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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 *escape 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

32 1. INTRODUCTION

33 Attracting a general audience to chemical engineering is a major challenge and
34 developing motivating, inspiring or active teaching methods is important to help
35 students to improve their learning and understanding of the different concepts¹.
36 Educators have developed educational games²⁻⁵ to involve students in interactive and
37 entertaining activities⁶. Games are an excellent method of active learning in a
38 recreative environment⁷ and many methods have been tested in the past decade⁸:
39 word game⁹, quiz games¹⁰⁻¹⁸, card games^{19,20}, dice games^{21,22}, board games²³⁻²⁷,
40 computer games²⁸⁻³⁰ and memory/concentration game³¹⁻³³. Surprisingly, the use of
41 videogames to illustrate chemical engineering is relatively unexplored in the literature
42 even though pedagogical videogames exist ³⁴⁻³⁶. In all these activities, gaming is seen
43 as an alternative approach of boosting communication³⁷ between students, and might
44 allow them to learn in an entertaining way compared with the traditional lecture
45 format^{38,39}. However, most of these games are individual and do not develop team-
46 building or group communication⁴⁰. The use of educational *escape games* is relatively
47 new in the international sphere ⁴¹. Several attempts in real rooms with physical
48 materials have been made in computer science⁴², physics⁴³, chemistry ⁴⁴⁻⁴⁷ or
49 chemical engineering^{48,49}. These escape games use scientific concepts and some of
50 them take place in laboratory work rooms. Some educators⁵⁰ have set up an
51 adaptable, movable escape game in a practical chemistry workroom, using simple
52 chemical materials and reactions. Others ⁴⁵ have used a fake crime scene, with
53 students needing to use chemical techniques to conduct the investigation or specific
54 battle box⁵¹. Yet others have tried⁵² to lighten the "physical" part of the escape game
55 by offering a mixture of mechanisms/objects and online puzzles, taking advantage of
56 students' attraction to new technologies. It is in the continuity of this approach that
57 the present work position itself: by completely dematerializing the mechanisms in
58 order to integrate this pedagogy even more easily into the major disciplines, where

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

77 In order to get around these problems, this paper proposes two educational solutions
78 to adapt the escape games to as many people as possible without this being too time-
79 consuming for the teaching teams or too expensive to set up. The first is to use a
80 digital medium⁵³⁻⁵⁵: by accessing a website (www.onlinescape.org), students access
81 a scenario tracing the development of one of the world's first chemical engineering
82 processes, the Leblanc Process⁴⁸. Through scientific puzzles, students find
83 combinations of numbers or letters to open other mechanisms represented on the
84 online platform. This paper also proposes that students build their own escape game
85 as part of a project to be used at open house events. This not only reduces the

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

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

108 109 2. APPROACHES

110 2.1. Digital and mobile escape games

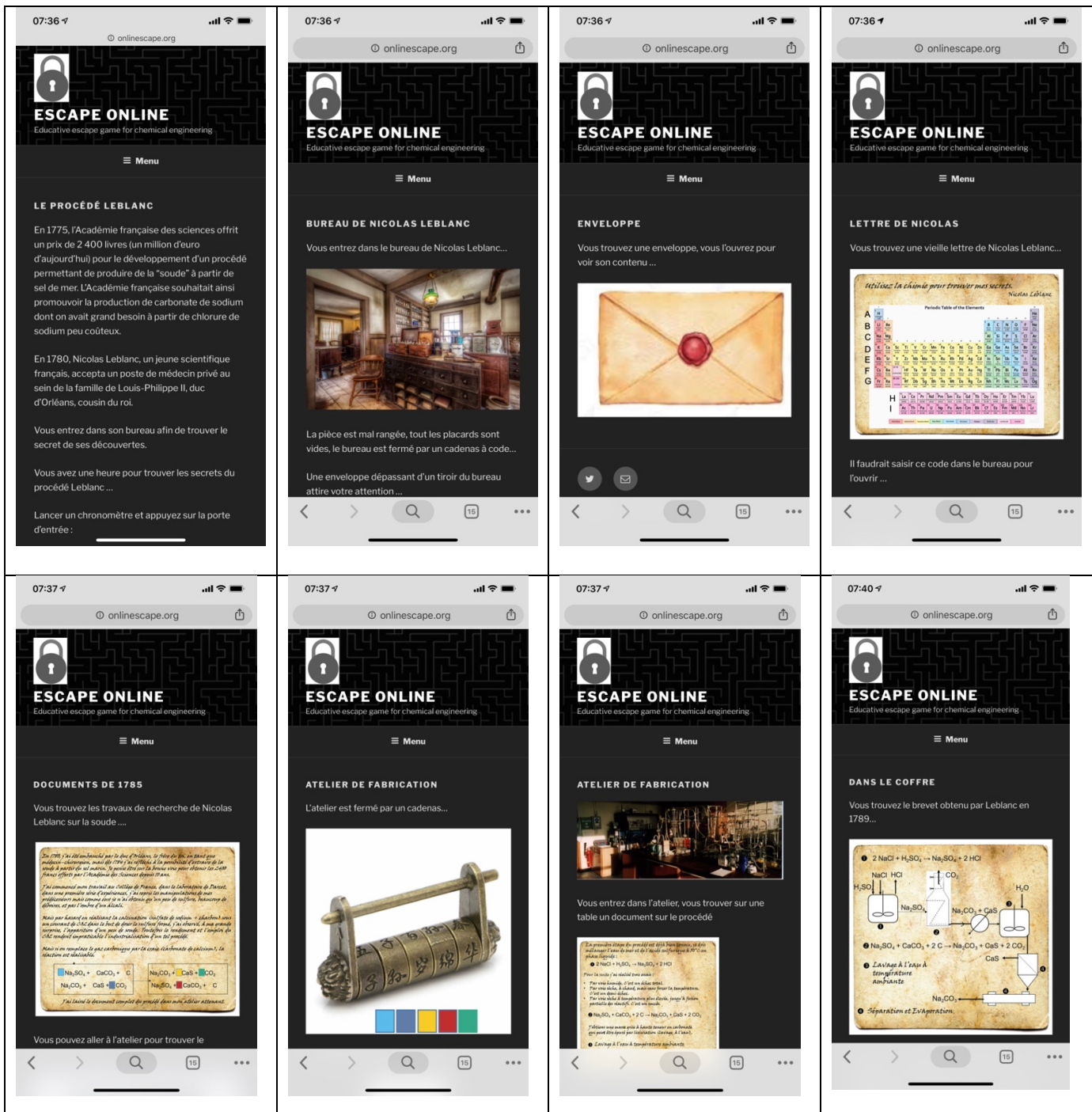
111
112 The pedagogical activity is organized by dividing the class/users from the general
113 public into small groups of 2 to 4 people, either in the room with the presence of the
114 teacher or as personal work (Figure 1). Each group needs a computer or a smartphone

115 and an internet connection. By accessing the <http://www.onlinescape.org> website, the
116 students launch the "Leblanc" scenario, tracing the development of one of the world's
117 first chemical engineering processes⁴⁸. The pedagogical activity leads students to
118 follow in the footsteps of Nicolas Leblanc, a young French chemist working during
119 the French revolution, who responded to a competition launched by the Academy of
120 Sciences in 1789 to produce "soda" industrially. This activity helps to restore the
121 importance of Nicolas Leblanc, who remains little known to the general public, unlike
122 his contemporaries, e.g. Antoine Lavoisier, even though his process is considered as
123 one of the founding acts of chemical engineering. Through scientific puzzles, students
124 access combinations of numbers or letters to open other mechanisms represented on
125 the online platform. Following a precise sequence, the students will thus advance in
126 groups by tracing the development of the Leblanc process. The escape is not the end
127 of the story: a debriefing at the end of the session highlights the consequences of the
128 process for the environment (passing of the alkali act) as well as its key points.



129
130 **Figure 1.** *The activity in progress in the active pedagogy room at INSA Toulouse 2018/2019.*
131

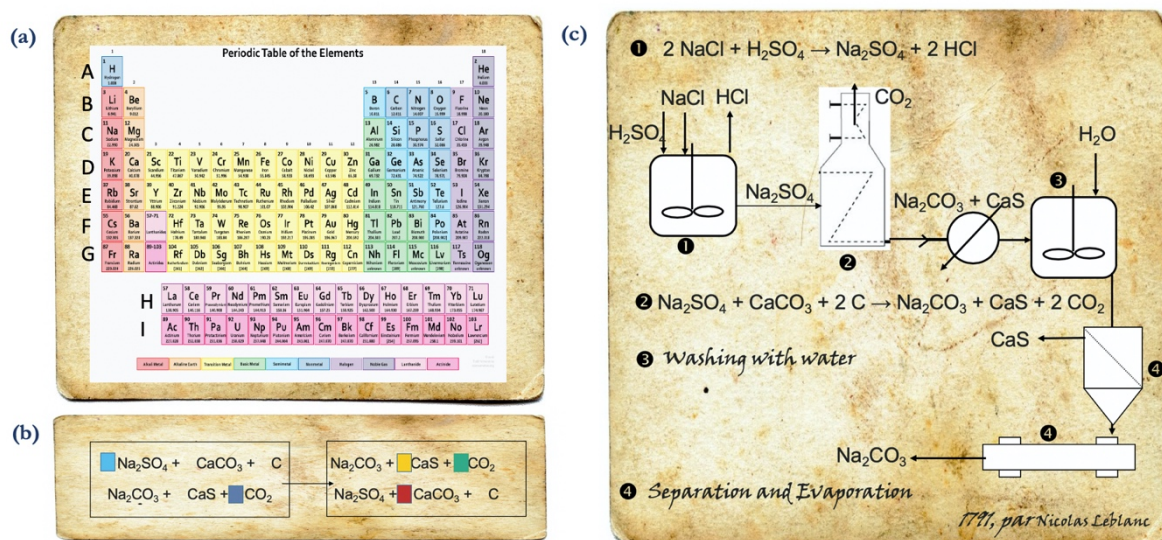
132 Figure 2 illustrates a few pages of the website, showing the puzzles and the different
133 digital "rooms" used. Even though this activity takes place only on a digital medium
134 with an internet connection, it is important to highlight places (office, laboratory, etc.)
135 to transpose the atmosphere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



138
 139 *Figure 2. Illustration of the dedicated website in mobile version: www.onlinescape.org/leblanc*
 140

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

145 students with a difficulty that will require and encourage them to work together.
 146 Students enter the answers via the address bar of their internet browser.
 147 Three examples of the enigmas depicted on the smartphone are given in Figure 3.
 148 The first enigma (Figure 3.a) is an easy puzzle based on the periodic table of
 149 Mendeleev. The objective of this game is to make students use the table and imagine
 150 how it could help them to open the first lock. As a first hint, the educator can point
 151 them towards the line number which is indicated on the left of the table. The solution
 152 of this first enigma is the first name of Nicolas Leblanc, spelled in elements: Ni, Co,
 153 La and S. With the line number of each element, it is then possible to access the first
 154 4 letter combination necessary to continue the adventure. The second puzzle (Figure
 155 3.b) refers to a citation of Lavoisier, in whose laboratory Nicolas Leblanc carried out
 156 his research. According to the Lavoisier citation, the objective is to balance the
 157 reaction and link the number obtained to the color combination of the second lock.
 158 The last puzzle (Figure 3.c) consists of finding a five-letter combination corresponding
 159 to the 5 steps of the process patented by Leblanc in 1791.
 160



161
 162 **Figure 3.** Example of puzzles present on the application (a) Periodic Table of the element (b) Balancing
 163 chemical equation (c) Creating the Leblanc process flowsheet.

164 Students from four separate courses used the escape game activity as a homework
165 project after attending a series of lectures (10 h) covering the content of chemical
166 engineering. The 117 students who participated came from either a Chemical
167 Engineering course (class 1, 37 students, in 2018; class 2, 43 students, in 2019) or
168 a Chemical Reaction master course (class 3, 19 students, in 2017; class 4, 18
169 students, in 2018). At the end of the activity, the teacher invited all students to
170 evaluate the activities by completing a printed form in French containing eleven
171 questions with responses based on a Likert⁵⁶ scale (Figure 4). The response rate was
172 95%. In general, all statements showed high levels of agreement (“agree” and “strongly
173 agree”), ranging from 63.2% to 93.2% of those surveyed.

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

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

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

193 It is worth noting that a large majority thought that this escape game helped them to
194 connect with other students (89.7%) to increase student communication skills.

195 Among panel members, 67.5% believed that the game helped students to be more
196 active than in a traditional classroom and a majority (67.5%) also agreed that the use
197 of this game helped them to think on aspects of the course (68.4%).

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

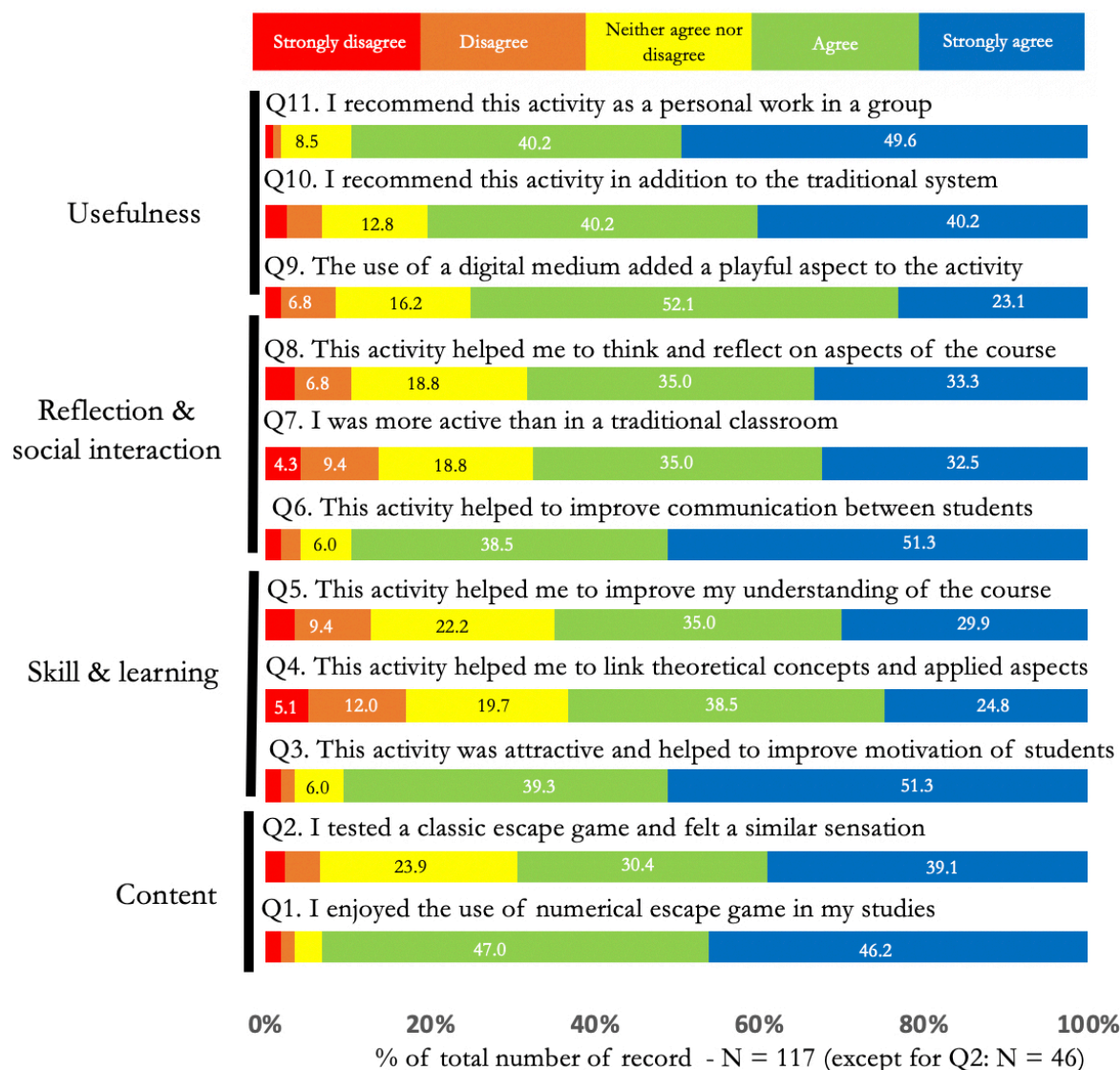
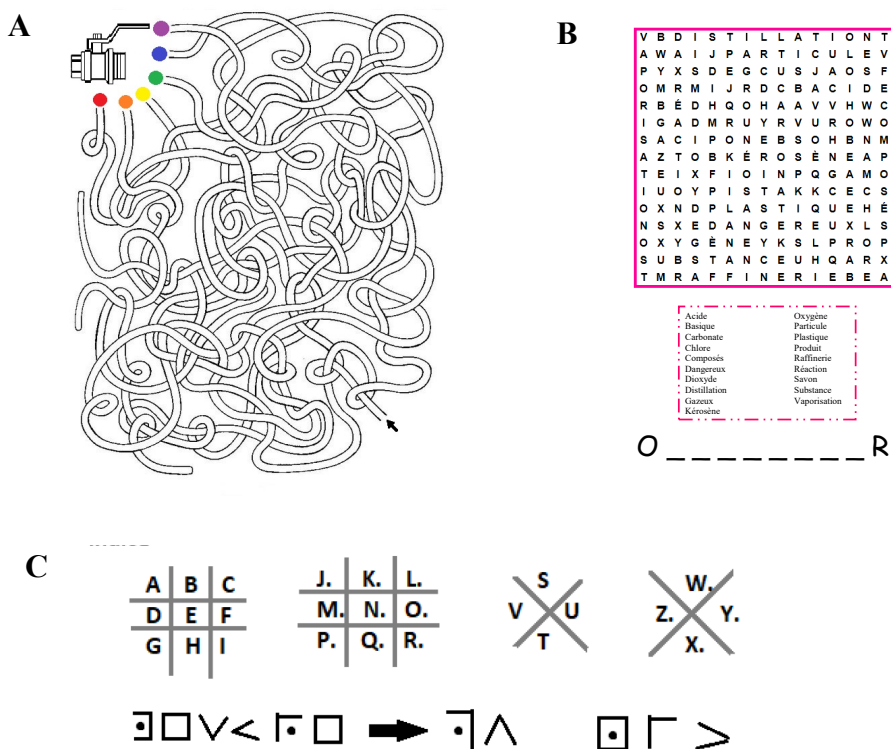


Figure 4. Student responses relating to the use of mobile escape games in the courses. Total number of respondents = 117 (academic years 2017/2019).

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

217 escape games for the visitors of the open house event of the chemistry department.
218 The escape games had to be designed to make the visitors discover the three practical
219 classrooms normally devoted to automated processes engineering and, more
220 generally, the specialization of industrial chemistry. This project was part of the
221 students' syllabus through a course called "supervised projects", the topics of which
222 were given by the teachers. The objectives of this course were to work in a team and
223 to manage a professional project involving the crosslinking of technical, technological
224 and general knowledge of the specialty. These objectives are in agreement with the
225 proposed topic of designing an escape lab. The project was developed from September
226 2018 to March 2019 with around 150 hours of students' personal work. The activity
227 represented 100 % of the course grade called "supervised projects" and this course
228 grade represented 8.3% of the total grade of the year. Although the students had
229 already worked with the lab facilities, the first step was for the students to become
230 familiar with handling the facilities and to reflect on the puzzles to be put in place.
231 They had to write their scenarios by imagining the different puzzles to "get out" of the
232 room. Some examples of puzzles are presented in Figure 5.



233

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

237

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

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

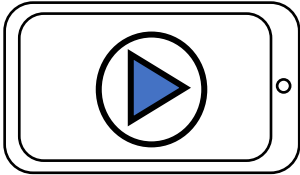

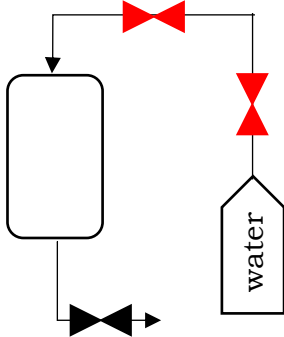






<p>1. Introductory movie explaining that the first part of the game is related to the facility called “Multi-loop 1”</p> 	<p>2. First riddle for which the answer is “water” and participants should understand that the following clue is in the water contained in the tank of the facility.</p> 	<p>3. Water level increase in the tank by opening the inlet valves thanks to a simplified diagram.</p> 
<p>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®”</p> 	<p>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.</p> 	<p>6. Reading of the 2 first figures of the flowrate displayed on the flowrate meter (first part of the final code)</p> 
<p>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”.</p> 	<p>8. Cable connections to display the answer of the pressure transmitter measuring water level in the tank (second part of the final code)</p> 	<p>9. Entering the code in the key box to get out of the room.</p> 

Figure 6. Example of scenario using chemical engineering facilities.

249
250

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

253 whiteboards and computers. The goods and services that were bought specifically for
254 the occasion were 3 key boxes and reprography, costing a total of only 70 €.
255 On the day of the open house event, the visitors were split into the 3 rooms in groups
256 of 5 to 10 people for 15 minutes. The visitors' basic knowledge of physics and
257 chemistry - and more generally their reflection and deduction - were needed to solve
258 the different stages of the game, which included various puzzles (labyrinths, half-
259 words, game differences, enigmas, etc.) in order to find a final 4-digit code to unlock
260 a box that contained the exit key. The visitors were also led to manipulate the lab
261 facilities, guided by the students, to solve the puzzles and complete the game. Some
262 pictures of the different facilities surrounded by the students and visitors are shown
263 in Figure 7. At the end, the students who designed the escape games had to write a
264 one-page report giving their final feedback, analysis and impressions.

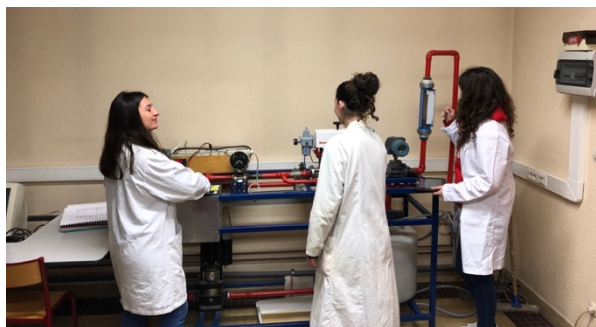


265
266 **Figure 7.** Escape lab designed by the students for the open house event of the chemistry
267 department of the university institute of technology of Aix-Marseille University in 2019.
268

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

274

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:



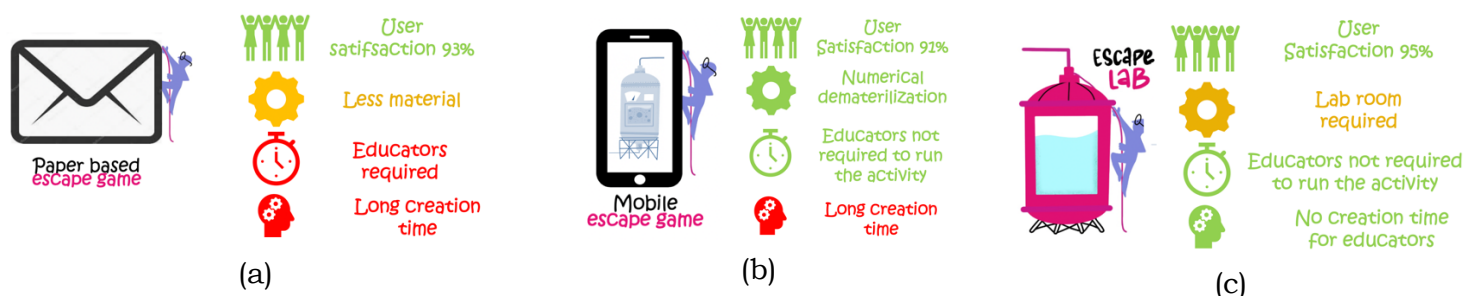
"Explaining the concept of Automated Process Engineering by a game is a very good idea because visitors have never seen such equipment. This allowed us to introduce the operating principles more easily and in a fun way. It is a modern project and the escape game is a game for all ages. We had a lot of 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. "

276 This project was also particularly appreciated by all the teaching staff in the
277 department. Thanks to the open house event, the approach echoed outside the walls
278 of the department and this type of action, combined with the other activities
279 proposed, contributed to the success of the open house event. A survey showed that
280 96% of visitors who responded to the questionnaire were interested in enrolling for
281 the degree course the next year. One of the teachers in charge of this project was co-
282 responsible for the recruitment of the degree course and found that some high school
283 students even made specific reference to these escape labs in their cover letters.

284 **3. DISCUSSION**

285 The use of escape games in university pedagogy has increased significantly since
286 their first use in 2015⁴¹. Numerous attempts have been made in the last few years in
287 various fields of university teaching and are reported in the recent scientific literature
288 (42,43,43-48,50,52,57-63). These activities have undeniable qualities and benefits, such as
289 increasing the motivation of students or developing their skills in collective
290 intelligence. However, the transposition of these activities into universities or
291 engineering schools on a large scale is a real problem and raises the question of
292 adaptation: immobilization of rooms and educators, cost of implementation and
293 significant time for creation and preparation (Figure 8.a). These issues are a real
294 obstacle for large student audiences. Some solutions have been presented in this
295 paper. The first solution involved the use of a digital support, which enables the
296 players to feel the sensations of escape games at lower cost and to change the
297 students' environment from conventional classrooms to dedicated workrooms or
298 spaces for personal work outside the teaching department. One of the strengths of
299 this educational innovation is the use of a dedicated website to circumvent material
300 and investment issues (Figure 8.b). Thus, it is possible for a large class to use a game
301 simultaneously in or outside the usual classrooms. This innovation can also be used
302 as a course support or as preparation for a course, such as work at home, thus saving

303 time in schedules. This will also save teachers the considerable amount of time that
 304 would otherwise be needed to reset and prepare for each session. While the time to
 305 create a new scenario remains significant, content can be shared easily and freely
 306 online (the website www.onlinescape.org, is free to access and can quickly be
 307 supplemented by other scenarios in all academic fields). The development cost is also
 308 greatly reduced: it costs less than 10 euros to purchase the domain name, which can
 309 be hosted on the institutional site of the university for free. Few computer skills are
 310 required: the *WordPress* modules to create the website that were used are free of
 311 rights and are explained in plentiful tutorials on the internet. Finally, the format of
 312 this alternative pedagogy reveals some students who are usually not among those
 313 who succeed in the traditional learning environment and this change in context and
 314 support helps students who tend to fail in front of an examination paper or in front
 315 of classical teachers.
 316



317
 318 **Figure 8.** Comparison of innovative approaches to implement escape game with
 319 large audience in chemical engineering: (a) paper based version⁴⁸, (b) mobile
 320 version, (c) escape lab.
 321

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

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

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350

351 **CONCLUSION**

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

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377 Note: The author declares no competing financial interest.

378

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