	O

Ga verder op de volgende bladzijde →

Vragen na het spelen van de box

Mijn rol tijdens het spelen van de box was (*kleur het bolletje in dat voor jou van toepassing is*):

○	○	○	○	○
boer	bevolking	dierenarts	arts	overheid & gemeente

We hebben de Q-koorts binnen de tijd bestreden (*kleur het bolletje in dat voor jou van toepassing is*):

○	○
ja	nee

Geef bij de onderstaande stellingen aan in hoeverre je het met de stelling eens bent door het bolletje in te kleuren, zoals in het voorbeeld. Links is helemaal mee oneens, rechts is helemaal mee eens.

Voorbeeld

○	○	○	●	○

Helemaal mee oneens – oneens – neutraal – eens – helemaal eens

---

1. Ik vond het een leuke les.

Helemaal mee oneens	○	○	○	○	○	Helemaal mee eens

2. Ik zou vaker een soortgelijke activiteit in de les willen doen.

Helemaal mee oneens	○	○	○	○	○	Helemaal mee eens

3. Ik had het gevoel dat ik in een verhaal zat.

Helemaal mee oneens	○	○	○	○	○	Helemaal mee eens

4. De moeilijkheid van de box en mijn vaardigheden zaten op een vergelijkbaar niveau.

Helemaal mee oneens	○	○	○	○	○	Helemaal mee eens

5. De box hield mijn aandacht vast.

Helemaal mee oneens	○	○	○	○	○	Helemaal mee eens

Ga verder op de volgende bladzijde →

6. Ik was bezig met de teams om mij heen die de box probeerden op te lossen.

Helemaal mee oneens ○ ○ ○ ○ ○ Helemaal mee eens

7. Ik was geneigd om te stoppen met spelen om te kijken wat er om mij heen gebeurde.

Helemaal mee oneens ○ ○ ○ ○ ○ Helemaal mee eens

8. De filmpjes, de kleding en de spullen droegen bij aan het verhaal.

Helemaal mee oneens ○ ○ ○ ○ ○ Helemaal mee eens

9. In de groep hebben we vaak gepraat over dingen die niet over de box gingen.

Helemaal mee oneens ○ ○ ○ ○ ○ Helemaal mee eens

10. Al mijn teamgenoten hebben goed samengewerkt om de puzzels van de box op te lossen.

Helemaal mee oneens ○ ○ ○ ○ ○ Helemaal mee eens

11. Mijn teamgenoten hebben belangrijke informatie gedeeld met de rest van de groep.

Helemaal mee oneens ○ ○ ○ ○ ○ Helemaal mee eens

12. Ik had het gevoel dat ik bij de groep hoorde.

Helemaal mee oneens ○ ○ ○ ○ ○ Helemaal mee eens

13. Door de box wordt het duidelijk dat samenwerken belangrijk is om een besmettelijke ziekte te bestrijden.

Helemaal mee oneens ○ ○ ○ ○ ○ Helemaal mee eens

14. Ik heb tijdens deze activiteit geleerd doordat ik iets aan anderen heb uitgelegd.

Helemaal mee oneens ○ ○ ○ ○ ○ Helemaal mee eens

Ga verder op de volgende bladzijde →

15. Ik heb tijdens deze activiteit iets geleerd doordat ik uitleg van anderen kreeg.

Helemaal mee oneens ○ ○ ○ ○ ○ Helemaal mee eens

16. De nabespreking was overbodig.

Helemaal mee oneens ○ ○ ○ ○ ○ Helemaal mee eens

17. Tijdens de nabespreking heb ik vragen gesteld.

Helemaal mee oneens ○ ○ ○ ○ ○ Helemaal mee eens

18. In de nabespreking werden mijn vragen voldoende beantwoord.

Helemaal mee oneens ○ ○ ○ ○ ○ Helemaal mee eens

19. De nabespreking heeft me geholpen om begrippen over immuniteit te begrijpen.

Helemaal mee oneens ○ ○ ○ ○ ○ Helemaal mee eens

20. Het spelen van de box en de nabespreking helpt me bij het voorbereiden op een toets over immuniteit.

Helemaal mee oneens ○ ○ ○ ○ ○ Helemaal mee eens

21. Door het spelen van de box en de nabespreking kan ik de begrippen uit het boek toepassen in echte situaties.

Helemaal mee oneens ○ ○ ○ ○ ○ Helemaal mee eens

22. De aankondiging van de activiteit motiveerde me om het hoofdstuk door te nemen voor de les.

Helemaal mee oneens ○ ○ ○ ○ ○ Helemaal mee eens

Wil je nog iets kwijt? Schrijf het dan hieronder op:

……

……

……

Bedankt voor je medewerking!

Appendix C – Observation schemes

Leerlingobservatie protocol klas …… door …….. Datum …….

Tijd	Arts	Dierenarts	Boer	Overheid	Bevolking	Leerling 6
0						
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
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22						
23						
24						
25						
26						
27						
28						
29						
30						
31						
32						
33						
34						
35						
36						
37						
38						
39						

Leerlingobservatie ethogram

Afkorting	Voluit	Beschrijving
OI	Off-task individueel	Zelf afgeleid (bijv. gebruik mobiel)
OO	Off-task omgeving	Afgeleid door iets buiten de groep
OG	Off-task binnen groep	Afgeleid door een teamlid
CF	On-task content fysiek	Fysiek aan het puzzelen
CO	On-task content overleggen	Aan het overleggen met een teamlid
CU	On-task content uitleggen	Iets aan het uitleggen aan een teamlid
CK	On-task content kijken	Kijkend naar de box, mogelijk nadenkend
CV	On-task content vraag	Vraag aan gamemaster of docent over inhoud box
GV	On-task game vraag	Vraag aan gamemaster of docent over procedure
GA	On-task game anders	Bezig met het spel, maar anders dan met de inhoud

Appendix D – Semi-structured interview questions

Vragen voor diepte-interviews na het spelen van de box

Instructie vooraf: de antwoorden die je geeft worden anoniem en niet herleidbaar verwerkt voor onderzoeksdoeleinden. Je antwoorden worden opgenomen voor verwerking achteraf en zullen verwijderd worden volgens het privacybeleid van het Freudenthal Instituut van de Universiteit Utrecht.

Algemene vragen

1. Zou je een soortgelijke activiteit vaker willen uitvoeren in plaats van een gewone les? Waarom wel/niet?

Vragen m.b.t. immersion (gecreëerd door verhaal, rollen en aankleding)

1. Hoe vond je het verhaal van de Q-koorts? Geloofwaardig? Ongeloofwaardig?
2. Hoe hielpen de video's om in het verhaal te komen?
3. Wat vond je ervan dat iedereen een rol had? Waarom zouden ze dat gedaan hebben?
4. In hoeverre hield je je aan de rol?
5. Hield iedereen zich aan zijn of haar rol?
6. Was het erg als mensen zich niet aan hun rol hielden? Waarom wel/niet?
7. Zorgden de geluiden uit de laptop ervoor dat je betrokken bleef bij het verhaal?
8. In hoeverre werd je afgeleid door je omgeving? Hoe kwam dat?
9. Wat vond je van de puzzels?
10. In hoeverre zorgt de vorm van de escape box ervoor dat je op het spel gefocust bent?

Vragen m.b.t. nabespreking

1. Was de nabespreking nuttig? Waarom wel/niet?
2. Wat heb je geleerd door de nabespreking?
3. Wat zou er verbeterd kunnen worden aan de nabespreking?

Vragen m.b.t. collaboration

1. Hoe ging de samenwerking?
2. Op welke manier heb je van elkaar geleerd tijdens het spelen van de escape box? Bijvoorbeeld door afkijken of overleggen of op een andere manier?
3. Wat heb je over samenwerken geleerd?
4. Wat heb je van elkaar geleerd tijdens het spelen van de escape box?
5. In hoeverre zorgt de vorm van de escape box ervoor dat je samen op het spel gericht blijft?

Appendix E – Detailed paired samples t-test statistics

Pair		*M*	*SD*	*N*
Pair 1	K1PRE	.07	.259	126
	K1POST	.96	.196	126
Pair 2	K2PRE	.10	.305	126
	K2POST	.94	.230	126
Pair 3	K3PRE	.03	.176	126
	K3POST	.77	.423	126
Pair 4	K4PRE	.01	.089	126
	K4POST	.60	.493	126
Pair 5	K5PRE	.09	.283	126
	K5POST	.87	.343	126
Pair 6	K6PRE	.53	.501	126
	K6POST	.96	.196	126
Pair 7	K7PRE	.46	.500	126
	K7POST	.95	.214	126
Pair 8	K8PRE	.58	.496	126
	K8POST	.75	.432	126
Pair 9	K9PRE	.63	.483	126
	K9POST	.75	.432	126
Pair 10	K10PRE	.89	.316	126
	K10POST	.93	.259	126
Pair 11	K11PRE	.72	.450	126
	K11POST	.81	.394	126
Pair 12	K12PRE	.71	.454	126
	K12POST	.93	.259	126
Pair 13	K14PRE	.54	.500	126
	K14POST	.84	.367	126
Pair 14	K15PRE	.51	.502	126
	K15POST	.73	.446	126
Pair 15	K16PRE	.55	.500	126
	K16POST	.68	.467	126
Pair 16	K17PRE	.46	.500	126
	K17POST	.87	.343	126
Pair 17	K18PRE	.23	.423	126
	K18POST	.87	.343	126
Pair 18	K19PRE	.69	.464	126
	K19POST	.75	.437	126

Appendix F – Detailed post-activity survey statistics and quick reference tables

Detailed statistics for the immersion items in the post-activity survey

		PAI3	PAI4	PAI5	PAI6INV	PAI7INV	PAI8	PAI9INV
N	Valid	126	124	126	126	126	124	125
	Missing	0	2	0	0	0	2	1
Mean		3.42	3.66	4.17	4.28	4.40	3.48	4.14
Median		4.00	4.00	4.00	5.00	5.00	4.00	4.00
Mode		4	4	5	5	5	4	5
Std. Deviation		1.007	.987	.919	1.115	.841	1.032	1.019
Variance		1.014	.974	.844	1.242	.707	1.064	1.038
Range		4	4	4	4	4	4	4

Quick reference table for the question numbers related to the immersion items in the post-activity survey

Question number	**Statement**
PAI3	Ik had het gevoel dat ik in een verhaal zat.
PAI4	De moeilijkheid van de box en mijn vaardigheden zaten op een vergelijkbaar niveau.
PAI5	De box hield mijn aandacht vast.
PAI6INV	Ik was bezig met de teams om mij heen die de box probeerden op te lossen.
PAI7INV	Ik was geneigd om te stoppen met spelen om te kijken wat er om mij heen gebeurde.
PAI8	De filmpjes, de kleding en de spullen droegen bij aan het verhaal.
PAI9INV	In de groep hebben we vaak gepraat over dingen die niet over de box gingen.

Detailed statistics for the collaboration items in the post-activity survey

		PAC10	PAC11	PAC12	PAC13	PAC14	PAC15
N	Valid	126	125	125	125	126	126
	Missing	0	1	1	1	0	0
Mean		4.50	4.35	4.50	3.87	2.98	3.33
Median		5.00	5.00	5.00	4.00	3.00	4.00
Mode		5	5	5	4	3	4
Std. Deviation		.713	.918	.779	1.000	1.043	1.049
Variance		.508	.843	.607	1.000	1.088	1.101
Range		3	4	4	4	4	4

Quick reference table for the question numbers related to the collaboration items in the post-activity survey

Question number	Statement
PAC10	Al mijn teamgenoten hebben goed samengewerkt om de puzzels van de box op te lossen.
PAC11	Mijn teamgenoten hebben belangrijke informatie gedeeld met de rest van de groep.
PAC12	Ik had het gevoel dat ik bij de groep hoorde
PAC13	Door de box wordt het duidelijk dat samenwerken belangrijk is om een besmettelijke ziekte te bestrijden.
PAC14	Ik heb tijdens deze activiteit geleerd doordat ik iets aan anderen heb uitgelegd.
PAC15	Ik heb tijdens deze activiteit iets geleerd doordat ik uitleg van anderen kreeg.

Detailed statistics for the debriefing items in the post-activity survey

		PAD16INV	PAD18	PAD19	PAD20	PAD21
N	Valid	126	121	125	125	123
	Missing	0	5	1	1	3
Mean		3.70	3.29	3.92	3.76	3.66
Median		4.00	3.00	4.00	4.00	4.00
Mode		4	3	4	4	4
Std. Deviation		.982	1.172	1.013	1.035	.957
Variance		.964	1.374	1.026	1.071	.915
Range		4	4	4	4	4

Quick reference table for the question numbers related to the debriefing items in the post-activity survey

Question number	Statement
PAD16INV	De nabespreking was overbodig.
PAD18	In de nabespreking werden mijn vragen voldoende beantwoord.
PAD19	De nabespreking heeft me geholpen om begrippen over immuniteit te begrijpen.
PAD20	Het spelen van de box en de nabespreking helpt me bij het voorbereiden op een toets over immuniteit.
PAD21	Door het spelen van de box en de nabespreking kan ik de begrippen uit het boek toepassen in echte situaties.