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Augmented Reality towards facilitating abstract concepts learning

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Abstract. Chemistry is often regarded as a complex and demanding subject for youth to learn, partly because of abstract concepts that are challenging to depict. These areas require spatial reasoning, defined as the ability to retain, generate and manipulate abstract visual images in space, either physically or mentally. By allowing the superimposition of virtual objects in the real world, Augmented Reality (AR) facilitates students' understanding of difficult concepts through spatial reasoning by making them visible and allowing for multidimensional perspectives. "Periodic Fable" is an AR serious game targeting 8 to 11-year-old children, designed to teach them basic chemistry concepts of the Periodic Table of Elements in non-formal settings. After designing and implementing the game, we conducted an exploratory study with 36 young participants, using a mixed-method approach. A comparative study between pre- and post-intervention questionnaires and observation results shows a positive learning outcome, demonstrating the potential of this tool in a non-formal context.

Keywords: Augmented Reality · Edutainment · Non-formal learning · Periodic Table.

1 Introduction

The acquisition and development of abstract reasoning is extremely important in children's. Great part of abstract reasoning acquisition happens during the learning process of school subjects. These subjects, involve inquiry, experimentation, evidence, the evaluation and analysis of ideas, problem-solving, creative thinking, and overall understanding of information by making connections with the real world [44]. Children's understanding of abstract concepts in STEM disciplines has been shown to increment by means of spatial reasoning [34] enabling them to reason about the space around while manipulating real or imaginary object configurations in space [7].

Playful educational experiences and games have shown positive effects in a wide spectrum of the development of cognitive skills [25, 19]. Educational games increase concentration levels and stimulate learning in children [1], allowing for

the exploration of teaching tools such as metaphors, analogies, and the spatial manipulation of 3D objects through technologies like Virtual and Augmented Reality [42]. Virtual and Augmented Reality serious games create compelling, collaborative and participatory experiences to enhance the user's engagement and learning. These experiences can provide alternatives to a real-world environment for situated learning, allowing the user to experience a sense of "being there" while applying acquired knowledge [11]. Immersive games hold great potential for cognitive and motor development, and represent a powerful tool to facilitate the teaching of school curriculum and an effective way of acquiring knowledge within a non-formal context. Playing games is also considered a crucial activity for human development of socialization, expression, and communication skills [35]. Given these conditions, knowledge is acquired through a participatory process whereby the learner is "transformed through his actions and relations with the world" [6]. As argued by John Dewey, teaching involves "engaging children in a fun and playful environment, imparting educational content, and instigating interest in learning more" [12].

Given the possibility of transporting knowledge to other settings, Augmented Reality enables the connection between content knowledge and user context, thus making the learning more effective. Many Augmented Reality games have proved especially effective for STEM subjects. AR enables users to visualize otherwise inaccessible representations and to experiment in a low-risk and low-cost platform [3]. Augmented Reality has also been shown to be a powerful tool in the development of spatial skills, such as student understanding of structures that can be either invisible to the naked eye or spatially complex [50, 15, 47].

The Periodic Table is one of the biggest achievements in the modern sciences, not only for chemistry, but also in physics, medicine, earth sciences and biology. In 2019, the United Nations celebrated the 150th international anniversary of the discovery of the Periodic System by Dmitri Mendeleev. As a result, numerous competitions, events and museum exhibitions have been dedicated to this topic. We took this opportunity to reflect on the Periodic Table and its elements and introduce them to young children, who might have not experienced them yet in their school curricula.

In this article, we present our research based on the design and preliminary testing results of Periodic Fable, a game intended to promote non-formal learning of the concepts of the Periodic Table for 11 years old and younger children, that have not tackled "chemistry" as a school subject yet. Periodic Fable incorporates image recognition, tangible objects, 3D virtual reconstruction of models, animations, and is part of a growing number of initiatives that seek to utilize this type of technology to create awareness and engage children in non-formal science learning. The project was designed and produced to complement the celebrations of the anniversary of the Periodic Table.

2 Related Work

2.1 Learning Framework

Situated learning builds upon social learning and development theories, according to which the quality of learning depends on social interaction with the learning context [41][27][49]. Many virtual games and immersive simulations have been designed for training and education, to motivate students by providing a more immersive and engaging learning environment to support situated learning. The seamless integration of virtual content with the real environment can evoke in the users a perceptual state of non-mediation, a sense of presence reinforcing immersion [40]. AR design strategies create virtual immersive experiences and games, which are based on action and symbolic and sensory factors. Research has shown that immersion in virtual environments can enhance education by allowing for multiple perspectives of the learning content, applying situated pedagogy and transfer of knowledge [11]. Even exceptional students in formal educational settings often find it difficult to apply what they learn in class to similar real-world contexts [11]. AR allows users to discern and interact with the real environment while simultaneously receiving additional digital information into their field of perception [5]. The simulation of real-world problems and contexts can be obtained by near transfer. This assimilation of knowledge can then be transferred to other situations, allowing for the construction of more knowledge. Examples of this process can be found in game simulations for flight and surgical training, whereby the user can practice and train certain skills, making mistakes and getting positive feedback when the task is performed in a low-risk environment before transferring this knowledge to real-world situations.

Children learn by using their senses, playing and performing activities, assimilating concepts in an intuitive manner [29]. Constructivism theory argues that children learn by interacting with the physical environment, socially, and by responding to external stimuli consciously. A constructivist environment allows children to build on previously acquired knowledge, in a reflexive process directed by a teacher, parent, or colleague [52]. Likewise, learning by doing is a fundamental activity in children. It is successful when the information is comprehended and used, and this, in turn, contributes to a change, hence transformation in cognitive structure [21]. The potential of Augmented Reality and educational games is supported by constructivism theories. Learning can also benefit from novelty effects due to new technologies [38], since the excitement and curiosity of the students cause them to be more engaged and motivated.

Research shows that students' performance is affected in different variables of the learning process, while engaging in an activity individually or in a collaborative process. [2]. Some effects are related to the intrinsic motivation (enjoying the activity itself), self-efficacy (believe in the capacity to solve a task) and self-determination (decision to do something). These results have been shown in many AR experiences where the activity is performed individually, but also studies shown that there is a tendency for active exchange of knowledge while

students performed an AR activity [26]. However limited of research is known about the learning efficacy when comparing both methods[32].

2.2 Augmented Reality

Augmented Reality (AR) is defined as the perception of reality that has been enhanced through computer-generated inputs and other digital information [3]. AR falls in the realms between a physical and a virtual reality spectrum, meaning that AR supplements reality, rather than completely replacing it. AR is demonstrating to hold great potential in the area of Edutainment (education and entertainment) [37]. As a pedagogical tool, AR enables critical thinking and develops creativity [51]. The continuous investment in Augmented Reality has led to a proliferation of apps in the educational realm, with an increase in off-the-shelf wearable devices, like Curioscope [9], a marker-based t-shirt that allows children to visualize 3D models of human anatomy. Elements 4D, by DAQRI, created an app for chemistry designed to simulate how elements of the periodic table react in real life [10]. Animal Alphabet uses AR Flashcards to learn letters. ZooKazam [30] and Bugs 3D [46] aim to teach about animal species. Arloon Plants [45] allows children to learn about the flora. Star Walk [48] AR app supports learning about the stars, the solar system and the planets. MerchEdu allows students to explore and interact with STEM concepts using a tangible cube [33]. Despite their usefulness, however, many of the commercial AR applications targeted at children have not been evaluated for their effectiveness in learning outcomes. In addition, Augmented Reality's ability to render objects that are hard to visualize using 3D Models (simulation), makes the understanding of abstract concepts more manageable. AR can enhance learning environments, engage, stimulate and motivate students [13, 14]. In scientific subjects, complex approaches are required for the students to envision concepts like micro and macro-worlds, and its assimilation remains a difficult and challenging process. Students make observations, collaborate with others, inquire, ask questions, investigate and interpret data when engaging with the AR system [11]. Chemistry in public schools with large size classes suffers from limited resources and time available, and, as a result, some students do not have the opportunity to conduct experiments. AR simulation helps to bridge this gap, contributing to the observation of some reactions on a one- to-one basis[16]. In Switzerland, an AR virtual chemistry laboratory was created for students to view and acquire atoms through a virtual drag-and drop technique. This platform allowed students to construct their own complex molecules, developing active learning skills [20]. Besides the allowance of inquiry-based learning, using this system also helped students to be active in the learning process [8]. Low- achieving students benefit considerably by interacting with 3D models of micro-particles, better understanding the composition of substances [8]. The teaching of molecule formation, covalent bond and molecule structure using AR vs traditional methods such as a textbook, proved to be more effective in improving student performance [36]. StereoChem is a mobile Augmented Reality application used to help students understand stereochemistry, focusing on the study of stereoisomers (molecular formulas that differ in spatial orientation)

to help in the perception of the 3D molecules[28]. Augmented Chemistry allows students to obtain and understand information about the spatial relations between molecules by using the input of keyboards and tangible interaction. Augmented Chemistry represents the molecules in a 3D environment, providing multiple viewpoints and control of the interactions [43].

2.3 Tangible Interfaces

The combination of tangible, physical interfaces with tridimensional virtual imagery allows children to play, engage, and have fun as they learn, facilitating the cognitive load [4] in a natural and genuine way [8].

Tangible interfaces can ease the communication of abstract concepts. This is the case of Digital MiMs, computer enhanced building blocks that support learning in mathematics, probabilistic behavior and more. Another example is ProBoNo, a software and tangible hardware prototype developed for children from four to six years of age. PrBoNo allows children to navigate virtual worlds more playfully and engagingly. A study of this system concluded that the tangible interface facilitated the transfer of knowledge acquired in a digital environment to a situation in the real world [22].

However, regarding the benefits of tangible interactions for children, Horn et Al.[24], advocate for a hybrid approach (a single interactive system that consists of two or more equivalent interfaces). Teachers and learners can select the most appropriate interaction according to the task and needs of a specific situation [24]. Moreover, Ambient Wood, a large-scale learning activity targeting 11-12-year-old children, aims to teach children about the nature of scientific inquiry by means of tangible discovery, reflection, and experimentation. A study of the system highlighted that, while tangibility per se is not enough to engage children in a task, it is crucial to have the appropriate tangible system [31].

3 Methods

3.1 System Design

Periodic Fable is a serious AR game for android mobile devices (with gyroscope, accelerometer and compass sensor), designed and produced to target 8 to 11-year-old children that come into contact with chemistry for the first time. The game developed using ARCore, Autodesk Maya, Mudbox and Adobe Photoshop, provides basic concepts about chemical elements like their symbols, atomic numbers, atomic weight, reactions with other elements, and products that contain the element. It also allows users to obtain information by scanning markers, and joining elements(depicted as creatures) to create reactions. Thus, the learning process becomes fun, engaging the students[11].

Content The content of the game was selected with the help of a Ph.D. student (in a Chemical biology related area) and two Chemistry teachers. It takes into

account the knowledge of chemistry that our target audience already acquired in science classes. Children from 8 to 11 learned some basic chemistry notions while learning about topics like pollution (carbon monoxide), blood components, the atmosphere, photosynthesis (carbon, oxygen), and the cycle of water (hydrogen, oxygen), to name some. It is not until later that chemistry becomes a curricular subject. The elements selected to feature in the Periodic Fable game are the most abundant in the environment, and have compelling reactions, which makes the students more curious, inspiring them to speculate about possible combinations. The Periodic Fable design relies upon constructivism as a learning method, allowing the children to explore and interact freely with the content, thus complementing their knowledge about the chemical elements. Moreover, to create a connection between the content and the real-world, we decided to include information that could be transferred to the everyday routine of the children.

Technology/Game Mechanics The AR game uses a marker-based system and tangible cubes as part of the mechanics. The camera of the mobile phone scans a pattern/image, recognizes it, and superimposes a digital image on the screen of the device (in our case, 3D models and animations, 2D images, video, text and audio). The criteria for the selection of the equipment is based on the children's ease of access to mobile devices, their portability, and affordability. Autodesk Maya, Adobe Photoshop, Adobe AfterEffects and Unity 3D were used for the development of the game.

We designed a tangible cube as a starting point. The child has to explore each facet of the cube to gain access to different information, which allows the user physical manipulation and exploration of spatial arrangement. The decision is the result of several iterations, heuristic evaluation and small sample testing to make playing the game easy, without need for supervision (almost intuitive). Few instructions are necessary, thus avoiding cognitive overload. The game features a cube per element, and each face of the cube expresses qualities and scientific facts about that element. At the moment we have developed five cubes, corresponding to oxygen, hydrogen, carbon and nitrogen, because they are the most important elements; their covalent bond combinations are responsible for most of the biological molecules on earth. We added chlorine to the list because, like the other elements, its properties and reactions can be the most interesting and engaging for the children. In the future, we hope to develop the experience for all the elements of the Periodic Table, allowing users to position each cube in the proper location, and to construct their own physical Periodic Table.

Aesthetics Each tangible cube is dedicated to one chemical element. All the facets of each cube (used as markers) are identified with text and a 2D image of the character holding an icon indicating the type of information that will be prompted (story/book, curiosities/ question mark, combination /silhouette of a group of characters, code name, habitat/building, information / letter "i").

The 3D characters were designed taking into consideration the properties of the elements that they represent. For example, oxygen is a highly reactive

element, and capable of combining with other elements. Because of this, oxygen is depicted as a friendly creature, illustrated with the code name of the symbol it represents: "O". The atomic number reflects the creature's age, and the atomic mass is indicated as its weight (see Fig. 2 number 1). We created these analogies for each element as a way to facilitate retention of the information. The creature's aesthetics, from color to animation, are also keyed to properties of the element and provided with several iterations to create more empathy with the user. The colors assigned to each character reflect the Robert Corey, Linus Pauline and Walter Koltun coloring standard convention known as CPK color, used to distinguish the atoms of chemical elements in molecular models [23]. The color scheme is associated with some properties of the elements. For example, hydrogen, a colorless gas, is white; chlorine is green; carbon is either charcoal or graphite; nitrogen is blue, since it makes up most of the atmosphere and oxygen is associated with combustion; blood is red. The inspiration for the base shape of our 3D character is the ball-and-stick model of the molecular models, whereas the body of the characters is rounded like the spheres that represented the atoms, and the arms and legs are rods that can connect and create bonds with other elements. We designed glasses for each of the individual characters, and feet, hands, and other human features to animate and give each element a different personality, so that children can associate the creatures to the element's properties, empathize and engage with them. For example, the animation for hydrogen is a calm Zen creature that floats while meditating, thus portraying its low density the fact that it is essential for life (see Fig. 1).



Fig. 1. Left to right -hydrogen, nitrogen, oxygen, chlorine and carbon

Story The concept of content-infused story games (CIS Games) builds on the fusion between games and stories to educate children [17]. Building upon this concept, a facet of the tangible cube is designed to identify with the element it represents holding a book. These animations feature in short, funny animation clips, turning into stories the outcome of joining two or more elements, and the reactions that this might trigger. For example, one of the stories dedicated to hydrogen presents the characters having fun in a water-park. Two hydrogens slide down a water toboggan and get stuck at the end of the ride. The oxygen

that slides next is unable to stop hitting the two hydrogen creatures, and all turn into water. Chlorine is depicted as a superhero that saves his friend from a huge bacterium in a lab. Our aim is to make children learn and remember some of the chemical combination's outcomes and properties while having fun.

Game-play The game starts with a short tutorial that guides the children in understanding the mechanics of the game: how to explore the faces of a tangible cube, gather the elements/characters, and use them to create reactions. The participant selects one of the cubes (this selection can be random) and scans one of the markers/images on each facet, generating/uploading the information linked to that particular pattern.

Facet 1 (Information) Triggers an animation of a 3D character representing a chemical element. It also provides information about the chemical symbol, including atomic mass, chemical name and atomic number(see Fig. 2 number 1).

Facet 2 (Habitat) Uploads an image of an apartment building divided according to the blocks of Periodic Table (atomic weight and arranged in horizontal rows/periods and vertical columns /groups). We decided to showcase the different characters in this blocks/apartment location creating an analogy (apartment building vs location of the element in the periodic table), so children will assimilate the lodging of the element in the Periodic Table (see Fig. 2 number 2).

Facet 3 (Curiosities) In this facet corresponding AR scenes, 3D models of products that have that element within their composition are visualised (see Fig. 2 left-number 3).For example, we depict oxygen as being a compound that can be found on a Pepsi drink, a cleaning product like Vanish (see Fig. 2 right - number 3). Our design took a situated learning approach, whereby children can create connections with the products in their surroundings and chemical elements.

Facet 4 (Stories) Capturing facet triggers short clip (less than one minute) dedicated to that particular element reaction with another elements (see Fig. 2 number 4)

Facet 5 (Combinations) Capturing facet 5 allows the children to select and explore the reactions of different elements. We placed icons on the left side of the screen for the user to select and then explore several reactions (water, fertilizer, ammonia, fire, ozone, or to create a diamond) (see Fig. 2 number 5). Once the user clicks on the button, the application will indicate what type of creatures/elements are needed, and the user will be prompted to scan the corresponding cube with the camera of the mobile device (see Fig. 2 number 6).

If this activity is performed correctly, the interface notifies the child with a message congratulating him or her for the reaction just created (see Fig. 3 number 2) and showing the elements that were part of the reaction (Fig. 3 number 3). Then an animation of the reaction just created plays out (see Fig. 2 number 6).

Each element experience ends when the user has explored all the facets of the cube dedicated to that element, and captured its reactions. The experience can be repeated for the other cubes, until all cubes have been explored. Since no dependencies of content have been designed, each child can explore one, two, three, or all the cubes, always achieving full closure with each experience.

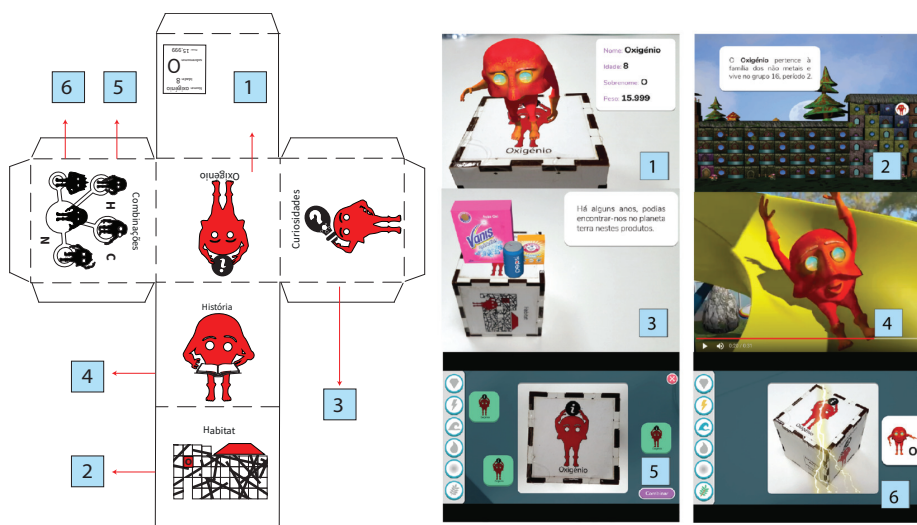


Fig. 2. Left: 2D representation of tangible cube; Right - Interaction with the faces. 1. information/animation; 2. Habitat- location of the characters/elements within the Periodic Table; 3. Products that contain the elements; 4. Stories; 5. Combination of the elements; 6. Reactions

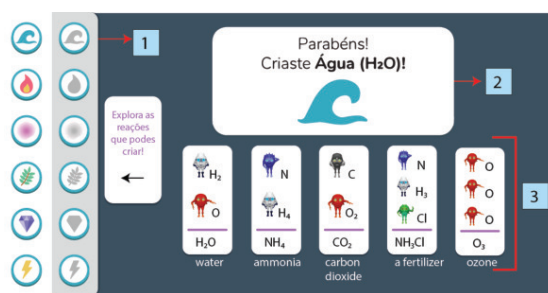


Fig. 3. 1. Icons reactions; 2. Congratulation messages; 3. Elements that participated in the reaction

3.2 Participants Demographic and Data Collection

According to school curricula in Portugal, Chemistry becomes available as a subject only during the 7th grade, where students are 12 years old. To experiment if the AR based game facilitated the learning of abstract concepts in early childhood we decided to evaluate our game with children before they had engaged with abstract concept of chemistry as a school curricular activity. We based our study at a Computer Science Club at a public school in Madeira. We engaged 36 participants, 20 females (55.6%) and 16 males (44.4%) ranging from 8 to 11 years old. The study was designed as in between study, where 18 participants experienced the Periodic Fable in pairs (50%)-Experimental Condition or Group 2, while 18 individually (50%) - Control Condition – or Group 1. The study was designed to explore if the AR game would support the learning of abstract concepts such as chemistry basic, in children with no previous exposure to the subject and to explore which interaction conditions (single or pairs) would yield the best learning outcome. The study took place during one day, on November 27, 2019.

3.3 User Technology Access

Most of the students (32; 88.9%) had access to a mobile device prior to the study, but four (11.1%) did not. 15 participants (41.7%) had access to a mobile device less than a year ago. 11 participants (30.6%) had had access to a mobile device for more than a year, 7 (19.4%) had had access to a mobile device for over 2 years, and only four (8.3%) had no access to a mobile device. 12 participants (33.3%) knew or had heard about AR technologies, while five (13.9%) had already used AR. Only four students (11.1%) had previous knowledge of the Periodic Table.

3.4 User Study Protocol

Recruitment was done through a local school at Santa Cruz, Madeira. The experimenter contacted a teacher from the school Computer Science club, explained the project's objectives and demonstrated the study procedures. Parents signed Parental Consent before the intervention, which included information about the date and time of the study. On the intervention day, we briefed the participants and asked them to answer a pre-test questionnaire, which included questions like: What happens when you combine one oxygen and two hydrogen? What is the symbol for nitrogen? What formed the ozone? What products have chlorine in them? What are the elements found in diamonds? After having answered the questionnaire, the participants were assigned randomly to one of the two groups, to avoid any bias.

Each group of participants experienced one condition. Group 1 (Control Condition) performed the intervention individually while, Group 2 (Experimental Condition) performed the intervention in pairs (see Fig. 4) While in the control condition, individual students were seated at their desks and given a set of 5

cubes and a mobile phone to explore the cubes by themselves; in the experimental condition, students sat in pairs and shared the 5 cubes and the mobile phone. Both groups of participants had to answer individually a post- intervention questionnaire with the same questions as in the pre-intervention questionnaire, but posed in different order, so as to assess the learning more accurately. The participants were monitored by three researchers during the interactions. Observation notes were taken regarding struggles with the application, the points students seemed to enjoy most, confusion with any of the tasks, and emotional reactions. The whole experience, including pre- and post questionnaires, took 30 minutes. The experiment material consisted of an android smartphone and the five tangible cubes. Data regarding usability and satisfaction on part of the students were collected using a questionnaire with a Smileyometer [39] Likert scale (it uses pictorial representation) of 5 levels - “1” for totally disagree and “5” for totally agree (see Table 1).

Table 1. Usability and engagement data results

Q#	Question	Percentage	Mean / SD
Q1	I enjoy using Periodic Fable	88.9%	4,89/0.319
Q2	It was easy to use the application	55.6%	4,39/0.803
Q3	I knew what to do during the game	75%	4,72/ 0.513
Q4	The instructions were easy to follow	61.1%	4,53/0.696
Q5	I always knew what to do during the game	52.8%	4,11/1.214
Q6	The capture of the information with the markers always worked	44.4 %	4,25/ 0.770
Q7	The camera never lost the information of the marker	55.6%	4,29/0.926
Q8	The application always read the correct marker	77.8 %	4,67/0.717
Q9	It was a great experience to play the game	88.9%	4,83/0.561
Q10	I was always performing the same action during the game	58.3%	4,36/0.961
Q11	The amount of information was enough	69.4%	4,58/0.692
Q12	The 3D objects always appeared on my mobile screen	66.7%	4,56/0.695
Q13	There was a tutorial	75%	4,67/ 0.676

Table 2. Again and Again / Engagement scale

Q#	Question	Percentage	Mean / SD
Q1	Do you want to see the animations of the elements/creatures again?	94.4%	1.06/0.232
Q2	Would you like to watch the stories again?	72.2%	1.25/0.500
Q3	Would you like to make more combinations of elements?	86.1%	0.66/ 0.398
Q4	Would you like to see the habitat of the elements again?	86.1.1%	1.08/0.439
Q5	Would you like to see more information about the elements?	80.6%	1.19/0.401
Q6	Did you learn any information from this experience?	88.9 %	1.11/ 0.319

The second measurement, related to enjoyment, was gathered through an Again-Again table. This measure is based on the knowledge that people like to do fun things again [39]. We also analyzed which part of the experience was most enjoyable for the participants by answering “Yes” as code 1, “No” code as 0, and “Maybe” as code 2 questions related to each side of the tangible cube (see Table2). To estimate gains in learning outcomes regarding the concepts of the Periodic Table, we used the multiple-choice pre-intervention and post-intervention questionnaire data. We also conducted two comparative analyses using a non-parametric test within and between groups

4 Results

The study aimed to assess whether the use of the AR Serious Game facilitates the learning of concepts related the Periodic Table. We also wanted to analyze whether interventions in pairs had higher gains than individual interventions.

The normality of the sample in terms of results was evaluated, and since the values of Skewness and Kurtosis ($p= 0.002$) showed that the assumption of normality was violated, we used a non-parametric test. For analysis within each group, we used the Wilcoxon signed rank test, with the game played individually (Control Condition or Group 1) and in pairs (Experimental Condition or Group 2). The results show that the post-intervention learning outcome is significantly higher for participants in the Control condition (Mdn = 2), $T= 78$, $p=0.001$, $r=0,54$ (large effect) as well as in the Experimental Condition (Mdn=1), $T=36$, $p=0.010$, $r=0.43$ (large effect). In sum, the application had a strong, positive effect in the learning of concepts about the Periodic Table in both groups (see Fig. 4).

We conducted a between group analysis – using the Mann-Whitney test – with the same conditions as above. When measuring the children’s knowledge before playing the game (Mdn=.00) $U= 110.00$, $p= 0.10$, $r=-0.31$ (medium effect), the results show that the difference in learning outcomes between groups was not significant. However, in the post- intervention test, the children that played individually had significantly higher results than those that did the intervention in pairs (Mdn= 1), $U= 98.50$, $p=0.04$, $r=-2.09$ (medium effect). Contrary to the findings of Martín-SanJosé [32] individual intervention had higher learning gains that in a collaborative setting. We attribute these results to the fact that the participants that did not share the mobile device had more freedom to explore the tangible cube, controlling the areas that they wanted to visualize, the time dedicated to each area, and could repeat the tasks ad libitum (see Fig. 4).

We also performed a Whitney U analysis to evaluate if there were any gender differences in the learning outcomes. From the data, we can conclude that gender differences were not statistically significant ($U=139$, $p=.519$). The users were pleased with factors about the usability and engagement of the game (see Table 1). Question 6 (Q6) had the lowest score (Mean=4,25). Few children had difficulties when scanning the cubes images/ markers(see Fig. 4).

Related-Samples Wilcoxon Signed Rank Test Summary			
		Individual intervention	Pair intervention
Within Groups Learning Outcome	Total N	18	18
	Test Statistic	78.000	36.000
	Standard Error	12.124	6.955
	Standardized Test Statistic	3.217	2.588
	Asymptotic Sig. (2-sided test)	.001	.010

Independent-Samples Mann-Whitney U Test summaries			
		Pre test	Post test
Between Groups Learning Outcome	Total N	36	36
	Man - Whitney U	110.000	98.500
	Wilcoxon W	281.00	269.500
	Test Statistic	110.000	98.500
	Standard Error	27.842	30.415
	Standardized Test Statistic	-1.881	-2.088c
	Asymptotic Sig. (2-sided test)	.060	.037
	Exact Sig. (2 -sided test)	.104	0.44

Fig. 4. Top: Results within subject learning outcome - Bottom: Results between subjects learning outcome

The Kruskal-Wallis test results do not demonstrate any difference in the usability and engagement of the activity between the groups conditions, $\chi^2(1) = 0.22$, $p = 0.15$.

5 Discussion, Limitations and Future Work

Our results reinforce the positive effects of gaming techniques and AR technologies in the engagement and motivation of the students [4]. According to the questionnaire, the AR visualization of the animated characters/elements introducing themselves to the players was the most enjoyable part of the experience, hence we can infer that the creatures/elements captivating characterizations as funny looking, intriguingly futuristic characters was a successful factor in engaging the children (see Table 2). The participants' reactions show that they enjoy combining the elements through the cube facets that triggered the AR scenes. One of the students commented aloud "I just made water!" and another responded, "I just created a diamond!" According to the data, the 2D animated short stories about the elements were the least captivating part of the experience. Overall, the participants acknowledged that they had learned something new about the Periodic Table. The data also show that the application increased the curiosity of the children regarding other chemical elements.

The results of the preliminary study reported that our game, has positive learning outcomes regarding basic Periodic Table concepts in non-formal settings. Our results also show that there is potential in combining smart phones and Augmented Reality in non-formal spaces to facilitate the learning of content

that is not available through the school curriculum, and that this helps to create intrinsic motivation towards future STEM subjects. Young students who came in contact with chemistry through the Periodic Fable game for the first time were able to learn while engaging in the activity.

Exploring all the faces of the tangible cube to gather/visualize information was an intuitive and rewarding process. Nevertheless, some technical challenges were identified regarding the ease of use of the Augmented Reality application. Technical problems such as tracking loss made the interaction difficult for some. Since our application depended on image-based tracking, the experience stopped when moving away from the marker. This was frustrating to some children who wanted to view the animations without being interrupted. Other technical limitations when using AR marker-based technology are dependency on light quality to read the images/markers; delays in the rendering of data; over-heating of the equipment; battery consumption; the need for robust equipment with the required sensors (gyroscope, accelerometer, and compass).

The results of the study enabled us to distill insights that could be beneficial when designing an AR serious game for a young audience: 1) find the appropriate pedagogical framework for the content to be delivered [18], AR benefits situated and constructive methods; 2) pay attention to the adequacy of aesthetics to the age range; 3) design analogies and metaphors carefully, ensuring that they support the mental images and the construction of ideas needed to facilitate the understanding of the concept; 5) balance the amount of information delivered with the usability load to avoid cognitive overload.

6 Conclusion

In this paper we have reported on the design and preliminary study of a Periodic Fable AR serious game designed to support children's understanding of abstract concepts such as those found in chemistry. Our study demonstrated that the AR game facilitated the understanding of chemistry and the learning of abstract concepts in non-formal settings. Further research is needed to categorize its benefits and limitations more clearly, and to develop clear guidelines and appropriate tools to address these challenges.

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References

1. Arcos, C.G., Fuertes, W., Villacis, C., Zambrano, M., Noboa, T., Tacuri, A., Aules, H., Toulkeridis, T.: Playful and interactive environment-based augmented reality to stimulate learning of children. 2016 18th Mediterranean Electrotechnical Conference (MELECON) pp. 1–6 (2016)
2. Arvanitis, T.N., Williams, D.D., Knight, J.F., Baber, C., Gargalakos, M., Sotiriou, S., Bogner, F.X.: A human factors study of technology acceptance of a prototype mobile augmented reality system for science education. *Advanced Science Letters* **4**(11-12), 3342–3352 (2011)
3. Azuma, R.T.: A survey of augmented reality. *Presence: Teleoperators & Virtual Environments* **6**(4), 355–385 (1997)
4. Billinghamurst, M., Clark, A., Lee, G., et al.: A survey of augmented reality. *Foundations and Trends® in Human–Computer Interaction* **8**(2-3), 73–272 (2015)
5. Bower, M., Howe, C., McCredie, N., Robinson, A., Grover, D.: Augmented reality in education—cases, places and potentials. *Educational Media International* **51**(1), 1–15 (2014)
6. Britton, J.: Vygotsky’s contribution to pedagogical theory. *English in Education* **21**(3), 22–26 (1987)
7. Buckley, J., Seery, N., Canty, D.: A heuristic framework of spatial ability: A review and synthesis of spatial factor literature to support its translation into stem education. *Educational Psychology Review* **30**(3), 947–972 (2018)
8. Cai, S., Wang, X., Chiang, F.K.: A case study of augmented reality simulation system application in a chemistry course. *Computers in human behavior* **37**, 31–40 (2014)
9. Curiscope: Bring learning to life. <https://www.curiscope.com/>. (May 2020)
10. DAQRI: Elements 4d interactive blocks. <https://https://www.kickstarter.com/projects/daqri/elements-4d-interactive-blocks/>. (Jan 2014)
11. Dede, C.: Immersive interfaces for engagement and learning. *science* **323**(5910), 66–69 (2009)
12. Dewey, J.: *Liberalism and social action*, vol. 74. Capricorn books New York (1963)
13. Di Serio, Á., Ibáñez, M.B., Kloos, C.D.: Impact of an augmented reality system on students’ motivation for a visual art course. *Computers & Education* **68**, 586–596 (2013)
14. Duh, H.B., Klopfer, E.: Augmented reality learning: New learning paradigm in co-space. *Computers and Education* **68**(1), 534–535 (2013)
15. Dunleavy, M., Dede, C.: Augmented reality teaching and learning. In: *Handbook of research on educational communications and technology*, pp. 735–745. Springer (2014)
16. Edomwonyi-Otu, L., Aava, A.: The challenge of effective teaching of chemistry: A case study. *Leonardo Electronic Journal of Practices and Technologies* **10**(18), 1–8 (2011)
17. Fails, J.A., Druin, A., Guha, M.L., Chipman, G., Simms, S., Churaman, W.: Child’s play: a comparison of desktop and physical interactive environments. In: *Proceedings of the 2005 conference on Interaction design and children*. pp. 48–55 (2005)
18. Fisch, S.M.: Cross-platform learning: On the nature of children’s learning from multiple media platforms. *New directions for child and adolescent development* **2013**(139), 59–70 (2013)
19. Fissler, P., Kolassa, I.T., Schrader, C.: Educational games for brain health: revealing their unexplored potential through a neurocognitive approach. *Frontiers in psychology* **6**, 1056 (2015)

20. Fjeld, M., Schar, S.G., Signorello, D., Krueger, H.: Alternative tools for tangible interaction: A usability evaluation. In: Proceedings. International Symposium on Mixed and Augmented Reality. pp. 157–318. IEEE (2002)
21. Gardner, H.: Using multiple intelligences to improve negotiation theory and practice. *Negotiation journal* **16**(4), 321–324 (2000)
22. Göttel, T.: Probono: transferring knowledge of virtual environments to real world situations. In: Proceedings of the 6th international conference on Interaction design and children. pp. 81–88 (2007)
23. Helmenstine, T.: Science notes – learn science do science. <http://sciencenotes.org/category/chemistry/periodic-table-chemistry/page/2/> (Aug 2019)
24. Horn, M.S., Crouser, R.J., Bers, M.U.: Tangible interaction and learning: the case for a hybrid approach. *Personal and Ubiquitous Computing* **16**(4), 379–389 (2012)
25. Host'ovecký, M., Salgovic, I., Viragh, R.: Serious game in science education: How we can develop mathematical education. In: 2018 16th International Conference on Emerging eLearning Technologies and Applications (ICETA). pp. 191–196. IEEE (2018)
26. Hung, Y.H., Chen, C.H., Huang, S.W.: Applying augmented reality to enhance learning: a study of different teaching materials. *Journal of Computer Assisted Learning* **33**(3), 252–266 (2017)
27. Johnson, D.W., Johnson, R., Holubec, E.: Cooperation in the college classroom. Edina, MN: Interaction Book Company (1991)
28. KL, N.S., Chavan, P.S., Murthy, S.: Stereochem: Augmented reality 3d molecular model visualization app for teaching and learning stereochemistry. In: 2018 IEEE 18th International Conference on Advanced Learning Technologies (ICALT). pp. 252–256. IEEE (2018)
29. Kritzenberger, H., Winkler, T., Herczeg, M.: Collaborative and constructive learning of elementary school children in experiential learning spaces along the virtuality continuum. In: Mensch & Computer 2002, pp. 115–124. Springer (2002)
30. LLC, A.A.: Zookazam magical animals. <http://www.zookazam.com/> (Jan 2020)
31. Marshall, P., Price, S., Rogers, Y.: Conceptualising tangibles to support learning. In: Proceedings of the 2003 conference on Interaction design and children. pp. 101–109 (2003)
32. Martín-SanJosé, J.F., Juan, M., Torres, E., Vicent, M.J., et al.: Playful interaction for learning collaboratively and individually. *Journal of Ambient Intelligence and Smart Environments* **6**(3), 295–311 (2014)
33. MergeLabs, I.: Merge edu. <https://mergeedu.com/1/engage/> (2020)
34. Newcombe, N.S., Frick, A.: Early education for spatial intelligence: Why, what, and how. *Mind, Brain, and Education* **4**(3), 102–111 (2010)
35. Paredes, J.: Juego, luego soy. Teoría de la actividad lúdica. Sevilla: Wanceulen (2003)
36. Pasaréti, O., Hajdin, H., Matusaka, T., Jámbori, A., Molnár, I., Tucsányi-Szabó, M.: Augmented reality in education. INFODIDACT 2011 Informatika Szakmódszertani Konferencia (2011)
37. Pérez-Sanagustín, M., Hernández-Leo, D., Santos, P., Kloos, C.D., Blat, J.: Augmenting reality and formality of informal and non-formal settings to enhance blended learning. *IEEE Transactions on Learning Technologies* **7**(2), 118–131 (2014)
38. Radu, I.: Augmented reality in education: a meta-review and cross-media analysis. *Personal and Ubiquitous Computing* **18**(6), 1533–1543 (2014)

39. Read, J.C., MacFarlane, S., Casey, C.: Endurability, engagement and expectations: Measuring children's fun. In: *Interaction design and children*. vol. 2, pp. 1–23. Shaker Publishing Eindhoven (2002)
40. Riva, G., Waterworth, J., Murray, D.: *Interacting with Presence: HCI and the Sense of Presence in Computer-mediated Environments*. Walter de Gruyter GmbH & Co KG (2014)
41. Roth, W.M.: *Authentic school science: Knowing and learning in open-inquiry science laboratories*, vol. 1. Springer Science & Business Media (2012)
42. Shelton, B.E., Hedley, N.R.: Exploring a cognitive basis for learning spatial relationships with augmented reality. *Technology, Instruction, Cognition and Learning* **1**(4), 323 (2004)
43. Singhal, S., Bagga, S., Goyal, P., Saxena, V.: Augmented chemistry: Interactive education system. *International Journal of Computer Applications* **49**(15) (2012)
44. Squire, K.D., Jan, M.: Mad city mystery: Developing scientific argumentation skills with a place-based augmented reality game on handheld computers. *Journal of science education and technology* **16**(1), 5–29 (2007)
45. TM, A.: Arloon plants. <http://www.arloon.com/apps/plants/> (Jan 2019)
46. TTPM, P.T.: Bugs 3d interactive boom. <https://ttpm.com/p/9759/popart-toys/bugs-3d-interactive-book/> (Jan 2020)
47. Valimont, R.B., Gangadharan, S.N., Vincenzi, D.A., Majoros, A.E.: The effectiveness of augmented reality as a facilitator of information acquisition in aviation maintenance applications. *Journal of Aviation/Aerospace Education & Research* **16**(2), 9 (2007)
48. Vito Technology, I.: Star walk – the sky at your fingertips. <https://starwalk.space/en/>. (Jan 2020)
49. Vygotsky, L.S.: *Thought and language* (e. hanfmann & g. vakar, trans.) (1962)
50. Wijdenes, P., Borkenhagen, D., Babione, J., Ma, I., Hallihan, G.: Leveraging augmented reality training tool for medical education: A case study in central venous catheterization. In: *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems*. pp. 1–7 (2018)
51. Zünd, F., Ryffel, M., Magnenat, S., Marra, A., Nitti, M., Kapadia, M., Noris, G., Mitchell, K., Gross, M., Sumner, R.W.: Augmented creativity: Bridging the real and virtual worlds to enhance creative play. In: *SIGGRAPH Asia 2015 Mobile Graphics and Interactive Applications*, pp. 1–7 (2015)
52. Zurita, G., Nussbaum, M.: A constructivist mobile learning environment supported by a wireless handheld network. *Journal of computer assisted learning* **20**(4), 235–243 (2004)