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To cite this version:

Mathias Monnot, S. Laborie, G. Hébrard, N. Dietrich. New approaches to adapt escape game activities to large audience in chemical engineering: Numeric supports and students' participation. Education for Chemical Engineers, 2020, 32 (6), pp.50-58. 10.1016/j.ece.2020.05.007 . hal-02902064

HAL Id: hal-02902064

https://hal.science/hal-02902064v1

Submitted on 17 Jul 2020

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New approaches to adapt escape game activities to large audience in Chemical Engineering: numeric supports and students' participation

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ABSTRACT

Gamification is a widespread phenomenon that relies on using game mechanics in other areas, such as the learning situation. One of the most exciting types of games in the late 2010s is e*scape games,* where the principle is for the players to manage to escape from a room in which they are locked by finding hidden items and following a sequence of puzzles. The goal of using this type of game is to motivate/involve learners, to make them work and develop adaptability and responsiveness skills. Unfortunately, these *escape games* are only practiced in small groups, and the design is expensive and time-consuming. That is why cost-effective alternatives are proposed in this paper. They are either dematerialized, entirely based on a digital medium (smartphone/tablets/computer), or directly created by students, also with a digital medium, allowing integration into large classes, or at open house events.

GRAPHICAL ABSTRACT

KEYWORDS

Escape-game ; Gamification ; Mobile games ; Serious game ; Educative escape-game ; Student engagement ; Participatory design

1. INTRODUCTION

Attracting a general audience to chemical engineering is a major challenge and developing motivating, inspiring or active teaching methods is important to help students to improve their learning and understanding of the different concepts[1]. Educators have developed educational games[2–5] to involve students in interactive and entertaining activities[6]. Games are an excellent method of active learning in a recreative environment[7] and many methods have been tested in the past decade[8]: word game[9], quiz games[10–18], card games[19,20], dice games[21,22], board games[23–27], computer games[28–30] and memory/concentration game[31–33]. Surprisingly, the use of videogames to illustrate chemical engineering is relatively unexplored in the literature even though pedagogical videogames exist [34–36]. In all these activities, gaming is seen as an alternative approach of boosting communication[37] between students, and might allow them to learn in an entertaining way compared with the traditional lecture format[38,39]. However, most of these games are individual and do not develop team-building or group communication[40]. The use of educational *escape games* is relatively new in the international sphere [41]. Several attempts in real rooms with physical materials have been made in computer science[42], physics[43], chemistry [44–47] or chemical engineering[48,49]. These escape games use scientific concepts and some of them take place in laboratory work rooms. Some educators[50] have set up an adaptable, movable escape game in a practical chemistry workroom, using simple chemical materials and reactions. Others [45] have used a fake crime scene, with students needing to use chemical techniques to conduct the investigation or specific battle box[51]. Yet others have tried[52] to lighten the "physical" part of the escape game by offering a mixture of mechanisms/objects and online puzzles, taking advantage of students' attraction to new technologies. It is in the continuity of this approach that the present work position itself: by completely dematerializing the mechanisms in order to integrate this pedagogy even more easily into the major disciplines, where

groups are large. The examples mentioned above have been very successful with students, in terms of both increasing their motivation and attraction to scientific disciplines and allowing them to work on developing their teamwork and communication skills. These pedagogical games are therefore very interesting tools for an application in the pedagogical system that predominantly uses a classical lectures and/or tutorial approach, where adaptability, mutual aid, and immersion are rarely developed. However, implementation faces logistical problems, such as the immobilization of one or more rooms to simulate confinement and the significant cost of the equipment (locks, secret mechanisms, chests, boxes, etc.). This room must also be emptied of dangerous elements and those not related to the riddle. In addition, teachers face time problems, such as the creation time for scenarios, ideas and puzzles, or the time to test the sequence, test the puzzles and adapt the difficulty, and also the time to prepare for a session (place the mechanisms, prepare the locks, tools/elements) and the reset time for the next group. Finally, the small number of simultaneous participants, estimated to be between 3 and 5 for optimal activity, is also a strong limitation, which can multiply the number of sessions, thus increasing the need for the presence of a teacher to guide and/or help students who could be stranded on certain puzzles.

In order to get around these problems, this paper proposes two educational solutions to adapt the escape games to as many people as possible without this being too time-consuming for the teaching teams or too expensive to set up. The first is to use a digital medium[53–55]: by accessing a website (www.onlinescape.org), students access a scenario tracing the development of one of the world's first chemical engineering processes, the Leblanc Process[48]. Through scientific puzzles, students find combinations of numbers or letters to open other mechanisms represented on the online platform. This paper also proposes that students build their own escape game as part of a project to be used at open house events. This not only reduces the

invested time in the creation of the game by the teaching team but also encourages the students to work on their creativity, innovation, imagination and peer training skills. This, this allows better mastery of student's knowledge gains, as making them active participants in their training enables students to better memorize the knowledge they acquire.

The first objective of this paper is therefore to increase the motivation of students by taking advantage of their predilection for escape games and to help them to develop their skills of group work, adaptability, and communication. The use of a dedicated website will allow automated use by large groups working simultaneously and will also make it possible to play the game outside the usual classrooms or outside the times of contact with teachers, as a personal work tool. The second objective is to create really playful and pedagogical immersion, to break the monotony, to demonstrate the importance of trial and error, to show that failure is surmountable and to reveal the benefits of relying on collaboration/help between students. The use of online/digital escape games should be a suitable approach to capture and direct the expectations and attention of "Y Generation", who have been trained in video games and the internet from an early age. It also responds to the growth challenges expected to affect universities in the coming years, by allowing the digital offshoring of activity without losing innovation and educational originality. The final objective is to develop the creativity and innovation of the students, their pedagogical sensitivity and their involvement in their own institution by asking them to create educational escape games as part of an annual tutored project.

2. APPROACHES

2.1. Digital and mobile escape games

The pedagogical activity is organized by dividing the class/users from the general public into small groups of 2 to 4 people, either in the room with the presence of the teacher or as personal work (Figure 1). Each group needs a computer or a smartphone

and an internet connection. By accessing the http://www.onlinescape.org website, the students launch the "Leblanc" scenario, tracing the development of one of the world's first chemical engineering processes[48]. The pedagogical activity leads students to follow in the footsteps of Nicolas Leblanc, a young French chemist working during the French revolution, who responded to a competition launched by the Academy of Sciences in 1789 to produce "soda" industrially. This activity helps to restore the importance of Nicolas Leblanc, who remains little known to the general public, unlike his contemporaries, e.g. Antoine Lavoisier, even though his process is considered as one of the founding acts of chemical engineering. Through scientific puzzles, students access combinations of numbers or letters to open other mechanisms represented on the online platform. Following a precise sequence, the students will thus advance in groups by tracing the development of the Leblanc process. The escape is not the end of the story: a debriefing at the end of the session highlights the consequences of the process for the environment (passing of the alkali act) as well as its key points.

Figure 1. *The activity in progress in the active pedagogy room at INSA Toulouse 2018/2019.*

Figure 2 illustrates a few pages of the website, showing the puzzles and the different digital “rooms” used. Even though this activity takes place only on a digital medium with an internet connection, it is important to highlight places (office, laboratory, etc.) to transpose the atmosphere of the escape games, in order to accentuate the immersive, playful character of the proposed adventure.

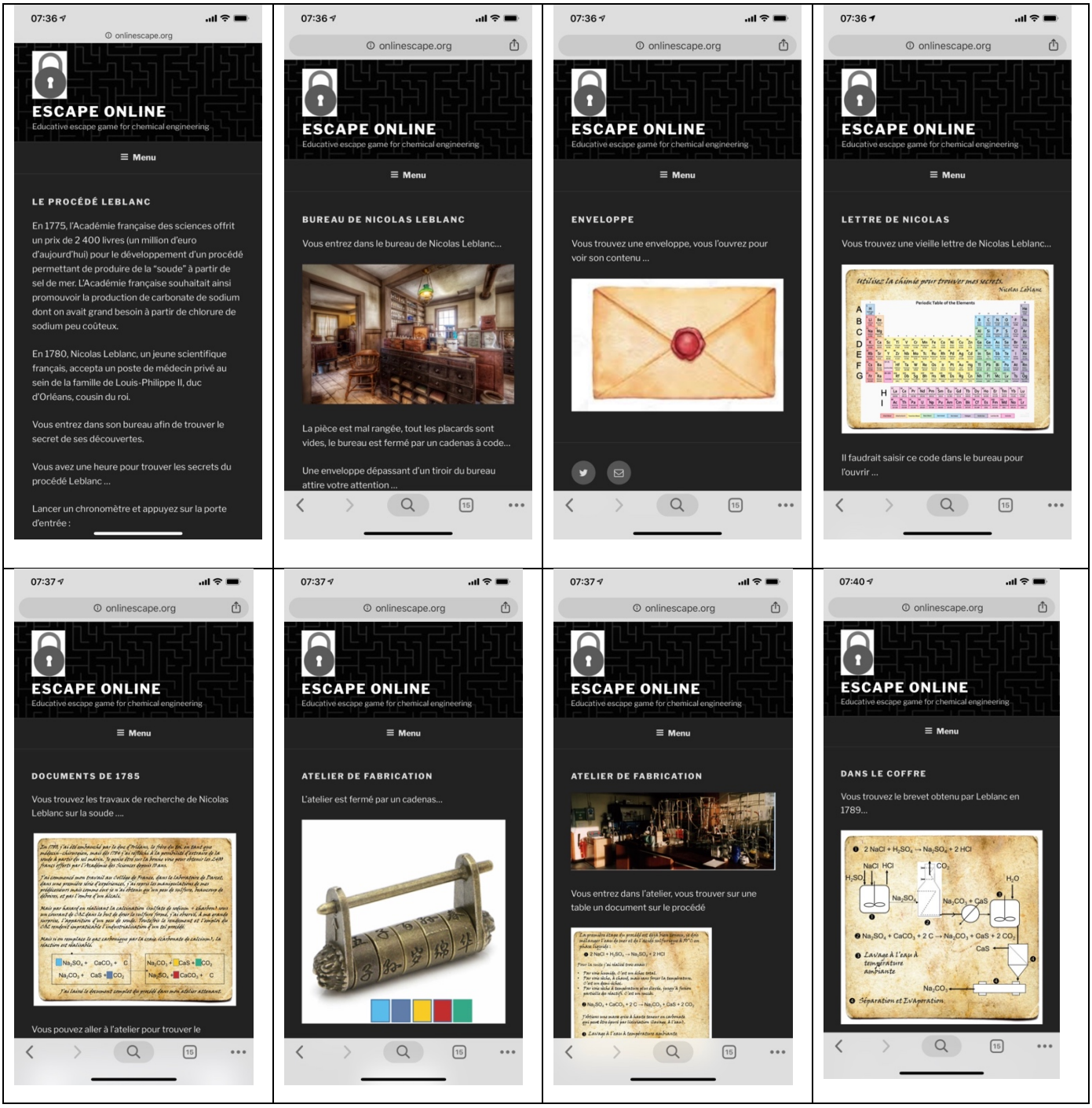


Figure 2. *Illustration of the dedicated website in mobile version: www.onlinescape.org/leblanc*

Ancient illustrations, on aged paper, are used to stress the historical/adventure or treasure hunt aspect (in this case the patent of the Procedure). Optional clues are placed on different web pages to help stranded students. These clues come at the three blocking moments of the *escape game*. These steps are important to face

students with a difficulty that will require and encourage them to work together. Students enter the answers via the address bar of their internet browser.

Three examples of the enigmas depicted on the smartphone are given in Figure 3. The first enigma (Figure 3.a) is an easy puzzle based on the periodic table of Mendeleev. The objective of this game is to make students use the table and imagine how it could help them to open the first lock. As a first hint, the educator can point them towards the line number which is indicated on the left of the table. The solution of this first enigma is the first name of Nicolas Leblanc, spelled in elements: Ni, Co, La and S. With the line number of each element, it is then possible to access the first 4 letter combination necessary to continue the adventure. The second puzzle (Figure 3.b) refers to a citation of Lavoisier, in whose laboratory Nicolas Leblanc carried out his research. According to the Lavoisier citation, the objective is to balance the reaction and link the number obtained to the color combination of the second lock. The last puzzle (Figure 3.c) consists of finding a five-letter combination corresponding to the 5 steps of the process patented by Leblanc in 1791.

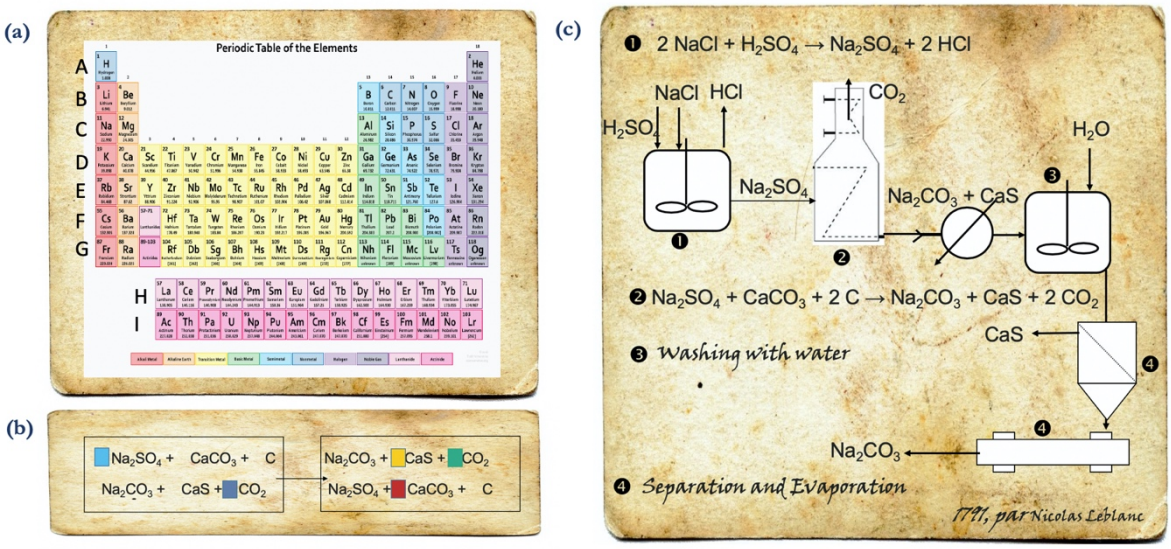


Figure 3. *Example of puzzles present on the application (a) Periodic Table of the element (b) Balancing chemical equation (c) Creating the Leblanc process flowsheet.*

Students from four separate courses used the escape game activity as a homework project after attending a series of lectures (10 h) covering the content of chemical engineering. The 117 students who participated came from either a Chemical Engineering course (class 1, 37 students, in 2018; class 2, 43 students, in 2019) or a Chemical Reaction master course (class 3, 19 students, in 2017; class 4, 18 students, in 2018). At the end of the activity, the teacher invited all students to evaluate the activities by completing a printed form in French containing eleven questions with responses based on a Likert[56] scale (Figure 4). The response rate was 95%. In general, all statements showed high levels of agreement ("agree" and "strongly agree"), ranging from 63.2% to 93.2% of those surveyed.

A majority of students (93.2%) enjoyed the use of numerical escape game in the courses and thought it was attractive and helped capture their attention (90.6%). Fewer students (63.2 %) agreed that the use of numerical escape games helped them make connections between the theoretical aspects of the course and their application and helped improve their understanding (64.9%).

Among panel members, 69.6% of participants who had already tested a classic escape game felt a similar sensation in the game presented here. 75.2% of the panel thought that the use of a digital medium added a playful aspect to the activity and did not alter the experience. In a free-response section of the questionnaire, students were asked to provide comments on the activities and despite the lack of physical mechanisms, the students got well involved in the game, the immersion worked and they greatly appreciated the activity: *"This activity is interesting, this fun game allows us to learn more about the history of processes"*, *"Very good activity, immersive, which gives the feeling of a real escape game"*, "This activity allows us to *concentrate while having fun; this escape game could be very useful in addition to sessions"*, *"This activity is very interesting and motivates us to work and apply what we have learned in class; it is a good tool for working at home"*, *"Interesting method of application of*

knowledge", "This activity is very good to help remember and apply the knowledge gained in classes or in tutorials".

It is worth noting that a large majority thought that this escape game helped them to connect with other students (89.7%) to increase student communication skills. Among panel members, 67.5% believed that the game helped students to be more active than in a traditional classroom and a majority (67.5%) also agreed that the use of this game helped them to think on aspects of the course (68.4%).

Finally, a large majority (80.3%) think that the use of numerical escape game is an excellent educational tool that can complement the classical approach in chemical engineering and 89.2% of students asked for the development of this type of activity in addition to the traditional system and proposed it as a tool to help with personal work in a group.

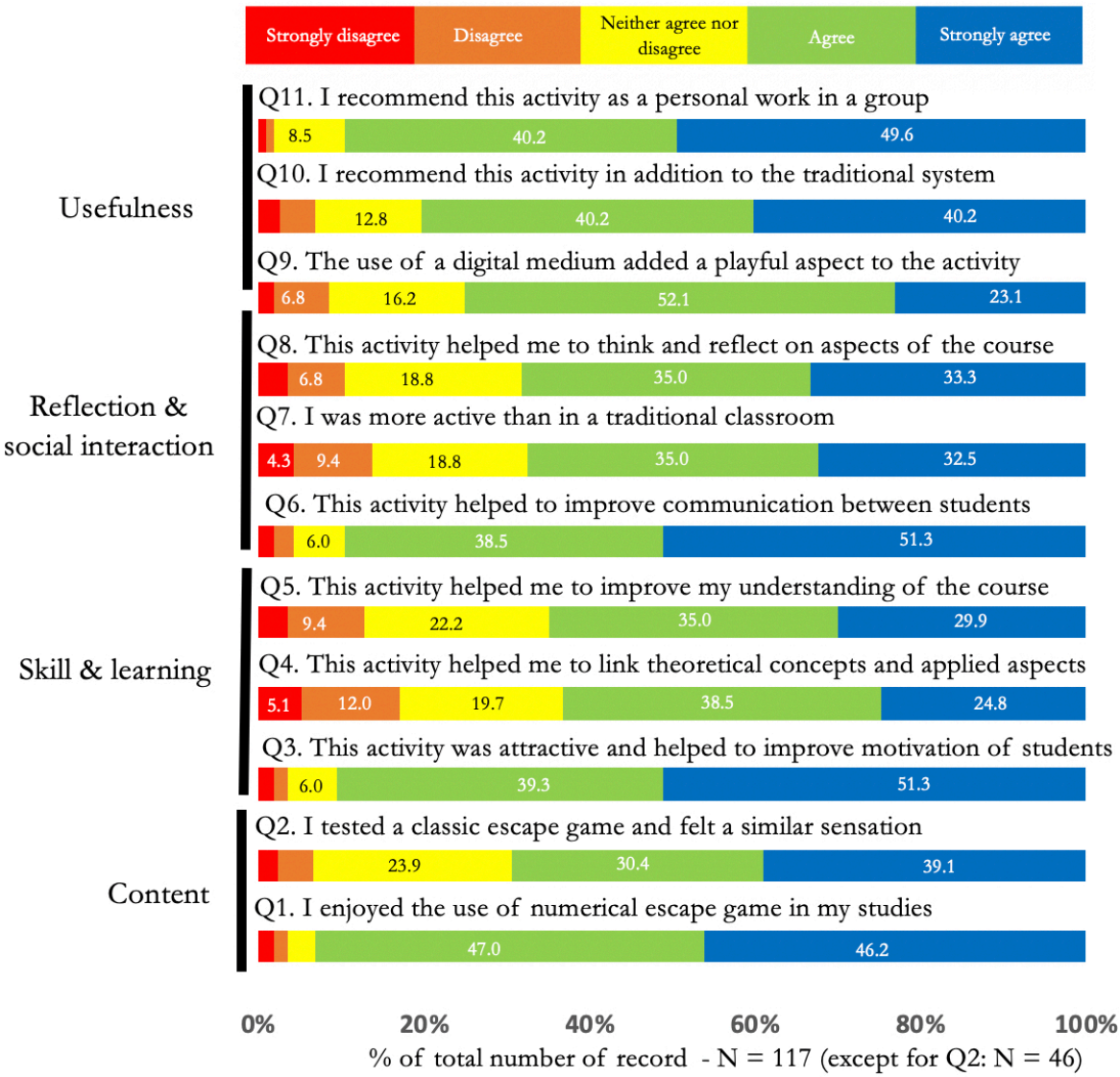


Figure 4. *Student responses relating to the use of mobile escape games in the courses. Total number of respondents = 117 (academic years 2017/2019).*

2.2 Escape lab designed by the students: creation and organization

In order to reduce the time that the teaching teams need to spend on creating the game or to avoid the installation of dedicated rooms, it was proposed that some escape games were built by the students themselves, using the rooms of practical classes in the teaching department and using digital media such as digital tablets. This project was given to the 2nd-year students in the Chemistry department at the University Institute of Technology of Aix-Marseille University, France. The students were specialized in industrial chemistry and were supervised by two teachers. A total of 9 students divided into 3 groups had to imagine, design and organize 3 different

escape games for the visitors of the open house event of the chemistry department. The escape games had to be designed to make the visitors discover the three practical classrooms normally devoted to automated processes engineering and, more generally, the specialization of industrial chemistry. This project was part of the students' syllabus through a course called "supervised projects", the topics of which were given by the teachers. The objectives of this course were to work in a team and to manage a professional project involving the crosslinking of technical, technological and general knowledge of the specialty. These objectives are in agreement with the proposed topic of designing an escape lab. The project was developed from September 2018 to March 2019 with around 150 hours of students' personal work. The activity represented 100 % of the course grade called "supervised projects" and this course grade represented 8.3% of the total grade of the year. Although the students had already worked with the lab facilities, the first step was for the students to become familiar with handling the facilities and to reflect on the puzzles to be put in place. They had to write their scenarios by imagining the different puzzles to "get out" of the room. Some examples of puzzles are presented in Figure 5.

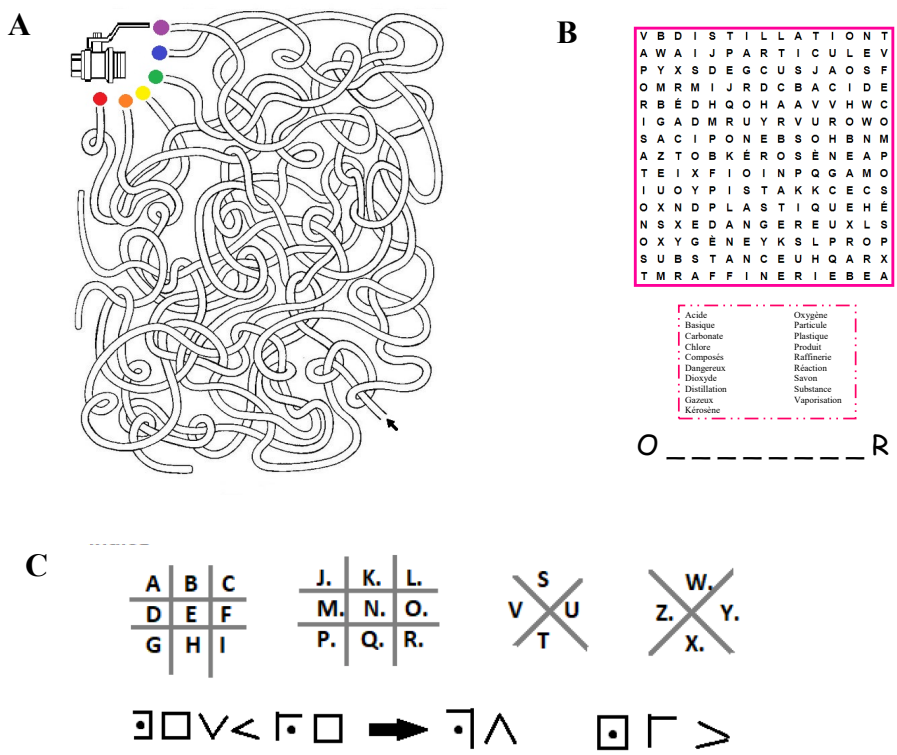


Figure 5. Examples of puzzles: labyrinth to find the color of the valve to open (A), word search grid to find the location of the next clue (B), symbol riddle to crack to find the right instruction (C)

One of the full scenarios is given in Figure 6. Figure 5 and Figure 6 show that the puzzles were of appropriate difficulty for the intended audience and that the activity really showed a real insight into the program of study that is to say: handling and maintenance of chemical engineering pilot plants.

Digital tablets could be used and served as a guide for the game with step-by-step instructions or as multimedia support for broadcasting clues and videos. Several preparation and set up meetings were organized with the students. The teachers constantly made sure that the puzzles and the level of difficulty were suited to the future audience. They validated each step of the game with the students. A last meeting was held a week before the open days to test the games in real conditions with other students or teachers of the class. Little adjustments had to be made.

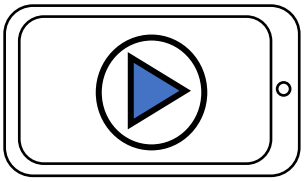
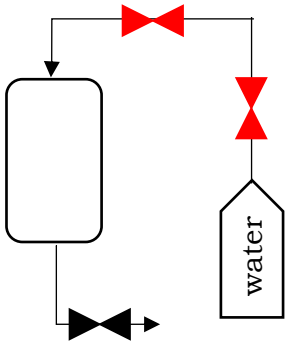
1. Introductive movie explaining that the first part of the game is related to the facility called “Multi-loop 1” 	2. First riddle for which the answer is “water” and participants should understand that the following clue is in the water contained in the tank of the facility.	3. Water level increase in the tank by opening the inlet valves thanks to a simplified diagram. 
4. Hidden clue appearance (floating little box) containing a code to unlock a short movie explaining that the next step is related to the facility called “Gunt®”	5. Three riddles to crack in order to find the 4 references of the valves to open. These 4 references also reveal a code to unlock a new short movie explaining how to start the pilot plant completely.	6. Reading of the 2 first figures of the flowrate displayed on the flowrate meter (first part of the final code)
7. Display of final message saying that the last part is related to the facility called “Multi-loop 2”. Final riddle for which the answer is “measurement of water level”.	8. Cable connections to display the answer of the pressure transmitter measuring water level in the tank (second part of the final code)	9. Entering the code in the key box to get out of the room.

Figure 6. *Example of scenario using chemical engineering facilities.*

The requisite materials already available in the institute, in addition to the lab facilities, were: digital tablets, chemistry glassware, periodic tables of elements,

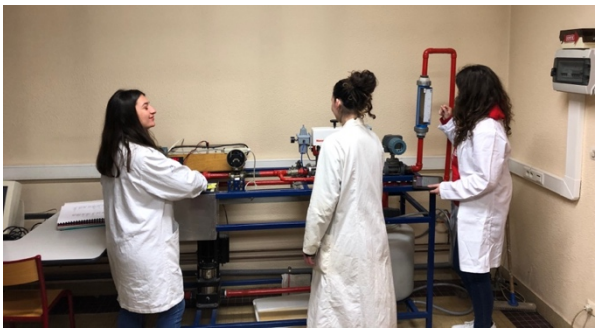
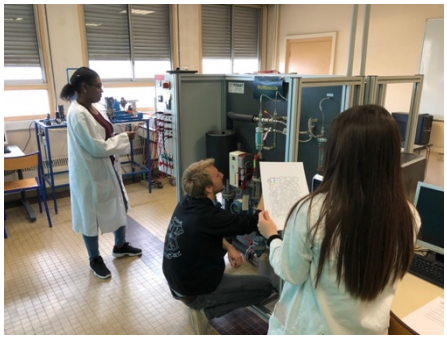
whiteboards and computers. The goods and services that were bought specifically for the occasion were 3 key boxes and reprography, costing a total of only 70 €.

On the day of the open house event, the visitors were split into the 3 rooms in groups of 5 to 10 people for 15 minutes. The visitors' basic knowledge of physics and chemistry - and more generally their reflection and deduction - were needed to solve the different stages of the game, which included various puzzles (labyrinths, half-words, game differences, enigmas, etc.) in order to find a final 4-digit code to unlock a box that contained the exit key. The visitors were also led to manipulate the lab facilities, guided by the students, to solve the puzzles and complete the game. Some pictures of the different facilities surrounded by the students and visitors are shown in Figure 7. At the end, the students who designed the escape games had to write a one-page report giving their final feedback, analysis and impressions.

Figure 7. *Escape lab designed by the students for the open house event of the chemistry department of the university institute of technology of Aix-Marseille University in 2019.*

The students were particularly committed to their task with the visitors during the open house event and experienced the moment as a fulfillment of their mission. This impression was confirmed by the students' final reports, some excerpts from which are given in Table 1. For all this completed tasks, the students obtained a final average grade of 8.3 out of 10.

Table 1. Reports on the experience

Account by Marie, Alexandra and Claire, designers of Escape lab n°1:  *"The preparation and implementation of the escape game for the open house event allowed us to put various skills into practice, such as our creativity and our reflection, our ability to put ourselves in the shoes of others, our sense of organization and, especially, our sense of teamwork. During the day, we used our sense of communication and our sense of adaptation. We really enjoyed this idea of discovery through a game, it was a very motivating and beautiful project. In most groups, the atmosphere was great, young people and adults were thinking together to crack the riddles. The game was completed by all groups, who found the exit keys. The players really enjoyed this game. The only difficulty was the shyness of high school students, especially their hesitation to handle the lab facilities. The concept of escape games is new and discovering our Industrial Chemistry specialization by a game is an idea to keep for the future. "*	Account by Fatuhiya, Lucie and Jean, designers of Escape lab n°2:  *"Explaining the concept of Automated Process Engineering by a game is a very good idea because visitors have never seen such equipment. This allowed us to introduce the operating principles more easily and in a fun way. It is a modern project and the escape game is a game for all ages. We had a lot of fun finding puzzles and we paid a lot of attention to the level of difficulty for high school students. After grouping everyone's ideas together, we selected the best ones and worked on their implementation together. We showed good team cohesion. The teacher advised us on the riddles and helped us to find the necessary material, to organize the appointments, to complete the game. On the day of the open house event, we had to speak in front of an audience, which helped us to become more and more comfortable speaking in public. Most groups of visitors completed the game and we are satisfied with this day. If it were to be done again, we would try to deepen the imaginary world around the puzzles so that visitors would be even more immersed in the concept. "*

This project was also particularly appreciated by all the teaching staff in the department. Thanks to the open house event, the approach echoed outside the walls of the department and this type of action, combined with the other activities proposed, contributed to the success of the open house event. A survey showed that 96% of visitors who responded to the questionnaire were interested in enrolling for the degree course the next year. One of the teachers in charge of this project was co-responsible for the recruitment of the degree course and found that some high school students even made specific reference to these escape labs in their cover letters.

3. DISCUSSION

The use of escape games in university pedagogy has increased significantly since their first use in 2015[41]. Numerous attempts have been made in the last few years in various fields of university teaching and are reported in the recent scientific literature ([42,43,43–48,50,52,57–63]). These activities have undeniable qualities and benefits, such as increasing the motivation of students or developing their skills in collective intelligence. However, the transposition of these activities into universities or engineering schools on a large scale is a real problem and raises the question of adaptation: immobilization of rooms and educators, cost of implementation and significant time for creation and preparation (Figure 8.a). These issues are a real obstacle for large student audiences. Some solutions have been presented in this paper. The first solution involved the use of a digital support, which enables the players to feel the sensations of escape games at lower cost and to change the students' environment from conventional classrooms to dedicated workrooms or spaces for personal work outside the teaching department. One of the strengths of this educational innovation is the use of a dedicated website to circumvent material and investment issues (Figure 8.b). Thus, it is possible for a large class to use a game simultaneously in or outside the usual classrooms. This innovation can also be used as a course support or as preparation for a course, such as work at home, thus saving

time in schedules. This will also save teachers the considerable amount of time that would otherwise be needed to reset and prepare for each session. While the time to create a new scenario remains significant, content can be shared easily and freely online (the website www.onlinescape.org, is free to access and can quickly be supplemented by other scenarios in all academic fields). The development cost is also greatly reduced: it costs less than 10 euros to purchase the domain name, which can be hosted on the institutional site of the university for free. Few computer skills are required: the *WordPress* modules to create the website that were used are free of rights and are explained in plentiful tutorials on the internet. Finally, the format of this alternative pedagogy reveals some students who are usually not among those who succeed in the traditional learning environment and this change in context and support helps students who tend to fail in front of an examination paper or in front of classical teachers.

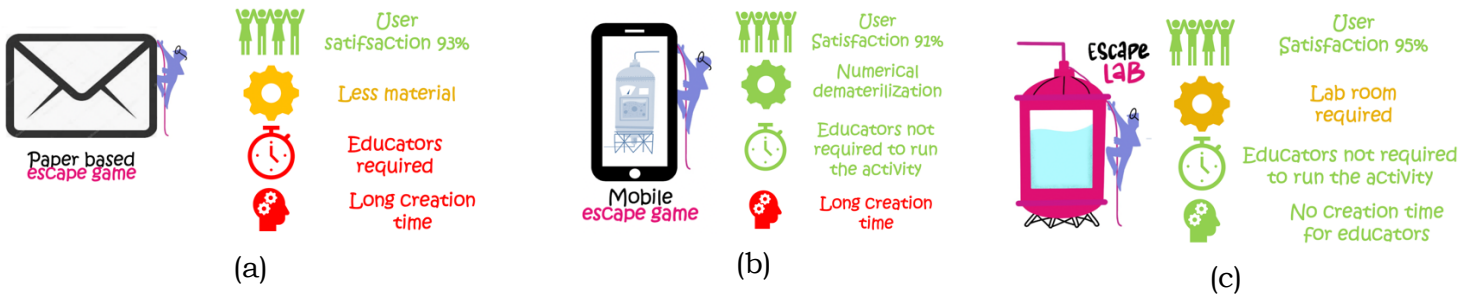


Figure 8. Comparison of innovative approaches to implement escape game with large audience in chemical engineering: (a) paper based version[48], (b) mobile version, (c) escape lab.

The second solution was the creation of escape games as the subject of a project carried out by the students themselves to develop their involvement in the teaching department and their sense of pedagogy and innovation. The case study presented in this paper was the setting up of an escape lab for an open-house event, starting from the existing automated chemical engineering lab facilities. However, the concept can be oriented towards other students of the same class (instead of outside visitors) and

other fields of teaching. The main objective was for the students to complete a long-term project dedicated to a large audience. The sub-objectives were multiple: time management, team work management, control of the lab facilities and development of creativity. The secondary objective was the success of the games by the escape lab users: moderate level of difficulty of the puzzles (neither so easy that the players lost interest, nor so difficult that they risked giving up) and use of lab facilities without risk. The teaching staff within the department had to be particularly committed to this innovative project: organizing numerous meetings with the students, purchasing the necessary materials in consultation with the students, making the communication supports (posters, signs, etc.). Nevertheless, the investment was less than for the creation of an escape game by the teacher alone (Figure 8.c). Hundreds of users were welcomed to the escape labs during a day. This large audience was managed by splitting participants into groups of up to 15 people and by reducing the time of the game (15 min). Very good feedback was received from users and student organizers. It was an innovative, original, fun, cheap project. The puzzles imagined could finally be transposed to the digital tool developed in the first part of this paper to be effective with even larger audiences and serve as an introduction to the practical classes of Chemical Engineering.

CONCLUSION

New approaches to apply escape game activities in large classes have been presented. They are based (i) on the use of a numeric platform to play the game on a smartphone or computer or (ii) on the creation of scenarios by the students in a laboratory room. One of the key points of these approaches is their great transferability in terms of both the topic and the level of the students. The level of puzzles can be adjusted, so it is easy to adjust the level from a discovery activity to specialized knowledge activities at the master level. These approaches can be applied in all areas of education, and the flexibility of the digital transposition of the escape game allows for ongoing use with the presence of the teacher or home use as a support and motivation aid for personal work. It can also be the subject of a project achieved by the students. The use of digital media makes it possible to apply and integrate the educational escape game on a larger scale while maintaining these advantages, namely increasing motivation and developing adaptability and mutual aid. The use of a website also enables broad, easy diffusion within the Universities.

ACKNOWLEDGMENT

The authors thank the C_2IP (Centre d'Innovation et d'Ingénierie Pédagogique) of INSA Toulouse for its support in pedagogy. The authors would like to thank the Chemistry Department of the Institute of Technology of Aix-Marseille University and, in particular, Mrs. Carine Franklin, head of the department and Mr. Marie-Jacques Arékion, the second teacher involved in the organization of the escape lab.

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