Drawing on Augmented Reality to Develop STEM Competencies in Primary Education

Belén Palazón
Rey Juan Carlos University
b.palazon@alumnos.urjc.es

Liliana Patricia Santacruz-Valencia
ETSII, Rey Juan Carlos University
liliana.santacruz@urjc.es

2022 IEEE Frontiers in Education Conference (FIE) | 978-1-6654-6244-0/22/$31.00 ©2022 IEEE | DOI: 10.1109/FIE56618.2022.9962692

***Abstract*—This article proposes PluggedAR, an application aimed at children aged 6 to 9 and based on Augmented Reality (AR) for mobile devices. PluggedAR allows working on basic concepts of programming as binary numbers, image representation, programming languages, graphics, and minimum spanning trees. In order to test the effectiveness of PluggedAR, a study has been conducted questioning whether the use of AR increases the enthusiasm of students to learn and encourages them to solve the proposed activities. In fact, all the participating students (100%) agreed that learning new concepts with PluggedAR is more entertaining and fun, and their desire to use it in the classrooms was expressed by all of them (100%). In addition, the wide variety of activities has been met with mixed preferences by students. A group of teachers has also participated, and a high percentage of them (50%) believe that PluggedAR is highly recommended for working with children, and 33% of them highlight the wide range of concepts offered by PluggedAR. It is expected that the use of PluggedAR supports the development of STEM (Science, Technology, Engineering, and Mathematics) skills such as problem-solving, logical thinking, or decision making.**

Keywords—Augmented Reality, STEM, competencies, Primary Education, programming

I. Introduction

Nowadays, many strategies and technologies are being used for introducing Computational Thinking (CT) skills and teaching programming-basic concepts [1], [2], [3], [4]. Both subjects are part of the STEM concept which is receiving strong attention since it is an essential skill that all 21st-century citizens should develop. To face the mentioned skills, interfaces can be implemented in order to enrich students' interactions using AR technology. AR literature reviews [5], [6] [7], [8], [9], show a quick growth of this technology in different educational scenarios, revealing its challenges and possibilities [10], [11], [12].

A recent systematic review of AR [13], confirms that AR applications in an educational context can have many positive impacts on aspects like students' motivation and enjoyment, while at the same time it can increase collaboration, creativity, critical thinking, satisfaction, the performance of physical tasks and their understanding of several programming concepts and their learning retention in working memory [13].

The before-mentioned review emphasizes how AR can be used for benefit of children's programming learning and one of the most remarkable conclusions is that AR activities could be embedded into regular Computer Science (CS) curricula and not just seen as an extracurricular activity.

This paper presents PluggedAR, an AR-based application for mobile devices that allows working programming-basic concepts. The cognitive load of learning is low and most of the participants defined the App as fun and engaging.

The paper is structured as follows. Section II offers a brief introduction to STEM and learning experiences with AR for promoting STEM. Section III presents the main characteristics of PluggedAR. Section IV describes the research statements and the methodology used for collecting the data. Section V highlights the limitations of our work. Finally, in Section VI, we conclude with a summary and future work.

II. Context

STEM education gives students an integral development through science, with which they achieve a deep understanding of the world; technology, which prepares them to adapt to technological changes; engineering, with which they improve their problem-solving skills; and mathematics, thanks to which they can analyze information, eliminate errors and make decisions. Hence the importance of introducing it as soon as possible in the classroom to lay the foundations that promote optimal learning [14], which prepares them to transform society through innovative ideas and sustainable solutions.

A. STEM education, an approach to responding to a changing working world

STEM profiles are increasingly in demand as reveled in recent reports on employment projections [15], but the reality is that there are not enough staff to respond to such demand due to a lack of interest in acquiring this type of formation [16]. Hence some reports present initiatives to promote STEM education [17], which must be supported in four fundamental pillars: *(i)* the psychological: to encourage the active involvement of students, teachers and the family to reflect on skills interests and the strengthening of scientific and technical skills required in STEM; *(ii)* training: to raise awareness of job opportunities in line with the needs of the industrial sector; *(iii)* education: to improve the acquisition of STEM competencies at the level of knowledge, skills and attitudes; and finally *(iv)* social: to improve the image of STEM careers in society in general.

Another way to promote STEM training is to change the perception that there is today about some subjects such as ICT (Information and Communication Technology) or Mathematics and support initiatives that encourage training in these subjects [18] and better guidance on job opportunities. To this end, two key points are identified: Children's approach to technology through education and teacher training in STEM subjects [19].

B. *Augmented Reality for promoting STEM*

AR provides a direct link between the physical reality and the virtual information about that reality [20]. Literature offers many works that support the use of AR for STEM learning [8], [21], [22], [23], [24], [25], [26], as well as its potential to promote the learning process in a scenario of learning with technology [27], [28]. AR can transform the school environment into a more technology-friendly one mixing both realities, the real and virtual world, enabling physical and cognitive immersion with the learning material, and allowing collaborative and interactive work on complex and abstract concepts, making learning easier by concretizing these abstract concepts [29]. Furthermore, recent researches show that AR is more efficient compared to traditional lecture-based teaching or multimedia use [7]. Other authors consider AR as an adaptable, responsive, engaging, individualized and appropriate technology for learning [30] since it promotes effective and in-depth understanding of the topics thanks to the increased motivation, collaboration [9], and positive attitude [6], [31] of the students and a favorable and effective use of the content [32], [33].

Concepts such as binary numbers, image representation, programming languages, graphs and minimum spanning trees, can be complex to understand for children. Therefore, the use of interactive visual tools can facilitate their understanding [34] because it allows better visualization and interaction through the manipulation of augmented content [35], [36], [37], helps to acquire basic STEM and digital skills [38], [39] and promotes collaborative work and problem-solving [40].

C. *Pedagogical approach*

This study is a student-centered approach where the student is engaged and motivated to guide their learning experience while awakening their curiosity and overpass challenges through problem-solving [41]. This active participation is necessary for the learning process to happen, leading to understanding, retention, and transfer of knowledge [42].

III. PLUGGEDAR

"PluggedAR" (Fig. 1) is a mobile application based on AR aimed at Primary Education students between 6 and 9 years old. Through this App, students will be able to work on basic programming concepts to acquire and enhance skills closely related to STEM such as the following:

- *Binary numbers*. Through this activity, students learn to represent words with zeros and ones improving a mathematical skill as relevant as knowing how to count.
- *Representation of Images*. This activity is related to the ability of computers to store information using only numbers. Students learn the basics for the development of mathematics, sequencing, or graphics abilities.
- *Programming languages*. This activity allows students to follow instructions, which is a very important ability when it comes to create programs.
- *Graphs*. The use of graphs allows everyone to represent problems and can improve task-clarity and efficiency.
- *Minimum Spanning Trees*. The goal of this classic game, the maze, is to promote problem-solving, search for the best solution, and improve decision-making.

Students must overcome each of these activities to acquire or enhance these skills. Activities are divided into 3 different levels according to the age of the students and the previous knowledge needed.

As mentioned above, one of the qualities of PluggedAR is the use of the AR technology. Each PluggedAR activity (Table 1) merges reality with the virtual content through AR.

TABLE 1: PluggedAR Activities.

Level	Concept	Activity	Age	Market
1	Binary Numbers	Binary numbers (BN)	6-7	2
2	Representation of Images	Find the secret word (SW)	7-8	3
	Programming Language	Chef in distress (CD)	7-8	1
	Graphs	Let's color it up! (LC)	7-8	2
3	Minimum Spanning Trees	Escaping to the labyrinth (EL)	8-9	2

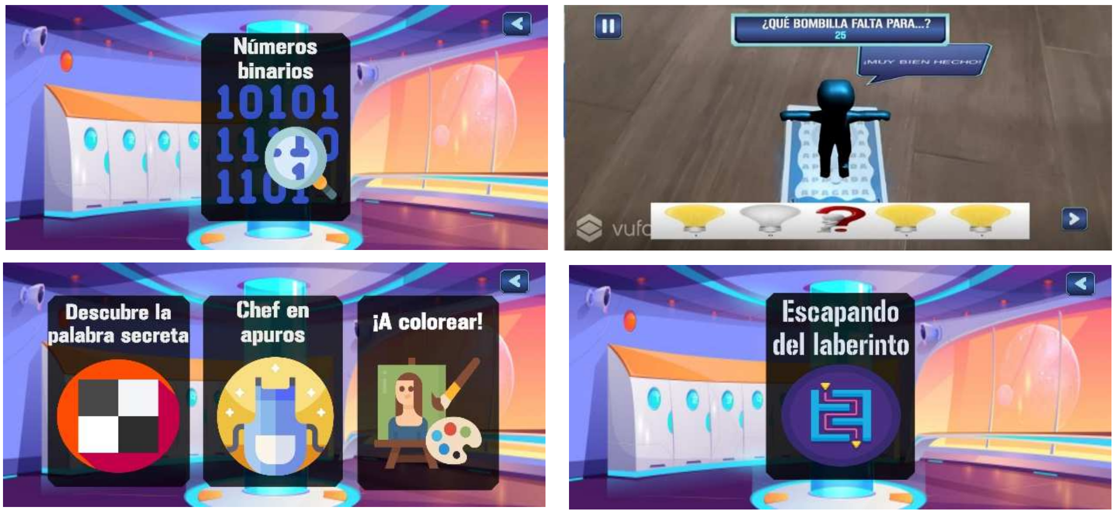

Fig. 1: Example of screenshots of the Levels Section and gameplay of activity Binary Numbers from Level 1.

IV. RESEARCH STATEMENTS AND METHODOLOGY

A. Research statement

This paper aims to answer two research questions:

RQ_1: Do students find PluggedAR motivating and challenging?

RQ_2: Can AR facilitate abstract concepts comprehension?

B. Methodology

Firstly, it's going to be described the characteristics of the sample and the process carried out.

1) Characteristics of the sample

The study has been adapted to the current Coronavirus pandemic situation. For this reason, it took place in the home of the participants in the study.

On the one hand, the participants were six Primary School students from ages 7 to 9. The characteristics of the sample population are shown in Table 2. All of them have used PluggedAR to play with its different activities and learn basic programming concepts in a more enjoyably and dynamic way. Since the students deciding to participate voluntarily, the grouping was done randomly and heterogeneously.

A wide variety of Android devices has been used as a result of the survey carried out in the participants' homes. In addition, the Image Targets necessary to visualize the augmented content and interact with PluggedAR have been distributed to the students.

On the other hand, a group of six teachers participated in the study, analyzing the user interface and the possibilities offered by PluggedAR in the classroom.

TABLE 2: Sample Population

Variable	Category	N = 6	(%)
Age	7	1	16.7
	8	3	50
	9	2	33.3
Gender	Male	2	33.3
	Female	4	66.7
Prior Programming Experience	High	1	16.7
	Low	5	83.3

2) Process

Once the sample group of students was defined, they used the App to solve all of the three levels of activities that belong to it. To consider valid their experience, they had to obtain the highest rating on each one of the activities while they interact with the AR.

To confirm the credibility of the results, we asked each group to fill up the questionnaire formed with six questions which represent six qualitative variables (represented as Q_1 to Q_6). The results can´t be generalized due to the small size of the sample. The questions were as follows:

- *Q_1*: How entertaining did you find PluggedAR?
- *Q_2*: Which activities did you like more and which did you like less? Please, enumerate them by order.
- *Q_3*: Would you like to use PluggedAR in your school classes?
- *Q_4*: Did you need to use at least one time the "Help" section?
- *Q_5*: Did you need help from an adult to understand or solve any of the activities?
- *Q_6*: Had you felt any of the following emotions while using PluggedAR? (Curiosity / Happiness / Surprise / Frustration).

As for the group of teachers, we asked them about the functionality and usefulness of PluggeddAR. The questions were as follows:

- *Q_1*: Have you found PluggedAR attractive and suitable for children?
- *Q_2*: Would you integrated PluggedAR in the classroom?
- *Q_3*: Have you experienced any of the problems described below during your experience with PluggedAR? (The App was confusing / There was a malfunction of the App at some point / The App did not respond or stopped responding / No problem / Other).
- *Q_4:* What is the highlight of PluggedAR in your opinion? (Appearance / Content / Navigation and Dynamics / Other).
- *Q_5*: Do you think PluggedAR can motivate students to learn?
- *Q_6*: Is there an aspect you would like to improve or include in PluggedAR?

The approximate duration to answer the survey was 10 to 15 minutes for students and teachers as well.

V. PRELIMINARY TEST AND RESULTS

A. Data Analysis

We applied individual and anonymous questionnaires for the group of students and teachers. To collect the answers about their experience with PluggedAR, the questionnaire was published online so they could complete it from their own homes.

The survey carried out for the group of students was focused on their experiences and their perception during the interaction with the App and the use of AR. To the Q_1 6 of the 6 students stated the learning process was fun and enjoyable. For the Q_2 the students indicated their preferred activities as shown in Table 3:

TABLE 3: Preferred Activities

Rating / Activities	1	2	3	4	5
EL	1	4		1	
CD	3	1		1	1
BN	1	1	1		2
LC			4		1
SW	1			3	1

Regarding the Q_3, 6 of 6 students indicated that they would like to use PluggedAR in the classroom.

Regarding the use of the "Help" section (Q_4), 4 of 6 students indicated they need it in any activity while 2 of 6 students said they needed it to perform all activities.

As for Q_5, 4 of 6 students needed adult supervision at some point while 2 of 6 did not need any. This shows that, even though PluggedAR promotes independent learning, it is advisable to have supervision while using the App.

According to Q_6, students experimented the following emotions: curiosity (2 of 6), happiness (2 of 6), surprise (4 of 6) and frustration (0 of 6).

It's important to bring out that 4 of 6 students didn't experience any issue during their interaction with PluggedAR but 1 of 6 students did experiences issues due to not using a suitable device as they had a lower version than required. In addition, 3 of 6 students were asked about the problems they faced with the App, in particular due to the use of a laminated Image Target which generates a poor Image Target detection, reflections, poor quality and loss of definition.

Regarding questions asked to teachers, for Q_1, 2 of 6 teachers found the App attractive while 2 of 6 considered it suitable.

For the Q_2, 6 of 6 teachers agreed to include PluggedAR in the classroom.

As for the Q_3, 0 of 6 teachers found the App confused, 3 of 6 teachers found that there was a malfunction at some point, 0 of 6 teachers said the App did not respond or stopped responding, 4 of 6 teachers reported no problem, and 1 of 6 referred to a problem other than listings.

Regarding Q_4, 2 of 6 teachers remarked the appearance of the App, while 2 of 6 considered remarkable its content. On the other hand, 1 of 6 teachers emphasized the navigation, dynamics, the content covered, and the design.

As to the Q_5, 6 of 6 teachers agreed that AR can motivate students to learn.

Finally, for the Q_6, as an aspect to be improved, all teachers suggested expanding the number of activities and levels of the App.

B. *Qualitative evaluation*

In this section we answer the research questions. Regarding RQ_1 and considering the data analysis, we can say students have felt motivated, something that could be related to the emotions they experimented when interacting with PluggedAR, especially the emotion of surprise. This is remarkable since there is evidence that the introduction of a surprise element can help improve different psychological constructs such as memory, the ability to explain concepts or curiosity [48], [49]. In our case, AR is a great surprise element which awakens curiosity and encourages motivation. On the other hand, when looking at the results, regarding the use of the Help section, it could be said that it has been a challenge to use PluggedAR, probably because students faced a new topic and a new form of interaction as well.

As far as RQ_2 is concerned, we believe that the students were able to understand the concepts since they completed the activities proposed in PluggedAR considering that the topics addressed through the App are complex and demanding for Primary School students, mainly due to the abstract nature of the concepts and the inherent difficulty in describing them. In addition, these are contents that require a spatial-reasoning skill [50], which implies being able to manipulate, either mentally or physically, visual images (associated with these abstract concepts and perceived through sight) in space. For us, this represents an interesting opportunity to use AR because, adding virtual information (which can be represented by different multimedia elements) to objects of the real world, allows students comprehension of complex concepts through the display of such information from different visual planes.

Although the sample is small, the results have served to illustrate important aspects of the use of AR and its usefulness for learning complex concepts.

However, we believe that it is necessary to repeat the study with a large sample and use validated questionnaires to collect information on learning CT concepts as well as emotions before and after interacting with AR.

VI. Discussion

AR is having a great impact on education as it offers great possibilities not only because it helps to embody abstract objects, teach invisible objects and events, presents complicated topics or demonstrate dangerous cases [46], but also because it provides flexibility to learners, boosts creative thinking skills [51] and interpretation or problem-solving activities [47]. In other words, AR-based applications represent alternative solutions in problem-solving contexts, work safety and time training [51].

A wide variety of initiatives use different types of markers as QR codes to encourage user interaction with AR [52] or introduce a key piece in pedagogical innovation to improve the teaching of students with special needs [51].

But AR not only helps to better understand the processes and concepts [53] mentioned above, some research on the educational attainment of AR technology finds that it also facilities comprehension [51], provides interaction and makes learning more appealing and effective [46], increases motivation [54], draws the attention [55], establishes links with real-life experiences [56], and helps students enjoy the learning process [57]. In short, it is increasingly common to find studies that point to the integration of AR in the educational context, many of which highlight the positive emotional effects that the use of such technology has on the attention and motivation of the students [58] and reported great outcomes on learner's achievement and satisfaction [59], [60], [61].

On the other hand, STEM education can also benefit from the use of AR as it allows students to practice from anywhere and anytime according to their needs. It also facilitates the understanding of theoretical knowledge and promotes the development of conceptual understanding [62], [63], [64]. But the integration of AR can raise many doubts even though there are works that, after synthesizing the findings of previous studies, provide a practical roadmap for educators and could facilitate the integration of AR in the STEM context [48].

VII. Limitations and Future Work

The limitations of our study were as follows. First, this study was organized within the scope of the research with a limited number of participants due to the pandemic situation. We therefore would like to emphasize that our findings presented are part of a single case with a small number of students. It was also a self-selecting sample, which is not a representative sample of all students' populations. Moreover, it relied on learners' self-reports of usability, preference, and efficiency to evaluate the learning effects

Secondly, it would be interesting to increase the questionnaire and include more levels and activities to introduce new concepts such as "cryptography" or "human-computer interaction", adding value to PluggedAR by increasing the age range and making users acquire more skills.

Thirdly, from a technical point of view, PluggedAR is currently available for Android devices so a major improvement would be to expand compatibility with iOS devices. This would allow most schools to own PluggedAR-supported devices.

Finally, although PluggedAR can support some sensory, cognitive and motor limitations that students may present, it is important to expand accessibility possibilities such as customizing contrast for students with vision problems or adding voice command control or voice assistant options for those with motor or visual difficulties.

VIII. Conclusions

This paper presents "PluggedAR", an AR-based application that allows working concepts such as image representation, algorithms, representation of procedures or intractable problems by means of games such as escaping the maze or everyday actions like cooking. The experience for the students was very motivating, which was manifested in the enthusiasm with which they faced the challenges proposed.

Integrating AR into class activities has been shown to increase student learning achievement, contribute to students' long-terms retention of the concepts and helps students to understand and analyze the problem scenarios in more depth [40] while providing an unprecedented sense of immediacy [65]. The use of AR can increase participation, understanding, and learning, all of them key elements in the educational systems' [66].

Our study is in line with others whose results agree that the use of AR increases motivation, especially when students' curiosity is triggered, which favors their enjoyment.

Through this study it has been possible to corroborate that, as collected in the literature, the interest in a subject favors his learning [67]. Thus, integrating learning with real-world situations can increase students' development of competencies such as STEM [68]. However, it is sometimes difficult to establish such a relationship with the real world. [69], but thanks to technologies involving simulations, students can experience situations that they would not normally be able to experience first-hand.

AR can be considered as a teaching tool that allows transforming learning methods. That is why from the beginning of the inclusion of AR as an educational tool, its potential was recognized — "a system that allows the user in the classroom to manipulate 3D objects and receive information from a real environment is clearly of great relevance in the educational field" [70].

The combination between the real world and a virtual environment allows concepts and knowledge to be presented at an early age in a less intrusive way. In addition, using AR could facilitate learning without continuous adult supervision, giving the students independence and freedom to explore and understand on their own. Furthermore, this entertaining and interactive learning process could help to retain easily and quickly complex concepts.

Finally, we consider that through this study we have done our bit to: *(i)* the introduction of basic programming concepts linked to STEM through the use of AR with PluggedAR, *(ii)* the use of AR as a surprise element to awaken curiosity and encourage motivation, and *(iii)* the use of AR as a means for the development of spatial reasoning skills. Our desire is to be able to collect data in a large sample and offer more significant results.

IX. Data Availability Statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

X. Ethics Statement

Before gathering data from the students, the research objectives were told to the respondent. It was also guaranteed the confidentiality of their information. The respondents were also informed that participation in this study is a voluntary contribution. The student can quickly opt-out of the research and this decision will not affect him/her. Besides, any questions which will help to identify the participant were not asked.

XI. Author Contributions

All authors have contributed equally to data collection, data analysis and manuscript writing.

Acknowledgment

This work was supported by research grants e-Madrid-CM of the CAM (ref. S2018/TCS-4307) and high-performance LITE research group of the URJC. The e-Madrid-CM grant also is co-financed by the Structural Funds FSE and FEDER.

References

[1] B. H. de Paula, A. Burn, R, Noss, and J. A. Valente. "Playing beowulf: Bridging computational thinking, arts and literature through game-making". International Journal of Child-Computer Interaction, vol 16, 39–46, 2018

[2] T. C. S. Gomes, T. P, Falcão., and P. C. de A. R. Tedesco. "Exploring an approach based on digital games for teaching programming concepts to young children". International Journal of Child-Computer Interaction, vol 16, 77–84, 2018

[3] E-S. Katterfeldt, M. Cukurova, D. Spikol, and D. Cuartielles. "Physical computing with plug-and-play toolkits: Key recommendations for collaborative learning implementations". International Journal of Child-Computer Interaction, vol 17, 82, 2018

[4] S. Papavlasopoulou, K. Sharma, and M.N Giannakos. “How do you feel about learning to code? Investigating the effect of children’s attitudes towards coding using eye-tracking”. International Journal of Child-Computer Interaction, vol 17, 50–60. 2018

[5] M. Akçayir, and G. Akçayir, G. “Advantages and challenges associated with augmented reality for education: A systematic review of the literature”. Educational Research Review, vol 20, 1–11. 2017.

[6] J. Bacca, S. Baldiris, R. Fabregat, S. Graf, and Kinshuk. “Augmented reality trends in education: A systematic review of research and applications”. Journal of Educational Technology and Society vol 17, 133–149, 2014.

[7] J. Garzón, and J. Acevedo, J. “A meta-analysis of the impact of augmented reality on students' learning effectiveness”. Educational Research Review, vol 27, 244–260. 2019.

[8] M.B. Ibáñez, and C.Delgado-Kloos, C. “Augmented reality for STEM learning: A systematic review”. Computers & Education, vol 123, 109-123. 2018

[9] I. Radu. “*Why should my students use AR? A comparative review of the educational impacts of augmented-Reality*.” In Proceedings of the 2012 IEEE International Symposium on Mixed and Augmented Reality (ISMAR), Atlanta, GA, USA, 5–8 November 2012.

[10] C-Y. Chung, and I-H. Hsiao “*Computational thinking in augmented reality: An investigation of collaborative debugging practices*.” In 2020 6th international conference of the immersive learning research network (pp. 54–61). 2020. [Online]. Available: http://dx.doi.org/10.23919/iLRN47897.2020.9155152.

[11] N. Dass, J. Kim, S. Ford, S. Agarwal, S., and (Polo) D.H Chau. “*Augmenting coding: Augmented reality for learning programming*”. In Proceedings of the sixth international symposium of Chinese CHI (pp. 156–159). Montreal, QC, Canada: Association for Computing Machinery, 2018. [Online]. Available: https://doi.org/10.1145/3202667.3202695.

[12] S. Sittiyuno, and K. Chaipah. “Arcode: Augmented reality application for learning elementary computer programming”. *In 2019 16th international joint conference on computer science and software engineering* (pp. 32–37). 2019 [Online]. Available: http://dx.doi.org/10.1109/JCSSE.2019.8864173.

[13] A. Theodoropoulos, and G. Lepouras. “Augmented reality and programming education: A systematic review”. International Journal of Child-Computer Interaction, vol 30, 1-16. 2021.

[14] La gran guía de STEM. 2019. *Euroguidance Centre Spain. Euroguidance España. Orientación Profesional a lo Largo de toda la Vida.* [Online]. Available: https://www.educacionyfp.gob.es/dam/jcr:44a0831d-c0c1-4496-896d-ad57f39f03ce/lagranguiadestem-bla.pdf

[15] S. Fayer, A. Lacey, and A. Watson, A. “STEM occupations: Past, present, and future. Washington, D.C.: U.S. Bureau of Labor Statistics”. 2017 [Online] Available: https://stats.bls.gov/spotlight/2017/science-technology-engineering-and-mathematics-stem-occupations-past-present-and-future/pdf/science-technology-engineering-and-mathematics-stem-occupations-past-present-and-future.pdf

[16] El desafio de las vocaciones STEM. DigitalES. Asociación Español para la Digitalización. 2019. [Online] Available: https://www.digitales.es/wp-content/uploads/2019/09/Informe-EL-DESAFIO-DE-LAS-VOCACIONES-STEM-DIGITAL-AF-1.pdf

[17] J. M. Cavero, and D. R. Quejido. “Educación para la innovación y el emprendimiento: una educación para el futuro. Recomendaciones para su impulso.” 2017 http://www.raing.es/sites/default/files/EDUCACION_PARA_INNOVACION_Web.pdf

[18] J. M. Verano, L. P. Santacruz-Valencia and J. Gomez. “When Math is a Game”. *SIIE. 2020.*

[19] J., Piedade, N., Dorotea, A., Pedro, and J., F., Matos. ”On teaching programming fundamentals and computational thinking with educational robots: A didactic experience with pre-service teachers”. Educations Sciences, vol 10, 214, pp.2-15. 2020

[20] D., Schmalstieg, and T., Höllerer, “Augmented Reality-Principles and Practice”; Addison-Wesley Professional: Boston, MA, USA, 2016.

[21] C. Muntean, D. Bogusevschi, and G. Muntean. “Innovative Technology-based Solutions form Primary, Secondary and Tertiary STEM Education”. Paragon Publishing. 2019

[22] J., Ferrer-Torregrosa, J., Torralba, M. A., Jimenez, S., García, and Barcia, J. M. (2015). “ARBOOK: Development and assessment of a tool based on augmented reality for anatomy”. Journal of Science Education and Technology, vol 24, 1, 119–124. https://doi.org/10.1007/s10956-014-9526-4

[23] S. Kü.ük, S. Kapakin, and Y. Göktaş, Y. “Learning anatomy via mobile augmented reality: Effects on achievement and cognitive load”. Anatomical Sciences Education, vol 9, 5, 411–421. 2016. https://doi.org/10.1002/ase.1603

[24] J. Martín-Gutiérrez, J. L. Saorín, M. Contero, M., Alcañiz, D. C. Pérez-López, and M. Ortega. “Design and validation of an augmented book for spatial abilities development in engineering students.” Computers & Graphics, vol 34, 1, 77–91. 2010. https://doi.org/10.1016/j. cag.2009.11.003

[25] C. Roca-González, J. Martin-Gutierrez, M. García Dominguez and, M. del CarmenMato Carrodeguas. “Virtual technologies to develop visual-spatial ability in engineering students”. Eurasia Journal of Mathematics, Science and Technology Education, vol 13, 2, 441–468. 2017. https://doi. org/10.12973/eurasia.2017.00625a

[26] Z. Turan, E. Meral, and I. F. Sahin. “The impact of mobile augmented reality in geography education: Achievements, cognitive loads and views of university students”. Journal of Geography in Higher Education, vol 42, 3, 427–441. 2018. https://doi.org/10.1080/03098265.2018.1455174

[27] C. Panciroli, A. Macauda, and V. Russo. “Educating about Art by Augmented Reality: New Didactic MediationPerspectives at School and in Museums.Proceedings., vol 1, 1107. 2017

[28] F. Del Cerro Velázquez, and G. Morales Méndez. “Augmented Reality and Mobile Devices: A BinominalMethodological Resource for Inclusive Education (SDG 4). An Example in Secondary Education.Sustainability, vol 10, 3446, 2018

[29] M. J. Maas, and J. Hughes. “Virtual,, augmented and mixed reality in K-12 education: A review of the literature”. Technol. Pedagog. Educ. vol 29, 231–249. 2020

[30] P. Plamen, and T. Atanasova. “The effect of Augmented Reality on Students’ Learning Performance in STEM Education”. Information, vol 11, 209; doi:10.3390/info11040209. 2020

[31] I., Stojsic, A., Ivkov-DziGurski, O., Maricic, J., Stanisavljevic, J. Milankovic, and T. Visnic. “Students’ attitudes towards the application of mobile augmented reality in higher education”. Journal for General Socilal Issues. 2018.

[32] A. Estepa, and L. Nandolny. “The effect of an Augmented Reality Enhanced Mathematics Lesson on Student Achievement and Motivation.” Journal of STEM Education Vol 16, 3, 40-48. 2015

[33] G. Gómez, C. Rodríguez, and J. Marín. “La trascendencia de la Realidad aumentada en la motviación estudiantil. Una revisión semántica y meta-análisis”. Las posibilidades educativas de la realidad aumentada, virtual y mixta, Vol 15, 1, pp. 36-46, 2020.

[34] G. Yi-Ming K, and G-A, Ruan. “Design and Evaluating a high interactive augmented reality system for programming learning”. Computers in Human Behavior, vol 132, 2022.

[35] T. Coimbra, T. Cardoso, and A. Mateus. “Augmented Reality: An Enhancer for Higher Education Students in Math’s Learning? *Procidia Computer Science. 6th International Conference on Software Development and Technologies for Enhancing Accessibility and Fighting Infoexclusion (DSAI 2015).* 332-339. Elsevier. https://doi.org/10.1016/j.procs.2015.09.277. 2015

[36] P. C. H, Dasgupta, C., Murthy, and A., Joshi. “MathRealiy: A Bridge from Concrete to Abstract via an AR App for Mathematics Concepts of Exponents”. *IEEE 19th International Conference on Advanced Learning Technologies (ICALT)*. IEEE, 2019

[37] Manisha and, M., Archana. “An Augmented Reality Application for Basic Mathematics: Teaching and Assessing Kids’ Learning Efficiency”. *5th International Conference on Computing Communication Control and Automation (ICCUBEA)*. IEEE, 2019

[38] R. Fernández-Enríquez and L. Delgado-Martín. “Augmented Reality as a Didactic Resource for Teaching Mathematics”. Applied Science, vol 10, 2560, 11-19. doi:10.3390/app10072560. 2020

[39] A. Fuentes, J. López and, S. Pozo. “Análisis de la Competencia Digital Docente: Factor Clave en el Desempeño de Pedagogías Activas con Realidad Aumentada”. REICE. Revista Iberoamericana sobre calidad, eficiencia y cambio en Educación, *vol* 17, 2, 27-42. https://doi.org/10.15366/reice2019.17.2.002. 2019

[40] M. Fidan, and M. Tuncel. “Integrating augmented reality into problem-based learning: The effects on learning achievement and attitude in physics education”. *Computers & Education*, vol 142. https://doi.org/10.1016/j.compedu.2019.103635. 2019

[41] M. Christie, and E. Graa. The philosophical and pedagogical underpinnings of Active Learning in Engineering Education. Eur. J. Eng. Educ, 42, 5–16. 2016

[42] R. L. DeHaan. “The Impending Revolution in Undergraduate Science Education. J. Sci. Educ. Technol, vol 14, 253–269. 2005

[43] N. S. Lukychova, N. V. Osypova, and G. S. Yuzbasheva. “ICT and current trends as a path to STEM education: implementation and prospects”. CTE 2021: 9th Workshop on Cloud Technologies in Education, vol 3085, 16, 44-45. 2021. https://doi.org/10.4324/9780203464007.

[44] D. Yang, and S.J. Baldwin. "Using Technology to Support Student Learning in an Integrated STEM Learning Environment". International Journal of Technology in Education and Science, 4(1), 1-11. 2020. https://doi.org/10.46328/ijtes.v4i1.22

[45] H. Wu, S.W. Lee, H. Chang, and J. Liang. “Current Status, Opportunities and Challenges of Augmented Reality in Education”, Computers & Education, vol 62, 41-49 2013. https://doi.org/10.1016/j.compedu.2012.10.024

[46] K. Walczak, R. Wojciechowski, and W. Cellary. “Dynamic interactive VR network services for education”. Proceedings of the ACM Symposium on Virtual reality software and technology (VRST '06). Association for Computing Machinery, New York, NY, USA, 277–286. 2006. https://doi.org/10.1145/1180495.1180552

[47] K. Schrier. “Using augmented reality games to teach 21st-century skills”. ACM SIGGRAPH 2006 Educators program (SIGGRAPH '06). Association for Computing Machinery, New York, NY, USA, 15–es. 2006. https://doi.org/10.1145/1179295.1179311

[48] A., Colomina (2019). El “Wow factor”. Experiencias de aprendizaje en la asignatura Taller I: Conservación y restauración de bienes culturales. En V. Vega y E. Vendrell (Eds.), IN-Red 2019, V Congreso de Innovación Educativa y Docencia en Red (pp. 378-393). Universitat Politècnica de València.

[49] M. I., Foster, and M. T., Keane (2013). Surprise! You’ve got some explaining to do… En M. Knauff, M. Pauen, N. Sebanz y I. Wachsmuth (Eds), Thirty-Fifth Annual Conference of the Cognitive Science Society (pp. 2321-2326). Cognitive Science Society.

[50] G. Città, M. Gentile, M. Allegra, M. Arrigo, D. Conti, S. Ottavi, F. Reale and M. Sciortino. “The effects of mental rotation on computational thinkning”. Computers & Educaton, vol 141, 2019. https://doi.org/10.1016/j.compedu.2019.103613

[51] S., Mystakidis, A., Christopoulus, and N. Pellas “A systematic mapping review of augmented reality applications to support STEM learning in higher education”. Education and Information Technologies, (27), 1883-1927. 2022

[52] Quiver. https://play.google.com/store/apps/details?id=com.puteko.colarmix&hl=

[53] E. Klopfer, and K. Squire. Environmental Detectives—the development of an augmented reality platform for environmental simulations. Education Tech Research Dev, vol 56, 203, 228. 2008. https://link.springer.com/article/10.1007/s11423-007-9037-6

[54] Á. Di Serio, M. B. Ibáñez, and C. D. Kloos, ‘‘Impact of an augmented reality system on students’ motivation for a visual art course’’. Computers and Education, vol. 68, pp. 586–596. 2013

[55] K. A. Aziz, N. A. A. Aziz, A. M., Yusof, and A. Paul. “Potential for Providing Augmented Reality Elements in Special Education via Cloud Computing”. Procedia Engineering, vol 41, 333-339. 2012. https://doi.org/10.1016/j.proeng.2012.07.181

[56] S. Ternier, R. Klemke, M. Kalz, P. Ulzen, and M. Specht. “ARLearn: Augmented Reality Meets Augmented Virtuality”. Journal of Universal Computer Science, 2012.

[57] M. Núñez, R. Quirós, I. Núñez, J. B. Carda, and E. Camahort. “Collaborative augmented reality for inorganic chemistry education”. Proceedings of the 5th WSEAS/IASME international conference on Engineering Education (EE'08). World Scientific and Engineering Academy and Society (WSEAS), Stevens Point, Wisconsin, USA, 271–277. 2008.

[58] H.-C., Chu, J.-M., Chen, G.-J., Hwang, and T.-W., Chen. (2019). “Effects of formative assessment in an augmented reality approach to conducting ubiquitous learning activities for architecture courses.” Universal Access in the Information Society, 18(2), 221–230. https:// doi. org/ 10. 1007/s10209-017- 0588-y

[59] S. M., AlNajdi, M. Q., Alrashidi, and K. S., Almohamadi, “The effectiveness of using augmented reality (AR) on assembling and exploring educational mobile robot in pedagogical virtual machine” (PVM). Interactive Learning Environments. 2018. https:// doi. org/ 10. 1080/ 10494 820. 2018.15528 73

[60] P., Lin, and S., Chen “Design and evaluation of a deep learning recommendation based augmented reality system for teaching programming and computational thinking”. IEEE Access, 8, 45689–45699. https:// doi. org/ 10. 1109/ ACCESS. 2020. 29776 79

[61] M., Thees, S., Kapp, M. P., Strzys, F., Beil, P., Lukowicz, and J. Kuhn.“Effects of augmented reality on learning and cognitive load in university physics laboratory courses.” Computers in Human Behavior. https:// doi. org/ 10. 1016/J. CHB. 2020. 106316

[62] G., Singh, A., Mantri, O., Sharma, R., Dutta, and R. Kaur. “Evaluating the impact of the augmented reality learning environment on electronics laboratory skills of engineering students”. Computer Applications in Engineering Education, 27(6), 1361–1375. 2019. https:// doi. org/ 10. 1002/cae. 22156

[63] Y., Wang,, S. K., Ong, and A. Y. C., Nee, “Enhancing mechanisms education through interaction with augmented reality simulation”. Computer Applications in Engineering Education, 26(5), 1552–1564. https:// doi. org/ 10. 1002/ cae. 21951. 2018

[64] S., Vassigh, D., Davis, A. H., Behzadan, A., Mostafavi, K., Rashid, H., Alhaffar, and G., Gallardo. “Teaching building sciences in immersive environments: A prototype design, implementation, and assessment”. International Journal of Construction Education and Research. https://doi. org/ 10. 1080/ 15578 771. 2018. 15254 45. 2018

[65] J. Jesionkowska; F. Wild, and Y. Deval. “Active Learning Augmented Reality for STEAM Education – A Case Study”. Education Science, vol. 10, 198, pp. 2-15 https://doi.org/10.3390/educsci10080198, 2020

[66] J. L. Chiu, C. J. Dejaegher, and J. Chao. “The e ects of augmented virtual science laboratories on middle school students’ understanding of gas properties”. Comput. Educ, 85, 59–73. 2015.

[67] YS. Hsu, Y. H. Lin, and B. Yang. “Impact of augmented reality lessons on students’ STEM interest”. RPTEL 12, vol 2. 2017. https://doi.org/10.1186/s41039-016-0039-z

[68] I. Zeid, J. Chin, C. Duggan, and S. Kamarthi. “Engineering based learning: a paradigm shift for high school STEM teaching”. International Journal of Engineering Education, 30(4), 867–887. 2014.

[69] P. D. Petrov, and T. V. Atanasova. “The Effect of Augmented Reality on Students’ Learning Performance in Stem

Education". Information. 11(4), 209. 2020. https://doi.org/10.3390/info11040209

[70] F. Del Cerro Velázquez, and G. Morales Méndez. "Augmented Reality and Mobile Devices: A Binominal Methodological Resource for Inclusive Education (SDG 4). An Example in Secondary Education". Sustainability, 10, 3446. 2018. https://doi.org/10.3390/su10103446