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# USING AUGMENTED REALITY TO STIMULATE STUDENTS AND DIFFUSE ESCAPE GAME ACTIVITIES TO LARGER AUDIENCES

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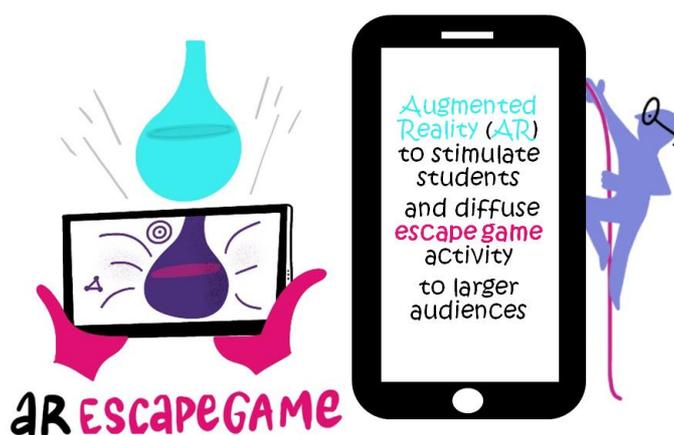
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## ABSTRACT

In a world engaged in a perpetual race for progress, Augmented Reality (AR) is a new frontier that has attracted much research attention in recent years. The generalization of smartphones and the miniaturization and democratization of connected gadgets are leading to new uses and new expectations. In this article, we provide an AR application to the trending educational activity of escape games in order to diffuse AR to a large audience. As the application of an educational escape game, which is a good tool to improve the motivation and communication skills of students, requires considerable time for design, manufacturing and operating, a numeric, mobile AR version is proposed here. For this purpose, an original paper-based version of the scenario is presented, principally turning around the Solvay Process for high-school/college audience. In this scenario, the students are led to follow in the footsteps of a young Belgian physicist, Ernest Solvay. Through enigmas, participants discover a secret room containing Solvay's secrets in Brussels. Puzzles about the periodic table of elements, the CPK color code, chemical reaction balancing, the notion of molar mass, the Solvay process, or the philanthropic conferences organized by Solvay and the many other scientists involved are used to illustrate the chemical process discovered. This scenario and the Leblanc process scenario have been adapted to an AR experience with the open application *Metaverse*. Unlike conventional escape game or escape lab activities, our AR escape games can be easily diffused to large audience classrooms without the presence of any teacher being required and without any systematic preparation. The advantages and limits of such tools are discussed. The feedback received from students that participated in a test exercise with the tool corroborates the increase of motivation through such activities.

## GRAPHICAL ABSTRACT



## KEYWORDS

General Public, Chemical Engineering, Collaborative / Communication / Puzzles / Games, Reactions /History, Philosophy/ Inquiry-Based/Discovery Learning, Physical Properties, Student-Centered Learning

## 40 INTRODUCTION

41 Augmented Reality (AR) refers to an expression coined in the early 1990s to describe a new  
42 form of interaction between the user and a machine, based on the association of real  
43 objects, derived from the user's environment, and virtual ones, i.e., created by the  
44 computer. Reality is called "enhanced" because the machine superimposes a new layer of  
45 information on this reality, intended to bring enriching elements to the user's environment.  
46 AR is an interactive experience of a real-world environment where the objects that reside in  
47 the real-world are enhanced by computer-generated perceptual information, including  
48 visual, auditory, haptic and olfactory.

49 The earliest functional AR systems providing immersive mixed reality experiences for users  
50 were invented in the early 1990s, starting with the Virtual Fixtures system developed at the  
51 U.S. Air Force's Armstrong Laboratory<sup>1</sup>. Commercial augmented reality experiences were  
52 introduced in entertainment and gaming businesses.

53 With the technological advances of recent years, including the democratization of  
54 smartphones and tablets, AR has gradually become a reality, and its use has increased and  
55 diversified<sup>2</sup>. The presence of one or more cameras on these devices makes them particularly  
56 suitable for contextualized use and inclusion in situations, the camera capturing the real  
57 and displaying it on the screen of the device with other information. Today, this technology  
58 has become common in some areas and applications have spanned commercial industries  
59 such as education, communications, medicine, and entertainment. In education, content  
60 may be accessed by scanning or viewing an image with a mobile device or by using  
61 markerless AR techniques<sup>3,4</sup>. For example, like Quick Response (QR) codes, it allows the  
62 educator to encode information (text, URL) that is then accessed via a scanner connected to  
63 a computer. In class, codes have begun to appear as a means of accessing space  
64 enrichment. Thus, a student can scan a code displayed at a strategic location in the  
65 classroom (on a resource, a dedicated corner, a book, etc.) and access virtual content such  
66 as Nobel Prize winners<sup>5</sup> or the periodic table of the elements<sup>6</sup>. Students can then access  
67 resources made available by the teacher (instructions, procedures, readings aloud) by  
68 simply scanning a code. Another use of augmented reality is related to the use of various  
69 applications, including Aurasma (recently HP Reveal) and MirageMake<sup>7</sup>. These applications

70 allow the educators to set triggers in the real world. When the camera encounters one of  
71 these triggers, an action is launched on the screen: playing a video, bringing up a text, an  
72 image, link to an internet page, etc.

73 With the help of advanced AR technologies, the information about the real world  
74 surrounding the user becomes interactive and digitally manipulated. Information about the  
75 environment and its objects is overlaid on the real world. Nowadays, there are two types of  
76 augmented reality commonly used on smart phones: markerless (adding of digital  
77 information to the image on a cell phone camera based on the global positioning system,  
78 such as GPS location) and markered (uses a physical reference point) <sup>8,9</sup>. Markered  
79 augmented reality is especially useful for chemists because it provides an easy way to  
80 connect information directly to a physical object, like a scientific instrument, or to place a  
81 Web link on a sheet of paper or a book<sup>10,11</sup>. Recently, Augmented Reality has been used in  
82 the laboratory<sup>12</sup>, as instructions for analytical instrumentation design, enabling students to  
83 see directly how the instruments that are in their own laboratory (flame atomic absorption  
84 spectrometer, gas chromatograph–mass spectrometer, liquid chromatograph, and double-  
85 beam UV-vis)<sup>13</sup>, can be employed in chemical kinetics classes<sup>14</sup> or organic chemistry  
86 classes<sup>15</sup> to perform a colorimetric titration<sup>16</sup> or even for learning safety<sup>17</sup>.

87  
88 Mobile games are particularly suitable for an escape game activity as such activities were  
89 firstly developed as videogames in the early 1990s<sup>18</sup>. In 2007, they were adapted to real  
90 physics classrooms in Japan, in a live-action team-based game where players cooperatively  
91 discover clues, solve puzzles, and accomplish tasks in one or more rooms in order to  
92 progress and accomplish a specific goal in a limited amount of time. This game has been  
93 adapted for educational purposes since 2015<sup>18–26</sup>. Several attempts have been made in  
94 classrooms or rooms specific to computer science<sup>27,28</sup>, physics <sup>29</sup>, chemistry <sup>30,31</sup> or  
95 chemical engineering<sup>32</sup>. Some experiments have also been done in laboratories<sup>33,34</sup>, using  
96 simple chemical materials and reactions or even at a fake crime scene, with students  
97 needing to use chemical techniques to solve the investigation<sup>35,36</sup>.

98 The examples mentioned above have been very successful with students, both in terms of  
99 increasing their motivation and attraction to scientific disciplines and allowing them to work

100 and develop their teamwork and communication skills. These pedagogical games are  
101 therefore very interesting tools because adaptability, mutual aid and immersion are rarely  
102 developed and practiced through a classical approach. However, implementation faces  
103 logistical problems: the immobilization of one or more rooms, the significant cost of the  
104 equipment (locks, secret mechanisms, chests, boxes), and the time problems faced by  
105 teachers for design, test, preparation and reset operations. Moreover, the small number of  
106 simultaneous participants, estimated to be between 3 and 5 for optimal activity, means  
107 multiplying the sessions, and thus the presence of a teacher to guide/help students blocked  
108 on certain puzzles.

109 Educators have tried <sup>37</sup> to reduce the "physical" part of the escape game by offering a  
110 mixture of real mechanisms/objects and online puzzles, taking advantage of students'  
111 attraction to new technologies. It is in this continuity that we position our study, by  
112 completely dematerializing the escape game mechanisms in order to integrate this pedagogy  
113 into large audience even more easily. A new scenario, based on the Solvay Process (also  
114 available as a paper version in the supplementary section) is first proposed for high  
115 school/college audience, then adapted thanks to the Metaverse platform. Finally, a  
116 discussion about benefits and limitations will be presented.

## 117 **THE SCENARIOS**

118 For this activity, two different scenarios were used. The first one is the physical and  
119 paper version of the Leblanc Process, published in 2018<sup>32</sup>. We present a new scenario here,  
120 which we propose first in a standard paper version. The Solvay process<sup>38</sup>, named after its  
121 inventor, Ernest Solvay<sup>39</sup>, is an industrial process for the production of soda ash<sup>40</sup> (sodium  
122 carbonate - Na<sub>2</sub>CO<sub>3</sub>) created in 1861. In the 20th century, it was the main industrial  
123 process used. The Solvay process makes sodium carbonate from brine (sodium chloride -  
124 NaCl) and from calcium carbonate (limestone - CaCO<sub>3</sub>). The overall reaction is:



126 This process is the result of careful observation of ancient practices by an expert  
127 chemist and excellent practitioner of aqueous solutions. Helped by his brother, Ernest  
128 Solvay founded his first factory at Couillet (Charleroi, Belgium) in 1863 and further

129 perfected the process until 1872, when he patented it. Solvay process plants were  
130 established worldwide (70 Solvay process plants are still operational in 2020). The  
131 exploitation of his patents brought Solvay considerable wealth, which he used for  
132 philanthropic purposes, including the establishment of universities in Belgium and a series  
133 of important conferences in physics, known as the Solvay Conferences. Participants  
134 included luminaries such as Max Planck, Ernest Rutherford, Maria Skłodowska-Curie,  
135 Henri Poincaré, and Albert Einstein.

136 The class is divided into groups of 5-7 students. The game starts with an introduction to  
137 the historical background by the teacher: "Walking in the streets of Brussels, the capital of  
138 Belgium, you found a statue of Ernest Solvay, the great Belgium physicist. Observing the  
139 letters of Solvay's first name (**ERNEST**), you push them to make the word ENTER in the  
140 statue sign. You open a secret staircase leading you to a massive stone door". The timer for  
141 solving the room's secret is set to 60 minutes and each group receives a first enigma sheet  
142 (supplementary elements). The first enigma is an easy puzzle based on the Mendeleev  
143 periodic table. The objective of this game is to make students use the table and imagine how  
144 it could help them to open the first lock. The objective is to find the element composing the  
145 name Solvay: S, O, Lv and Y. A hint is given to avoid confusing with the element Argon, the  
146 symbol for which was A and not Ar before 1957. By summing the element numbers, the  
147 student obtains a code, opening the second enigma. The second enigma, depicted in Figure  
148 1, consists of finding a molecule for which the CPK color representation is very close to the  
149 flag of Belgium, the country where Ernest Solvay was born.



150

151

**Figure 1.** Second enigma sheet of the Solvay process scenario.

152 The CPK color code is a convention for distinguishing atoms of different chemical  
153 elements in molecular models (from Robert Corey, Linus Pauling and Walter Koltun<sup>41</sup>). With  
154 the color code<sup>42</sup>, the students can easily find the molecule OCS, and then the combination  
155 of the second lock, which is the element number of each element: 8, 6, 16. The third puzzle  
156 is related to the chemical discovery of Solvay. Thanks to the text “In 1855, Ernest Solvay  
157 discovered that limestone (calcium carbonate) and brine (sodium chloride) could create soda  
158 ash (sodium carbonate)”, the students have, first, to identify the compound and then write  
159 the chemical equation of the overall process (Equation 1). Once the equation is written, a  
160 hint suggests organizing the compound, from the smallest molar weight to the largest. With  
161 this indication, a four-digit number is formed: 1861, which corresponds to the year the first  
162 Solvay process was set up in Belgium. Finally, the students have access to the last enigma  
163 sheet, available in the supplementary section. In this puzzle, the global equation of the  
164 process is given, as is its cyclic aspect, and a calculation of the daily atmospheric release  
165 capacity of carbon dioxide is requested. This step represents the application area of the  
166 process and its impact on the environment. As the process is intricate, all the carbon  
167 dioxide produced is, in fact, consumed in the process, and there is no carbon by-product.  
168 The answer to this enigma is then 0000. This important element of the Solvay Process has  
169 to be underlined and confronted with the HCl waste product from the Leblanc Process that  
170 caused the first environmental law<sup>32</sup> to be drawn up. After the student solves this enigma, a  
171 message of congratulations is given to him, with a photograph of one of the Solvay  
172 conferences showing some of the great scientists that Solvay brought together.

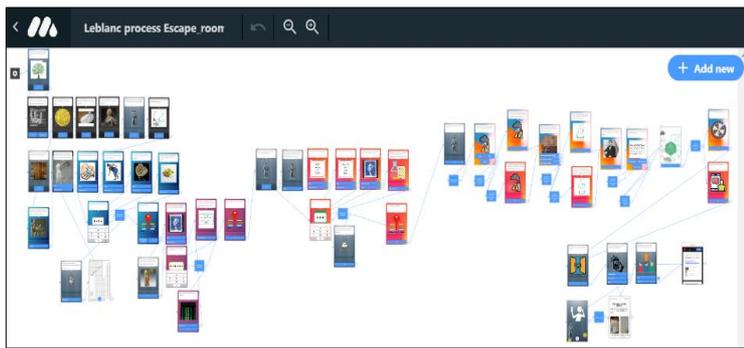
173

## 174 **MATERIAL & METHOD**

175 Metaverse is a free platform that permits unlimited Augmented Reality experiences to  
176 be created without the need for coding. Experiences are created online in the Metaverse  
177 Studio and viewed on the Metaverse smartphone application (iOS and Android). It is  
178 possible to create augmented reality scavenger hunts, games, stories, quizzes, tours,  
179 geocaches and virtual escape rooms. The experiences can be placed at specific locations  
180 with GPS and can feature polls, videos, timed challenges, google drive documents, links  
181 to a webpage, audio narration, and a leaderboard that tracks scores of points awarded

182 to users. Simple objects can be detected, digital items given and requested, and more.  
183 The platform has several resources to help the user, including a comprehensive Manual  
184 under the “Learn” button, a YouTube channel with very detailed instructional videos  
185 (“Tutorials”), a Blog and a Forum. There is also a spreadsheet available, with a list of  
186 Metaverse educational experiences (Breakouts) by topic<sup>43</sup>. Metaverse was launched in  
187 2017 and the company describes it as a “democratized platform that lets anyone create  
188 interactive content in augmented reality”. The website presents several testimonials  
189 from teachers and students using this platform in the classroom to create AR  
190 experiences<sup>44</sup>. To manage Experiences from multiple creators, the option “Collections” is  
191 available, for a monthly fee. This feature is mainly useful for teachers. It is only  
192 possible, at this time, to copy (clone) entire experiences. Remixing experiences,  
193 copy/paste for individual Scenes and Blocks are features that are not available at the  
194 moment but could greatly enhance the potential use of this platform. Each project is  
195 created in an “Experience Storyboard” which is an object-oriented drag-and-drop  
196 workspace. The user can create a simple experience in a few minutes by using scenes  
197 and blocks, and get instant feedback by using the QR code produced to test it. It is  
198 necessary to open the Metaverse app and scan the QR code to start the experience on a  
199 mobile device. The Leblanc process paper-based escape room<sup>32</sup> was adapted in  
200 Metaverse . For this implementation, although the authors had no previous knowledge  
201 of the Metaverse platform, more time was spent figuring out how to adapt the storyline,  
202 puzzles and find appealing images than on the actual Experience Storyboard layout of  
203 scenes and blocks. This is a rather complex experience and was built with 51 scenes  
204 and 12 blocks (the blue squares in Figure 2.a) linked together using transitions (more  
205 details on their implementation can be found in the Supporting Information).

206



(a)



(b)

207 **Figure 2.** Experience Storyboard for (a) the Leblanc escape game (b) the Solvay escape  
 208 game.

209 The new escape room scenario focusing on the Solvay process was built in the  
 210 Metaverse Studio (Figure 2.b). Some features not previously employed were engaged in  
 211 order to create a meaningful experience, namely giving digital items to the player and  
 212 requesting such items from him (Figure 4d), adding sound or a timer to a scene,  
 213 providing various comments and the number of correct questions in a trivia game. The  
 214 scenario presented in this paper required 106 scenes and 27 blocks in Metaverse  
 215 Studio. As with the Leblanc escape room adaptation to Metaverse, in this Solvay  
 216 experience more clues are given than in the paper version and some are modified. The  
 217 hint relating to Argon is an example of such a modification since it was replaced with a  
 218 clue using the fictional element Adamantium (Figure 4c).

### 219 **THE AUGMENTED REALITY ACTIVITY**

220 To play these escape rooms, a smartphone/tablet per team is required with internet  
 221 connection and the free Metaverse app downloaded from an application distribution  
 222 platform (the links to download the application are given in the supplementary  
 223 information section). To view the scenario, students only need to open the app and, in  
 224 the home screen menu, scan a Metaverse QR code by tapping "Scan code" at the top of  
 225 the screen. The QR codes for both scenarios are available in Figure 3.



226

227

**Figure 3.** Metaverse QR codes for Leblanc and Solvay escape rooms

228 The experiences have several scenes in AR mode, in which the students view a  
 229 character in Augmented Reality in their room since the app enables the camera on a  
 230 mobile device to underlay the surrounding environment (Figure 4).

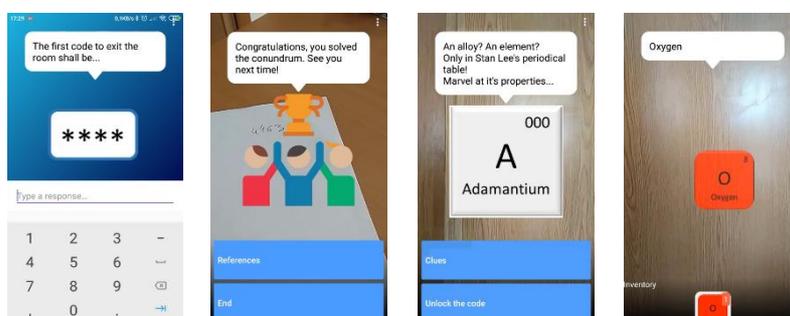
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236 **Figure 4.** Illustration of the AR escape games (a) and (b) from the Leblanc scenario and (c)  
 237 and (d) from the Solvay scenario.

238 The duration for each scenario is around 20-25 minutes depending on the number of  
 239 players and the level of each participant. A video of each scenario is given in the  
 240 supplementary information section.

## 241 DISCUSSION

242 A lesson using augmented reality is always welcomed by a class<sup>45</sup>. Novelty and  
 243 originality can arouse interest and curiosity. Augmented Reality in the classroom makes  
 244 the student active, and it offers a particularly interesting playful aspect that increases  
 245 students' attention and motivation. It also captivates teachers who find a huge potential  
 246 to boost their courses as it provides them with new opportunities to enrich their  
 247 educational activities. The interaction is much stronger than with a simple book or  
 248 handout because the student can freely manipulate the objects or scenes presented and  
 249 scroll them at his own pace<sup>46</sup>. Like conventional escape classroom activities, an AR

250 escape game strongly stimulates students to discover scientific concepts in a team in a  
251 playful way and gives them the opportunity to develop their adaptive and responsive  
252 skills. These games have been tested on 50 students and volunteers, including more  
253 than five teachers from university and high-school in France and Portugal. The activity  
254 has been tested by more than 70 volunteers (paper or mobile version). 95% of the  
255 participants succeeded at the games within 30 minutes for the paper version and 15  
256 minutes for the mobile version. This difference is mainly due to the automatic presence  
257 of hints in the mobile version that can be accessed directly. Concerning the 5% of non-  
258 success, it was mainly due to a smartphone interface problem (technical problem  
259 independent to the Metaverse application). A survey form was completed by students  
260 (N=57) and teachers (N=13) and showed that 96% of the survey panel thought the game  
261 was suitable to develop teambuilding and was a good tool for increasing motivation  
262 (96%) and students' communication (95%). 80% of the panel did not recommend this  
263 activity for groups bigger than 3-4 participants. The central role of the smartphone and  
264 its small screen could place a severe limit on the number of students using it together  
265 (1, 2 or 3 maximum). This can reduce the team skill benefits but the activity remains  
266 interesting. Students are immersed in a story and given an opportunity to accomplish a  
267 fictional objective within a given time limit. It is also a chance for them to compete with,  
268 and against, their classmates, show off their individual skills, interact with each other,  
269 and experience moments of discovery and wins. 75% of the panel who had already  
270 tested a classical escape game felt a similar sensation in the game presented here. This  
271 number is bigger than for a paper-based escape classroom activity. The numeric  
272 support is thus a benefit in the "escape game" mood, thanks to the increase of  
273 intensity/action during the game. 72% of the panel thought the game helped the  
274 students to be more active than in a traditional classroom. 60% of the panel did not  
275 recommend this activity to replace a traditional class, so we propose to use it as a  
276 project, or personal work before or after the corresponding classes. This game does not  
277 replace classical lectures but it is a complementary tool that can be used punctually

278 and following the specific classes to take a break and to escape monotony in the  
279 classroom. Finally, 90% of the panel enjoyed the experience and recommended this  
280 activity for use in the classroom (more than in previous experimentation<sup>32</sup>). It is  
281 important to note that the post-activity debriefing<sup>32</sup> is really important to underline the  
282 main scientific concept of the activity. The AR part of this activity is not as developed, or  
283 original, as previous works of <sup>16</sup> or , but it is accessible for educators that do not have  
284 the coding skills, the required software or the money to buy full adapted AR  
285 experiences.

286 One of the strong points of this activity is its great adaptability, both in its theme and in  
287 the level of students. The level of puzzles can be adjusted, so it is easy to adapt the level  
288 from a discovery activity to specialized master level. The activity can be applied in all  
289 areas of teaching, and the flexibility of digital transposition of the escape game allows  
290 ongoing use with a teacher present, at home as a support to help motivation or to  
291 provide the subject of a project for students in order to feed the activity catalogue. In  
292 case these apps are used in a classroom with the presence of an educator, some QR  
293 code could be put at different locations around the classroom to add more physical into  
294 the escape game. In this case, the activity could be split in several smaller Metaverse  
295 activities at each location. The use of digital media makes it possible to apply and  
296 integrate educational escape games on a larger scale while retaining these advantages,  
297 namely the increase in motivation and the development of adaptability and mutual aid.

## 298 **CONCLUSION**

299 A mobile learning practice activity, based on the use of Augmented Reality for original  
300 escape games, is proposed in this paper. Firstly, a new, printable, paper-based scenario  
301 is detailed in order to apply the escape room activity to the discoveries of Ernest Solvay.  
302 This scenario is composed of a series of enigmas unraveling the different steps of the  
303 chemistry behind the Solvay process and the life of its inventor. Then this scenario, and  
304 that of the Leblanc Process, has been adapted, thanks to the Metaverse open platform,  
305 to an application with Augmented Reality experience. These two scenarios can be

306 played with a smartphone or tablet, with or without the presence of educators. The  
307 main advantage of this approach is that escape games are then not limited in space or  
308 by number of participants, so the activity could be diffused to a larger audience and  
309 could be used as personal work or a project for the student. The game provides a  
310 teaching method that is complementary to existing ones and helps the students to  
311 associate the basic concepts of chemistry (periodic table, balancing equations, and mole  
312 calculations) with simple enigmas in an immersive and stimulating environment on  
313 their smartphones. Students are more active than in a traditional classroom and are  
314 strongly motivated to use a smart device to practice science.

315 The game can be used as a way of discovering a specific chemist (Nicolas Leblanc or  
316 Ernest Solvay), the basics of chemical engineering, and some famous scientists. The  
317 limitation imposed by the use of a smartphone is the number of students who can work  
318 together simultaneously (maximum 3). This approach solves some of the material  
319 limitations of educational escape games (room, material, locks), the cost is very small  
320 and also the activity does not require the presence of the educators in the room. Time is  
321 still required to create the scenario but, in the future, it could be interesting to  
322 encourage students to create enigmas during a semester project. Organizing this escape  
323 classroom takes a certain time (material and scenarios) but the benefits of this  
324 technique are really stimulating.

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333

334 Note: The author declares no competing financial interest.

335

336 **ASSOCIATED CONTENT**

337 **Supporting Information**

338 Paper version of the Solvay scenario and METAVERSE tutorials (PDF, DOCX).

339 Example videos of both AR escape games walkthrough (link).

340 Video with the Leblanc Escape room (link [http://www.ndietrich.com/wp-](http://www.ndietrich.com/wp-content/uploads/2019/10/Metaverse_leblanc_petit.mp4)  
341 [content/uploads/2019/10/Metaverse\\_leblanc\\_petit.mp4](http://www.ndietrich.com/wp-content/uploads/2019/10/Metaverse_leblanc_petit.mp4))

342 Video with the Solvay Escape room (link [http://www.ndietrich.com/wp-](http://www.ndietrich.com/wp-content/uploads/2019/10/Metaverse_Solvay_petit.mp4)  
343 [content/uploads/2019/10/Metaverse\\_Solvay\\_petit.mp4](http://www.ndietrich.com/wp-content/uploads/2019/10/Metaverse_Solvay_petit.mp4))

344 A list of Metaverse Breakouts activities available (XLSX)

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