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

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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

INTRODUCTION

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

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

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

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

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

The examples mentioned above have been very successful with students, both in terms of increasing their motivation and attraction to scientific disciplines and allowing them to work and develop their teamwork and communication skills. These pedagogical games are therefore very interesting tools because adaptability, mutual aid and immersion are rarely developed and practiced through a classical approach. However, implementation faces logistical problems: the immobilization of one or more rooms, the significant cost of the equipment (locks, secret mechanisms, chests, boxes), and the time problems faced by teachers for design, test, preparation and reset operations. Moreover, the small number of simultaneous participants, estimated to be between 3 and 5 for optimal activity, means multiplying the sessions, and thus the presence of a teacher to guide/help students blocked on certain puzzles.

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

THE SCENARIOS

For this activity, two different scenarios were used. The first one is the physical and paper version of the Leblanc Process, published in 2018[32]. We present a new scenario here, which we propose first in a standard paper version. The Solvay process[38], named after its inventor, Ernest Solvay[39], is an industrial process for the production of soda ash[40] (sodium carbonate - Na_2CO_3) created in 1861. In the 20th century, it was the main industrial process used. The Solvay process makes sodium carbonate from brine (sodium chloride - NaCl) and from calcium carbonate (limestone - CaCO3)). The overall reaction is:

$$2\ NaCl + CaCO_3 \rightarrow Na_2CO_3 + CaCl_2 \quad (1)$$

This process is the result of careful observation of ancient practices by an expert chemist and excellent practitioner of aqueous solutions. Helped by his brother, Ernest Solvay founded his first factory at Couillet (Charleroi, Belgium) in 1863 and further perfected the process until 1872, when he patented it. Solvay process plants were established worldwide (70 Solvay process plants are still operational in 2020). The exploitation of his patents brought Solvay considerable wealth, which he used for philanthropic purposes, including the establishment of universities in Belgium and a series of important conferences in physics, known as the Solvay Conferences. Participants included luminaries such as Max Planck, Ernest Rutherford, Maria Skłodowska-Curie, Henri Poincaré, and Albert Einstein.

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

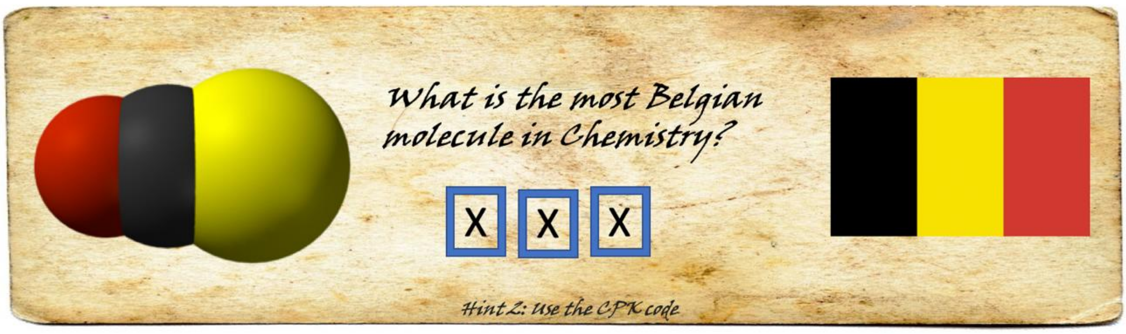
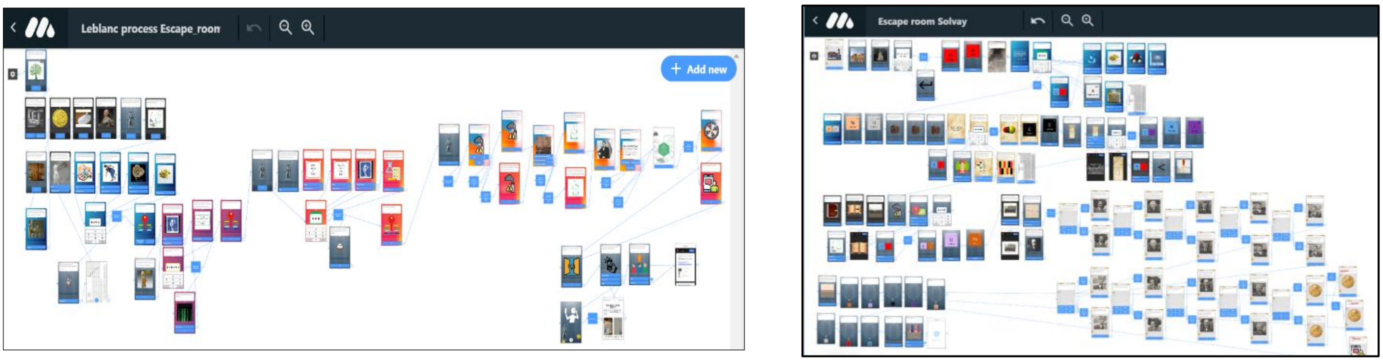


Figure 1. Second enigma sheet of the Solvay process scenario.

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

MATERIAL & METHOD

Metaverse is a free platform that permits unlimited Augmented Reality experiences to be created without the need for coding. Experiences are created online in the Metaverse Studio and viewed on the Metaverse smartphone application (iOS and Android). It is possible to create augmented reality scavenger hunts, games, stories, quizzes, tours, geocaches and virtual escape rooms. The experiences can be placed at specific locations with GPS and can feature polls, videos, timed challenges, google drive documents, links to a webpage, audio narration, and a leaderboard that tracks scores of points awarded to users. Simple objects can be detected, digital items given and requested, and more. The platform has several resources to help the user, including a comprehensive Manual under the “Learn” button, a YouTube channel with very detailed instructional videos (“Tutorials”), a Blog and a Forum. There is also a spreadsheet available, with a list of Metaverse educational experiences (Breakouts) by topic[43]. Metaverse was launched in 2017 and the company describes it as a “democratized platform that lets anyone create interactive content in augmented reality”. The website presents several testimonials from teachers and students using this platform in the classroom to create AR experiences[44]. To manage Experiences from multiple creators, the option “Collections” is available, for a monthly fee. This feature is mainly useful for teachers. It is only possible, at this time, to copy (clone) entire experiences. Remixing experiences, copy/paste for individual Scenes and Blocks are features that are not available at the moment but could greatly enhance the potential use of this platform. Each project is created in an “Experience Storyboard” which is an object-oriented drag-and-drop workspace. The user can create a simple experience in a few minutes by using scenes and blocks, and get instant feedback by using the QR code produced to test it. It is necessary to open the Metaverse app and scan the QR code to start the experience on a mobile device. The Leblanc process paper-based escape room[32] was adapted in Metaverse . For this implementation, although the authors had no previous knowledge of the Metaverse platform, more time was spent figuring out how to adapt the storyline, puzzles and find appealing images than on the actual Experience Storyboard layout of scenes and blocks. This is a rather complex experience and was built with 51 scenes and 12 blocks (the blue squares in Figure 2.a) linked together using transitions (more details on their implementation can be found in the Supporting Information).



(a) (b)

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

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

THE AUGMENTED REALITY ACTIVITY

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

The Leblanc Process The Solvay Process

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

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

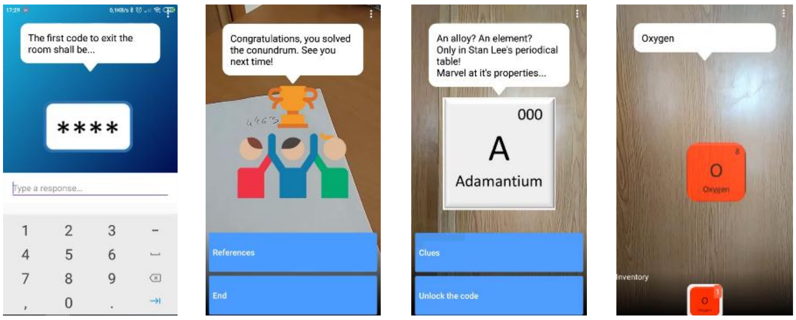


Figure 4. Illustration of the AR escape games (a) and (b) from the Leblanc scenario and (c) and (d) from the Solvay scenario.

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

DISCUSSION

A lesson using augmented reality is always welcomed by a class[45]. Novelty and originality can arouse interest and curiosity. Augmented Reality in the classroom makes the student active, and it offers a particularly interesting playful aspect that increases students' attention and motivation. It also captivates teachers who find a huge potential to boost their courses as it provides them with new opportunities to enrich their educational activities. The interaction is much stronger than with a simple book or handout because the student can freely manipulate the objects or scenes presented and scroll them at his own pace[46]. Like conventional escape classroom activities, an AR escape game strongly stimulates students to discover scientific concepts in a team in a playful way and gives them the opportunity to develop their adaptive and responsive skills. These games have been tested on 50 students and volunteers, including more than five teachers from university and high-school in France and Portugal. The activity has been tested by more than 70 volunteers (paper or mobile version). 95% of the participants succeeded at the games within 30 minutes for the paper version and 15 minutes for the mobile version. This difference is mainly due to the automatic presence of hints in the mobile version that can be accessed directly. Concerning the 5% of non-success, it was mainly due to a smartphone interface problem (technical problem independent to the Metaverse application). A survey form was completed by students (N=57) and teachers (N=13) and showed that 96% of the survey panel thought the game was suitable to develop teambuilding and was a good tool for increasing motivation (96%) and students' communication (95%). 80% of the panel did not recommend this activity for groups bigger than 3-4 participants. The central role of the smartphone and its small screen could place a severe limit on the number of students using it together (1, 2 or 3 maximum). This can reduce the team skill benefits but the activity remains interesting. Students are immersed in a story and given an opportunity to accomplish a fictional objective within a given time limit. It is also a chance for them to compete with, and against, their classmates, show off their individual skills, interact with each other, and experience moments of discovery and wins. 75% of the panel who had already tested a classical escape game felt a similar sensation in the game presented here. This number is bigger than for a paper-based escape classroom activity. The numeric support is thus a benefit in the "escape game" mood, thanks to the increase of intensity/action during the game. 72% of the panel thought the game helped the students to be more active than in a traditional classroom. 60% of the panel did not recommend this activity to replace a traditional class, so we propose to use it as a project, or personal work before or after the corresponding classes. This game does not replace classical lectures but it is a complementary tool that can be used punctually and following the specific classes to take a break and to escape monotony in the classroom. Finally, 90% of the panel enjoyed the experience and recommended this activity for use in the classroom (more than in previous experimentation[32]). It is important to note that the post-activity debriefing[32] is really important to underline the main scientific concept of the activity. The AR part of this activity is not as developed, or original, as previous works of [16] or , but it is accessible for educators that do not have the coding skills, the required software or the money to buy full adapted AR experiences.

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

CONCLUSION

A mobile learning practice activity, based on the use of Augmented Reality for original escape games, is proposed in this paper. Firstly, a new, printable, paper-based scenario is detailed in order to apply the escape room activity to the discoveries of Ernest Solvay. This scenario is composed of a series of enigmas unraveling the different steps of the chemistry behind the Solvay process and the life of its inventor. Then this scenario, and that of the Leblanc Process, has been adapted, thanks to the Metaverse open platform, to an application with Augmented Reality experience. These two scenarios can be played with a smartphone or tablet, with or without the presence of educators. The main advantage of this approach is that escape games are then not limited in space or by number of participants, so the activity could be diffused to a larger audience and could be used as personal work or a project for the student. The game provides a teaching method that is complementary to existing ones and helps the students to associate the basic concepts of chemistry (periodic table, balancing equations, and mole calculations) with simple enigmas in an immersive and stimulating environment on their smartphones. Students are more active than in a traditional classroom and are strongly motivated to use a smart device to practice science.

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

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Note: The author declares no competing financial interest.

ASSOCIATED CONTENT

Supporting Information

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

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

Video with the Leblanc Escape room (link http://www.ndietrich.com/wp-content/uploads/2019/10/Metaverse_leblanc_petit.mp4)

Video with the Solvay Escape room (link http://www.ndietrich.com/wp-content/uploads/2019/10/Metaverse_Solvay_petit.mp4)

A list of Metaverse Breakouts activities available (XLSX)

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