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EFFECTIVENESS OF AUGMENTED REALITY AS A PEDAGOGICAL ENGINEERING TOOL

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Abstract- This work is part of an exploratory approach aimed at evaluating and refining the use of augmented reality as an educational engineering tool, particularly for demystifying the phenomenon of volcanism among second year middle school students (ages 14 to 15). In order to achieve this goal, we utilized a semi-experimental approach that involved conducting a pre-test and a post-test. We segregated the participants into two distinct groups: a control group comprising 20 students, and an experimental group likewise comprising 20 students. The Results from the post-test revealed a notable improvement in the students' academic performance and an enrichment of their conceptual understanding of volcanism in favor of the experimental group.

Keywords: Augmented Reality, Educational Engineering, Student Conceptions, Volcanism.

1. INTRODUCTION

In the rapidly evolving context of Moroccan education, where the integration of technological advances is becoming imperative to enrich science teaching [1], [2], augmented reality (AR) is emerging as an avant-garde pedagogical engineering tool. By superimposing virtual elements on the real world, this technology promises to transform learning by making complex scientific concepts both visible and interactive. Our study is part of an exploratory approach aimed at evaluating and refining the use of AR as a pedagogical strategy, particularly for demystifying geological phenomena among secondary school students, with a specific focus on volcanism.

Volcanism, an essential but abstract subject in the life and earth sciences curriculum, frequently comes up against students' difficulty in grasping its dynamic and complex aspects. Conventional teaching materials, such as textbooks, struggle to capture the essence and movement inherent in volcanic processes, often leading to incomplete or erroneous understandings [3-9]. The adoption of AR in education offers a revolutionary way of overcoming these obstacles, facilitating students' immersion in geological mechanisms through three-dimensional visualization and thus fostering a deeper assimilation of scientific concepts.

This educational engineering framework, enriched by AR, has the potential not only to improve students' understanding but also to stimulate their engagement and motivation in science learning, creating a dynamic and interactive learning environment [10-13]. However, a thorough review of the literature reveals a lack of research specifically focused on the impact of AR on volcanic learning, highlighting the crucial importance of our study. We therefore set out to answer two main research questions: (1) Does the implementation of Augmented Reality lead to a significant improvement in students' academic performance in the field of volcanism? and (2) What impact does AR have on enriching students' conceptual understanding of volcanism? By exploring these questions, our aim is to demonstrate how AR can revolutionize the teaching of geological phenomena, offering practical insights for teachers, curriculum developers and educational decision-makers.

2. THEORETICAL FRAMEWORK

Augmented reality (AR), defined by [14] as a synergy between virtual elements and the real world that enriches our perception of the environment, is emerging as a transformative technology in the educational field. This interactive interface superimposes computer-generated data onto our field of vision, offering enriched contextual information [15]. Employed via devices such as smartphones, tablets or headsets, AR introduces virtual objects into our immediate environment, enabling an immersive learning experience [11].

The integration of virtual elements into the real world has led to a growing use of technology in education, offers an interactive teaching method that stimulates student curiosity and engagement [11]. A relevant example is the Merge Cube, a device that, by combining the tangible and the virtual, enables students to interact with 3D models in a real setting, facilitating the manipulation and understanding of abstract concepts [11]. The literature reveals several pedagogical benefits of AR, including its potential to increase student interest and motivation, encourage self-directed learning, and clarify otherwise abstract or invisible concepts [12], [15-18].

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In addition, studies attest to its positive impact on academic performance, considering it a superior teaching method to traditional approaches [12], [13], [19], [20]. Nevertheless, integrating AR into education is not without its challenges. The financial constraints associated with acquiring mobile devices and their accessories, in addition, there are health risks linked to long-term use, such as eye and mental disorders, underline the need for practical solutions for balanced implementation [21].

The pedagogical effectiveness of AR aligns with the principles of constructivism and connectivism, two theories that emphasize the importance of experience, autonomy and collaboration in learning. Constructivism emphasizes the learner's active role in the construction of knowledge, while connectivism, adapted to digital environments, envisions learning as a network of connections between individuals and technologies [22].

Within the particular realm of geological study curriculum at college level in Morocco (Table 1), which places considerable emphasis on external and internal geological phenomena, including volcanism, AR offers an opportunity to approach these complex concepts in an innovative way [23]. This technology promises to alleviate the difficulties encountered by students in understanding volcanism, by offering teaching aids that promote immersion and direct interaction with the phenomena being studied.

Table 1. Structure of the geology program at the secondary school level in Morocco

Level	Geology units	Topics taught	Hourly volume	Percentage of total program taught
The 1st year	External geodynamics	- Geological outing - Sedimentary rocks - Building a geological time scale - Water resources	34 H	50 %
The 2nd year	Internal geodynamics	- Plate tectonics - Earthquakes - Volcanism - Magmatic rocks - Tectonic deformation - Formation of mountain ranges	34 H	50%
3rd year	0	0	0	0%

3. RESEARCH METHODOLOGY

3.1. Experimental Approach

To examine the impact of AR applications on second-year college students' understanding of volcanism, we opted for a semi-experimental method. This method involved the use of a pre- and post-test on two distinct randomly formed groups: a control group (CG) and an experimental group (EG). These groups were formed by the school administration to ensure random sampling.

3.2. Study Sample

Our study covers 40 students, divided equally between the two groups. The demographic characteristics of these groups are detailed in Table 2, affirming the balance between them in terms of gender and age, thus guaranteeing the comparability of both groups.

Table 2. Attributes of the two groups: T.G and E.G.

Group		CG	EG
Number of students		20	20
Gender	Male	8	7
	Female	12	13
Age		Between 14 and 15 years	

3.3. Assessment Tools

A test consisting of three open-ended questions was designed to assess students' prior conceptions and acquired knowledge of volcanism. The test was used as both a pre-test and a post-test to measure changes in knowledge. The questions were developed to cover definitional, descriptive and explanatory aspects of volcanism, aligned with the pedagogical objectives of the college secondary cycle. An evaluation grid, including 9 criteria evaluated on ten points, was developed to ensure an objective analysis of the answers. In addition, the pupils' schematic productions were categorized according to a typology of conceptions (Appendix 1) inspired by the work of several researchers [4], [6], [7], [9], [24]. Validation of these tools was carried out thanks to the expertise of two teachers specializing in the field of life and earth sciences education, with over 20 years' experience.

3.4. Course of the Study

- Initial phase: Administration of the pre-test. In September 2023, before the start of the volcanism teaching unit, we administered a pre-test to all participants, separated into two categories: the control group (CG) and the experimental group (EG). The purpose of this initial assessment was to gauge their pre-existing understanding of volcanism and to establish a basis for comparison of the effectiveness of the teaching methods tested.

3.4.1. Traditional vs. AR-enhanced Instruction

During the subsequent 4 hours of instruction, delivered by the same teacher to ensure consistency of instruction, the control group continued with conventional learning, relying exclusively on printed resources. At the same time, the experimental group was given the chance to investigate the subject of volcanism through the addition of augmented reality applications, aimed at enriching their learning experience through interactive immersion in the content studied.

- **Implementation of AR Activities:** Following a two-hour theoretical session on volcanism and its links with plate tectonics, specific AR activities were organized to deepen and consolidate students' understanding. These practical exercises took place as follows:
- **Group Formation:** Students were organized into small groups consisting of four individuals and instructed to bring a mobile device (smartphone or tablet) and install the "Merge Explorer" app beforehand. This app was selected for its compatibility with the Merge Cube, its ease of installation, and its wealth of cost-free educational resources.
- **Distribution and Use of the Merge Cube:** Each group was given a paper Merge Cube, decorated with symbols acting as markers for the application (Figure 1). This interaction between markers and the application triggered an immersive AR experience directly on the cube.

Figure 1. Merge cube [25]

• **Interactive Exploration:** The students, guided by their teacher, activated the application and navigated to the section dedicated to volcanism. By directing the camera on their device towards the Merge Cube, they could view and interact with three-dimensional visualizations of volcanoes, enriching their understanding through multi-dimensional observation (Figure 2).

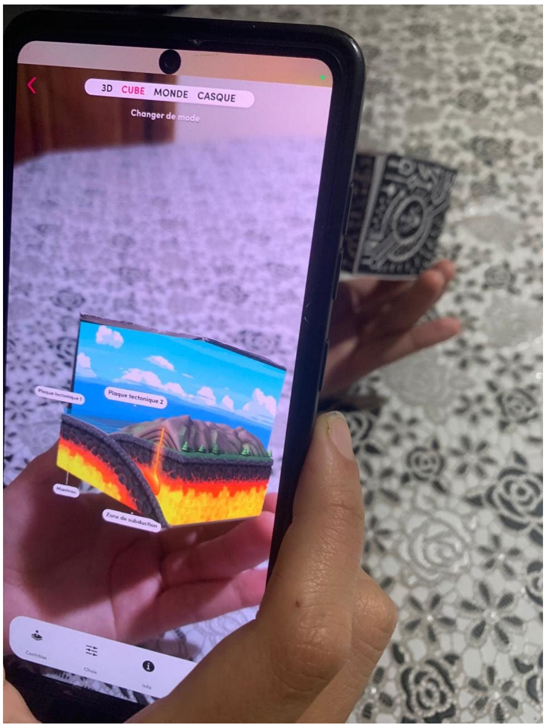

Figure 2. Practical session

• **Knowledge Application:** After a 15-minute manipulation session, a drawing exercise was proposed, inviting students to reproduce a volcano using the knowledge and perspectives acquired through AR.

• **Post-test Administration:** Immediately after these educational sessions, a post-test identical to the pre-test was distributed to both groups. The aim of this key step was to quantify the learning gains achieved, enabling us to assess the direct impact of integrating AR into the educational process. It is important to note that the results of these tests were intended exclusively for research purposes and did not influence the students' academic assessment.

• **Data Processing and Analysis:** The data underwent analysis utilizing IBM SPSS Statistics 21 and Microsoft Excel 365. The comparison of the performance between the two groups was conducted using the student's t-test., with prior verification of the conditions required for the application of this statistical test, namely independence of the groups, normality of the data distribution and homogeneity of the variances.

• **Ethical considerations:** The research adhered to ethical guidelines, which encompassed obtaining informed consent from all participants, and assurance that all data would be treated anonymously and confidentially.

4. RESULTS

4.1. Evaluation of Student Achievement

4.1.1. Students' Initial Performance

Initial assessment of student performance reveals close average scores between both experimental and the control group, suggesting a homogeneity of basic knowledge about volcanism. These data, represented in Table 3, highlight the similarity of the groups prior to any educational intervention, thus guaranteeing a valid post-intervention comparison.

Table 3. Descriptive statistics of initial performance

	N	Mean	Standard deviation	Var	Med	Min	Max	Standard error of the mean
EG	20	0.800	0.57124	0.32	1.00	0.00	2.00	0.12773
CG	20	0.875	0.55902	0.31	1.00	0.00	2.00	0.12500

Table 4 dedicated to the Shapiro-Wilk test, confirms the normality of the score distributions, since the values obtained are above the *alpha*=0.05 significance level. This is an essential criterion for the application of subsequent statistical tests such as the t-test for equality of means.

Table 4. Shapiro-Wilk Normality Test

Group	Shapiro-Wilk		
	Statistic	*ddl*	Significance
EG	0.917	20	0.085
CG	0.925	20	0.121

The outcomes of the t-test for assessing mean equality presented in Table 5 reveal that the *p*-value, obtained via Levene's test, stands at 0.84, thus exceeding the 0.05 threshold. This observation indicates that the variance between groups is uniform, attributing any variation observed to random selection of participants. Furthermore, the *t*-test yielded a *p*-value of 0.677, also exceeding the 0.05 threshold. This indicates the absence of statistically significant disparities in cognitive prerequisites between the two groups studied, affirming that the null hypothesis (equality of groups) cannot be rejected. These results suggest that the groups' initial knowledge was comparable, establishing a fair basis for assessing the impact of the pedagogical intervention.

Table 5. The t-test used to assess the equality of means

	Levene's test for equality of variances		t-test for equality of means				
	F	*Sig.*	*t*	*ddl*	Sig. (two-tailed)	Difference means	Difference standard deviation
Hypothesis of equal variances	0.041	0.84	0.42	38	0.677	0.075	0.17872

4.1.2. Post-Intervention Student Performance

Following the pedagogical intervention, analysis of the mean scores in Table 6 reveals a significant improvement in the experimental group (EG) compared with the control group (CG), underlining the potential positive impact of the intervention on learning.

Table 6. Descriptive statistics of final performance

	N	Mean	Standard deviation	Var	Med	Min	Max	Standard error of the mean
EG	20	6.12	1.36570	1.86	6.50	4.00	8.50	.30538
CG	20	5.20	1.33180	1.77	5.00	3.00	7.50	.29780

Post-intervention data also follow a normal distribution (Table 7), enabling valid comparison of group means.

Table 7. Shapiro-Wilk test for both groups

Group	Shapiro-Wilk		
	Statistic	*ddl*	Significance
EG	0.927	20	0.137
CG	0.953	20	0.422

Analysis of the differences between the means, through application of the t-test (Table 8), provides statistical evidence of the significant improvement in skills among students who benefited from the intervention.

Table 8. Post-intervention difference-in-means analysis

	Levene's test for equality of variances		t-test for equality of means				
	F	*Sig.*	*T*	*ddl*	Sig. (two-tailed)	Difference means	Difference standard deviation
Hypothesis of equal variances	0.278	0.60	-2.17	38	0.036	-0.925	0.4265

The p-value obtained from Levene's test, set at 0.601, surpasses the 0.05 threshold, suggesting that the variances observed in the two groups are comparable and likely due to random selection. In addition, the p-value of the t-test, evaluated at 0.036 and therefore below the significance threshold, reveals a significant post-intervention difference between the groups, justifying rejection of the null hypothesis. These observations affirm a notable enhancement in academic performance within the experimental group when contrasted with the control group, validating the effectiveness of using AR on second-year college students' understanding of volcanism.

4.2. Students' Perceptions of Volcanism

4.2.1. Initial Perceptions of Volcanism

Concerning the definition of volcano, the analysis of pre-intervention responses, illustrated in Figure 3, reveals varied and often imprecise perceptions of the volcano among the students. Descriptions oscillated between the volcano seen as a "mountain of fire" by a fraction of EG (6) and CG (5) students, and more metaphorical interpretations such as "explosion of the earth" or "natural phenomenon", indicating a lack of precise understanding of volcanic processes. A small number recognized the volcano as an "opening in the earth's surface", while a minority erroneously associated volcanism with non-relative phenomena such as the greenhouse effect, revealing significant conceptual confusion.

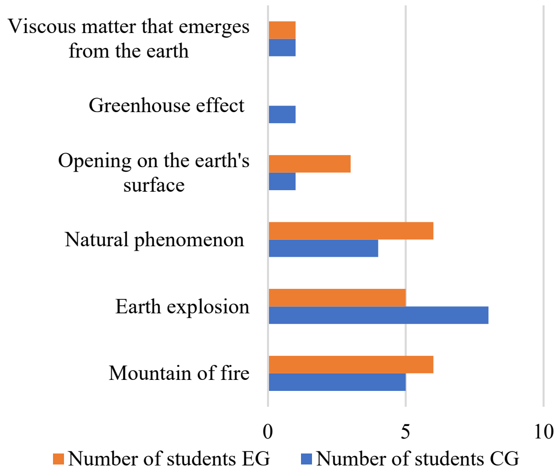

Figure 3. Students' definition of a volcano in the pre-test

Exploiting the typology of conceptions, detailed in Appendix 1, to examine students' representations of volcanism highlights the extent of pre-existing conceptions among students (Figure 4). Indeed, a majority (GT: 13, GE: 15) display a fuzzy understanding (C0) of volcanism, with a considerable number of students (GT: 5, GE: 3) unable to represent a volcano schematically. Only a few students (GT: 2, GE: 1) adhered to a "local conception" of the phenomenon (C1.2), perceiving volcanism as an isolated event detached from global terrestrial dynamics. Notably, only one GT student has the central conception (C2.2), where volcanism is interpreted as a process intrinsically linked to the properties of an Earth characterized by a solid crust above a magma reservoir.

In Figure 5, we observe a marked division in students' ability to explain the origin of lava. While a significant portion of students remain uncertain about this process, others attribute the origin of lava to a range of diverse sources, from "earthquakes" to "core pressure". These responses suggest a fragmented and often erroneous understanding of the mechanisms underlying volcanic activity, underlining the need for conceptual clarification through educational intervention.

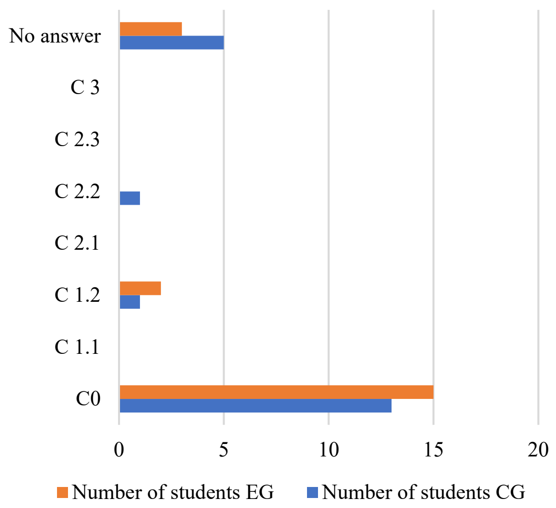

Figure 4. Students' conceptions of volcanism

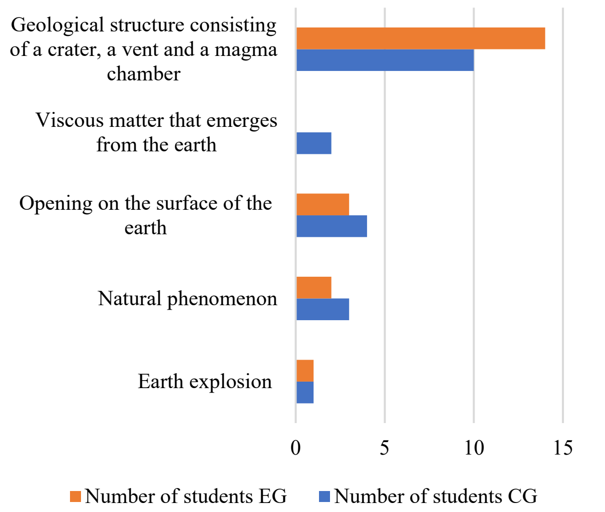

Figure 6. Volcano definition proposed by students after the intervention

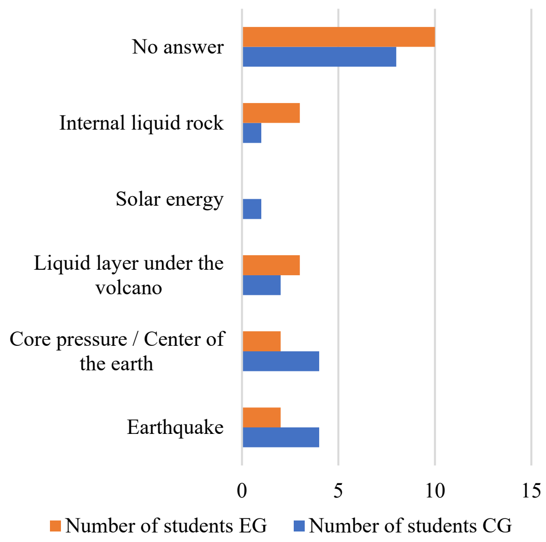

Figure 5. Origin of volcanic lava

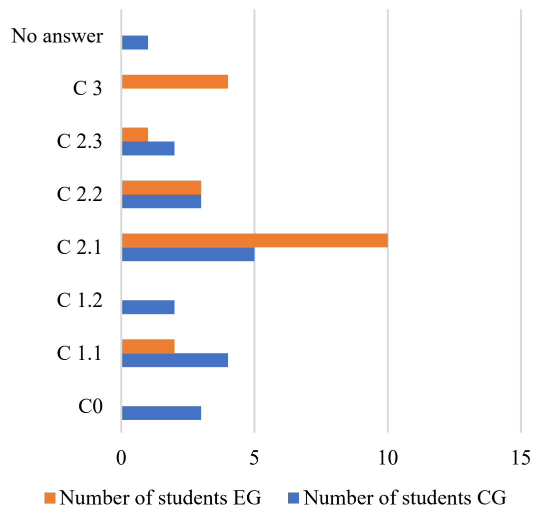

Figure 7. Type of conceptions about volcanism after the intervention

4.2.2. Changes in Understanding of Volcanism After the Intervention

After the educational intervention, Figure 6 illustrates a clear improvement in students' understanding of volcanoes, with a notable advance among those in the experimental group (GE). Among them, 14 precisely defined the volcano as a "geological structure including a crater, a vent and a magma chamber", demonstrating a successful assimilation of key concepts, compared with 10 students in the control group (GT). Despite this progress, some responses reiterated initial perceptions, suggesting a persistence of previous conceptions among a subset of students, who continued to see the volcano as a simple "land opening" or "natural phenomenon".

Figure 7 reveals significant changes in the way students conceptualize volcanism following the courses. The distinctions become more pronounced, with 10 EG students adopting a "central" view (C2.1) of volcanism, reflecting a deeper, more integrated understanding of the phenomenon, compared to 5 CG students.

This trend continues through other shades of the central conception (C2.2 and C2.3), showing a more balanced distribution between the groups. Notably, a minority of students continue to adhere to a "local conception" (C1.1), while a new "global" appreciation (C3) of volcanism emerges among 4 EG students, indicating an appreciation of the role of global tectonic dynamics.

Regarding the origin of the lava, the insights in Figure 8 reveal a maturing of the explanations provided by the students. A sizeable portion (EG: 8, CG: 5) correctly identified "partial fusion of rocks under specific conditions of pressure and temperature" as the origin of lava, a notable advance towards a scientifically valid interpretation. However, some students remain uncertain or continue to incorrectly link the origin of lava to phenomena such as earthquakes or the Earth's central pressure, suggesting areas requiring future clarification.

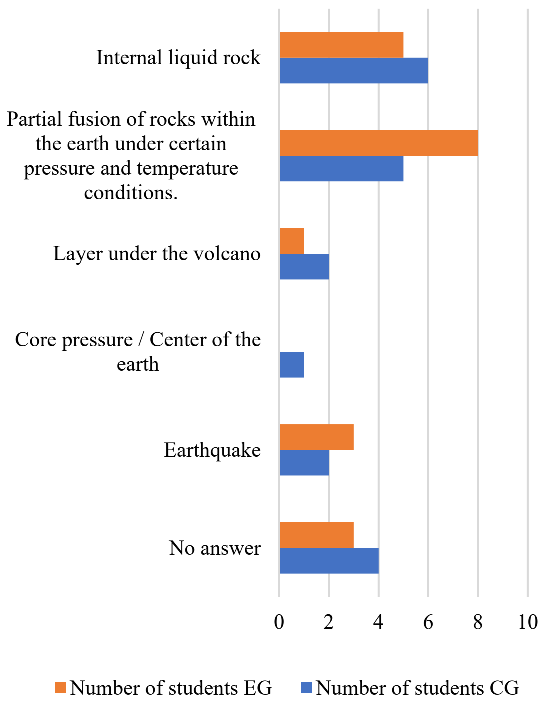

Figure 8. Understanding the origin of post-intervention lava

5. DISCUSSIONS

Analysis of the pre-intervention results highlighted a relatively modest basic understanding of volcanism among the students, with low mean scores No notable difference was observed between the control and experimental groups. This observation suggests not only a lack of prior familiarity with the subject, but also an opportunity to apply instructional engineering principles to improve learning. Building on the concept of "pre-existing conceptions" identified by [26], it becomes clear that integrating engineering into volcanism education could facilitate the deconstruction of misconceptions and the construction of robust, accurate scientific knowledge.

Students' simplistic perceptions, such as the association of volcanoes with "mountains of fire", reflect a need for educational approaches that go beyond the simple transmission of information to engage students in an active process of critical reflection and discovery. In this respect, educational engineering, with its emphasis on systematic design and innovation in teaching methods, offers a valuable framework. Post-intervention results reveal the effectiveness of such innovative methods, including the use of AR, in significantly improving students' understanding of volcanism. This technology not only enabled more concrete visualization of complex geological concepts, but also encouraged interactive exploration that enhances learning and recall.

The enhancement of spatial skills through AR, facilitating the transition between three-dimensional and two-dimensional representations of volcanic structures, is a prime example of the successful application of engineering principles in education.

This success corroborates previous research validating AR as a valuable pedagogical tool for enriching the educational experience and increasing student engagement and achievement [12], [15], [27], [28]. In addition, the engineering approach encourages the adoption of a teaching methodology that integrates experimentation, design and critical analysis, essential skills in scientific disciplines. Consequently, the introduction of engineering into volcanic education is not limited to improving understanding of natural phenomena, but extends to cultivating a set of analytical and problem-solving skills in students. They are prepared not only to better understand the world around them, but also to contribute innovatively to its understanding and management.

In conclusion, the integration of educational engineering into volcanic education, particularly through the use of technologies such as AR, has demonstrated considerable potential to transform the learning experience. It offers a promising route to overcoming traditional educational challenges, facilitating deeper understanding and developing critical skills essential for 21st-century learners. This approach strengthens the case for innovative, well-designed teaching methods, capable of meeting the diverse needs of students and effectively preparing the next generation of thinkers, creators and engineers.

6. CONCLUSION

The aim of this work was to investigate the contribution of AR as an educational engineering tool to improving secondary school students' conceptual understanding of volcanism. The results obtained, using a semi-experimental approach, showed a statistically significant improvement in student learning in favor of EG over CG. Indeed, the integration of AR applications into the teaching of volcanism favored the acquisition and understanding of scientific content related to this natural phenomenon and the promotion of spatial cognitive skills among learners. This innovative method offers a promising way of overcoming traditional educational challenges and making the learner the main actor in his or her learning. What's more, the students in the experimental group were highly motivated during the lessons and actively participated in the teaching-learning process. These results confirm that augmented reality applications are ideal for teaching and learning complex geological phenomena that are inaccessible and invisible to students.

This study has a number of methodological and didactic limitations. From a methodological point of view, the small sample size makes it impossible to generalize the results obtained. From a didactic and pedagogical point of view, this work did not take into account the teaching approach used, even though this is a parameter that plays a crucial role in improving learning. To overcome these limitations, it would be possible to conduct a similar study on larger samples, examining the impact of the teaching approach and pedagogical scenario adopted.

APPENDIX

Appendix 1. Typology of conceptions adapted from [4, 6, 7, 9, 24]

Conception	Description
Fuzzy (C0). Fuzzy explanation of volcanism.	-Volcanic cone with no structural details, - Origin of lava unclear or unidentified.
Local (C1). Volcanism is explained by a local function, independent of the structure and function of the globe.	C1.1: Well-defined cone with internal structure; - surface origin of lava linked to volcano
	C1.2: Cone filled with lava, associated with a deep-seated (but imprecise) origin of the lava "the lava is underground and rises to fill the volcano"
Central (C2). Volcanism is seen as a phenomenon linked to the characteristics of an Earth made up of a solid crust (of varying thickness) overlying a mass of magma	C2.1: Presence of a conduit communicating the volcanic edifice with a closed reservoir; or open; deep origin of the lava
	C2.2: Building with unfinished conduit; deep lava source - No volcanic reservoir
	C2.3: Conduit connecting the volcano with a layer or sheet of lava under the earth's crust
Global (C3). Volcanism is closely linked to global tectonics and the movement of lithospheric plates.	- Deep lava origin - Volcanic activity linked to the movement of lithospheric plates - Magma exists in specific places (ridges, subduction zones, hot spots)

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