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IMPACT OF INTEGRATING AUGMENTED REALITY WITH MERGE CUBE ON EARTH SCIENCES EDUCATION

M. El Mokhtari M. El Atlassi S. Smouni B. Nachit

Multidisciplinary Laboratory in Educational Sciences and Training Engineering (LMSEIF), Higher Normal School, Hassan II University, Casablanca, Morocco
mohbio@gmail.com, mohamedelatlassi78@gmail.com, sakina.smouni@gmail.com, nachitbrahim@yahoo.fr

Abstract- This study examines the impact of integrating augmented reality (AR) using the Merge Cube on the academic performance of second-year baccalaureate students in Morocco during geology lessons. A quasi-experimental post-test design was employed, comparing an experimental group utilizing the Merge Cube with a control group receiving traditional instruction. Performance was assessed across three cognitive domains knowledge, comprehension, and analysis based on Bloom's taxonomy. The findings reveal significant improvements in the experimental group's performance with the use of the Merge Cube, particularly in analysis, where scores increased by 16% compared to the control group ($p = 0.002$). Although comprehension also improved significantly ($p < 0.05$), knowledge level gains were not statistically significant ($p = 0.148$). These results underscore the potential of AR technology, specifically the Merge Cube, to enhance learning outcomes in earth sciences by fostering higher-order cognitive skills and improving students' understanding of complex geological phenomena.

Keywords: Augmented Reality, Merge Cube, Geology Teaching, Learner Performance, Cognitive, ICTE

1. INTRODUCTION

Teaching and learning science are a complex process that involves abstract concepts and requires mastery of practical skills. This is particularly true for geology, a discipline that demands the ability to visualize and conceptualize abstract geological phenomena. Teaching and learning earth sciences present unique challenges due to the abstract and complex nature of geological phenomena. Traditional methods often struggle to effectively convey concepts such as plate tectonics, mountain formation, and spatial-temporal dynamics, leaving students with misconceptions and limited engagement.

Study by [1] R. Chakour, and his colleagues identified several obstacles to effective geology instruction. These include students' difficulties in grasping abstract concepts, a lack of interest due to the perceived demotivating nature of the scientific content, insufficient teaching resources, and inadequate integration of technology into the classroom.

Augmented Reality (AR), with its immersive and interactive capabilities, offers promising solutions to these challenges by bridging the gap between abstract concepts and tangible understanding. From this perspective, augmented reality emerges as a promising tool and approach to addressing the challenges associated with teaching geology. Previous experiments on the positive contributions of integrating augmented reality into learning programs have shown highly encouraging results.

A study by Taufiq and his colleagues published in the Unnes Science Education Journal, provides further insight into using augmented reality in science education. This research specifically evaluated the applicability of augmented reality media based on the Merge Cube with secondary school science teachers. The findings highlighted the benefits of using the Merge Cube to enrich teachers' educational experiences and foster their pedagogical creativity. The Merge Cube's application of augmented reality has the potential to bridge the gap between abstract geological concepts and learners' understanding, which can contribute to enhancing students' performance in geology. In our research, our goal is to assess how augmented reality integration using the Merge Cube affects second-year high school geology students' performance.

1.1. Problematic

Over the past decade, numerous research projects have investigated the benefits and impact of integrating augmented reality (AR) into science teaching and learning contexts. An insightful meta-analysis by [3] Wenden Cao, Zhonggen Yu, 2023 revealed that integrating augmented reality had a positive influence on students' attitudes, motivation, and learning outcomes. Students who incorporated this technology into their learning showed significantly higher academic outcomes compared to those who did not. However, the study found no significant difference in terms of AR's impact on learner motivation, indicating the need for further research into how AR can enhance learning strategies and influence students' attitudes toward technology-assisted education.

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Regarding AR's effects on cognitive levels according to Bloom's taxonomy, another meta-analysis [4] conducted by (Qianqian Shen; and Pei-Wei Tsai, 2023) demonstrated that AR improved students' cognitive results, particularly at the lower tiers of Bloom's cognitive taxonomy pyramid, such as application and memorization. This study also highlighted that AR's impact is most evident in learning science and languages.

For higher cognitive levels in Bloom's taxonomy, a study [5] conducted by Erin Lespita, Andik Purwanto, and Ahmad Syarkowi demonstrated that the integration of an approach of learning based on problems, supported by AR, enhanced students' higher-order thinking skills. The study also emphasized the potential of AR technology as an effective tool for fostering reflective thinking, thereby confirming its relevance in educational contexts.

Additionally, a study conducted by [2] conducted by Muhamad Taufiq, Murbangun, Nuswowati Arif Widyatmoko (2021) examined the use of AR media through the Merge Cube among secondary school science teachers. The study revealed a high level of acceptance and adaptability of AR technology with the Merge Cube, making it an effective tool for science education. Teachers expressed high satisfaction with the use of Merge Cube in meeting educational objectives and facilitating science teaching, with an average compatibility rate of 87.0%, demonstrating the suitability of Merge Cube AR for improving science teaching.

From all the above, it is clear that augmented reality holds great promise for educational research, though it is still too early to draw definitive conclusions. Further studies are essential to better understand AR's long-term effects on learning, as well as its influence on teachers and different educational contexts. A literature review Murat Akcayir, and G€okce Akcayir (2017) on the benefits and challenges of using AR in education highlighted some difficulties, such as cognitive overload, associated with its implementation. In Morocco and other countries of the Arab Maghreb, few studies, if any, have been conducted on the impact of using the Merge Cube as an AR medium in teaching and learning geology. Given this context, our study intends to quantify the effects of integration using the Merge Cube on learners in a geology course for second-year secondary students in Morocco.

Our study aims to address the following primary question: How does the Merge Cube's use of augmented reality affect second-year secondary students' performance in the geology course? In accordance with Bloom's taxonomy, our study will specifically evaluate the effect on performance across three cognitive levels: the basic level of knowledge, the level of understanding, and finally the higher level of analysis.

2. RESEARCH METHODOLOGY AND MATERIALS USED

This section outlines in detail the methodology used to investigate the impact of Merge Cube-based augmented reality on learning about the geological phenomena involved in the formation of mountain ranges and their relationship to plate tectonics.

Cognitive Coherence Principle: According to this model, for a multimedia learning environment to be effective, it must ensure a coherent integration of visual and verbal components. This integration, which is a characteristic of augmented reality, can enhance learners' understanding and retention of geological concepts. Spatial Contiguity Principle: The use of the Merge Cube allows learners to directly manipulate geological models with their hands, creating a close overlap between the physical reality of geological objects and the virtual enhancements provided by AR. This spatial alignment facilitates the understanding of complex geological concepts such as plate tectonics.

2.1. Research Hypothesis

To address our research question, we formulated the following hypothese:

- Hypothesis 1 (H1): The application of augmented reality through the Merge Cube improves learners' performance in understanding geological concepts.

This methodological framework will help us evaluate the impact of AR technology on learners' cognitive performance, particularly in grasping challenging geological phenomena.

2.2. Methodological Approach

To conduct this research, we adopted a quantitative approach. Specifically, we employed a quasi-experimental design incorporating augmented reality through the use of the Merge Cube in the course titled 'Geological Phenomena Associated with the Formation of Mountain Ranges and Their Relationship with Plate Tectonics.' This course is part of the curriculum for second-year baccalaureate students specializing in physical sciences, taught in the second semester of the 2022–2023 school year. This research was conducted as part of a pedagogical sequence in geology exploring the origin of earthquakes and magma in subduction zones. The study involved secondary school students, working in pairs to encourage collaboration and critical thinking. Each pair was provided with a specially designed activity sheet to guide the use of the Merge Cube, allowing them to structure their investigation and document their observations.

The pedagogical sequences were carefully developed following an active inquiry-based approach. To foster collaboration and student engagement, students were organized into pairs and equipped with a structured activity sheet designed to guide them throughout their exploration. During the hands-on activities, each pair manipulated a Merge Cube linked to an augmented reality application, offering an immersive visual experience with dynamic 3D models.

Table 1. Characteristics of the sample

Group	Numbers of Classrooms	Boys	Girls	Total
Experimental	2 classrooms	35	39	74
Control	2 classrooms	39	36	75

Students recorded their findings by answering questions on the following key concepts: The distribution of seismic foci along the Benioff zone, subduction metamorphism, the origin of magma, and melting conditions. The control group was given conventional education without any augmented reality integration. The sample characteristics are detailed in Table 1.

The absence of a pre-test in both the experimental and control groups is justified by the underdeveloped prior conceptions of students regarding the tested concepts. These initial misconceptions, if assessed, could potentially reinforce erroneous representations and create cognitive obstacles to learning. By avoiding a pre-test, we minimize the risk of activating incorrect prior knowledge that may hinder the acquisition of new scientific concepts.

In order to evaluate how the Merge Cube affects students' performance, we administered a post-test to assess their understanding of the subject and to test the research hypotheses. We employed a quasi-experimental method, which allowed us to deliberately manipulate the learning conditions (with or without the use of Merge Cube-based augmented reality) in order to observe the effect of these variations on learners' performance.

2.3. Equipment Used: The Merge Cube

We will utilize the Merge Cube in conjunction with the free Object Viewer mobile application, which is linked to the Mini verse website. After creating an account, users will be able to download the models for use.

2.4. Empirical Study

2.4.1. Study Population and Sample

The course "Geological phenomena accompanying the formation of mountain ranges and their link to plate tectonics" is taught in two second-year baccalaureate options: Physical Sciences, across four different languages. Our sample consists of students in the Physical Sciences option, taught in French (BIOF). The sample was randomly selected from various high schools within the Casa-Settat Academy.

The study sample was divided into two groups: a control group (2 classes), where the course was taught using traditional methods without the Merge Cube, and an experimental group (2 classes), where the course was supplemented by the use of Merge Cube-based augmented reality.

We chose not to use a pre-test in our experimental research protocol for specific reasons. Previous studies have highlighted common misconceptions Moroccan learners have about the formation of mountain ranges. These studies have shown that learners often hold preconceived and sometimes inaccurate representations of geological concepts.

By considering these findings, a pre-test would likely reveal these misconceptions without adding value in terms of assessing learners' actual knowledge. Moreover, administering a pre-test could unintentionally reinforce these misconceptions through misleading questions. Therefore, by omitting a pre-test, we aim to avoid these risks and instead focus on correcting misconceptions as they arise during learning process, leading to more effective learning and a stronger understanding of the content.

2.4.2. Study Variables

- Independent variable: The use of Merge Cube-based augmented reality in teaching "Geological phenomena accompanying the formation of mountain ranges and their relationship with plate tectonics".
- Dependent variable: Learners' performance, measured by their results on questionnaires.

2.4.3. Group and Teacher Performance Equivalence Test

To ensure equivalence between the two sample groups at the end of the experiment, a pedagogical scenario was developed. This scenario outlined the course sequence, objectives, methodology, and teaching strategy for both groups. The only difference between the groups was the use (or non-use) of augmented reality via the Merge Cube.

We also ensured that students in both groups came from the same socio-cultural context and the same academic region, i.e., the Casa-Settat Academy. To avoid any bias related to teachers being aware of the research's expected outcomes, we maintained strict neutrality regarding the teaching-learning methods and did not influence the teachers' approach.

The questionnaire used to measure performance was designed following the guidelines provided by the University of Geneva, as described in Bolarinwa's (2015) "Questionnaire Validation" guide.

2.4.5. Procedure for using the Merge Cube

In our study, we followed these steps for integrating the Merge Cube:

- Material Preparation: Firstly, we prepared the necessary materials, including the Merge Cube (created using a cardboard model) and the free "Object Viewer" mobile application, alongside the "Mini verse" website. We created an account on Mini verse and downloaded the required 3D models for the course.
- Application Setup: After preparing the materials, we configured the Object Viewer application on mobile devices. We linked the app to our Mini verse account and ensured that necessary models were properly downloaded.
- Integration of Augmented Reality into the Course: Augmented reality based on the Merge Cube was incorporated into the course on geological phenomena and mountain formation. The experimental group participated in sessions where they used the Merge Cube to visualize 3D models related to the geological concepts being studied. The control group received the same course content but without the use of augmented reality.
- Explanation and Demonstration: Before introducing the Merge Cube, we provided a detailed explanation to the students about how it worked and its benefits for learning geological concepts. A practical demonstration was given, showing how to hold and manipulate the Merge Cube to view the augmented reality models.
- Using the Merge Cube During Learning Sessions: During the learning sessions, students in the experimental group used the Merge Cube to explore 3D geological models. They could manipulate the cube by rotating and flipping it to view different aspects of the models and interactively observe geological phenomena.

• Supervision and Support: Throughout the sessions, the teacher supervised the students, answered their questions, and provided guidance as they explored the models. Additional explanations were given where necessary to ensure that students fully understood the geological concepts presented.

3. PRESENTATION AND DISCUSSION OF THE RESULTS

Several measures were taken to guarantee the validity and quality of the data collected before the results were analyzed. Firstly, a validity check question was included in the questionnaire to assess whether participants responded seriously and consistently throughout. This question allowed for the identification and elimination of responses that appeared unreliable or inconsistent with the study's expectations. In the augmented reality sample, three questionnaires were excluded for this reason, while five were eliminated from the control group without augmented reality.

Next, a process of data identification and cleaning was implemented. This involved detecting atypical values or outliers in the collected data and addressing them appropriately. Outliers can distort analyses and interpretations, making it crucial to identify and, if necessary, eliminate or correct them. Additionally, a quality control check was conducted on questions requiring diagrammatic responses. This step ensured that participants correctly understood the instructions and provided coherent diagrams that met the study's expectations. Incorrect or inconsistent responses were identified and excluded when necessary (Table 2).

Table 2. Control of questionnaires collected

	Experimental sample	Control sample
Number of questionnaires collected	74	75
Wrong answer to the validity check question	3	5
No schema returned	2	3
A final number of questionnaires was selected	69	67

In our study evaluating the effect of using the Merge Cube in geology teaching on student performance, we adopted a comparative approach based on statistical parameters and employed Student's t-test. To enhance the rigor of the analysis, extrinsic factors such as students' prior knowledge and teacher variability were considered during data collection. Although these factors were incorporated into the overall statistical analysis, their detailed treatment will not be addressed in this article.

Effect sizes (Cohen's d) were calculated to measure the magnitude of the differences between the two groups, and 95% confidence intervals were provided for each estimate to ensure precise result interpretation. To conduct these analyses, we utilized SPSS software to perform statistical evaluations and identify any notable variations in the two groups' performances.

3.1. Performance Test at Three Taxonomic Levels (Knowledge, Understanding and Analysis)

3.1.1. Test of Performance in Improving Knowledge

Comparing the averages (Table 3), we observe that the experimental group has a slightly higher average score of 1.43 compared to the control group's average of 1.2.1. This indicates a trend toward improved performance in the experimental group. The experimental group has a greater standard deviation (0.581) than the control group, which has a standard deviation of 0.228. This implies that the experimental group's outcomes were more variable.

Several extrinsic factors may contribute to this variation, including individual differences in cognitive abilities, student motivation, prior experience in geology (notably, 4.5% of students in control group were repeaters, while none in the experimental group were), and teacher specialization, which was not accounted for in our study. These factors can influence student performance and, consequently, may explain observed dispersion in results.

Table 3. Descriptive data for two groups under experimentation and control

	Headcount	Minimum	Maximum	Mean	Standard Deviation
Experimental group results	69	0	2	1.43	0.581
Control group results	67	0	2	1.21	0.228

Table 3. results of the student test

results	Levene's test		t-test				
	F	Sig.	*t*	ddl	Sig. (bilateral)	Different average	standard error
hypothesis of equal variances	1.341	0.248	1.459	134	0.148	-0.226	0.091
hypothesis of unequal variances			1.959	130.49	0.210	-0.226	0.091

First, let's examine the results of Levene's test (Table 4). Based on the provided data, we obtained a Levene test statistic of $F = 1.341$, with an associated p-value of $p = 0.248$. This p-value exceeds the commonly accepted significance level ($\alpha = 0.05$), showing that there is not enough statistical support to draw the conclusion that the variances of the two groups differ significantly. Additionally, the Student's t-test findings showed a p-value of $p = 0.148$ and a t-value of 1.459. Once more, this p-value exceeds conventional significance level ($\alpha = 0.05$).

Therefore, we do not have enough statistical evidence to reject the null hypothesis (H0: the use of the Merge Cube in the geology course has no effect on improving learners' knowledge at the level of direct application), even though the experimental group's mean score improved. Consequently, we are unable to draw the conclusion that the two groups' means differ significantly.

Table 4. Two groups under experimentation descriptive and control

	Headcount	Minimum	Maximum	Mean	Standard Deviation
Experimental group results	69	0	5	2.67	1.462
Control group results	67	0	5	1.73	1.982

3.1.2. Performance Test for Improved Comprehension

To compare the effect of using the Merge Cube on understanding geological phenomena, we analyzed the differences between the experimental group (which utilized the Merge Cube) and the control group. The following comparison is determined by the standard deviation and mean (Table 5).

Table 5. Results of the student test

results	Levene's test		t-test				
	F	Sig.	*t*	ddl	Sig (bilateral)	Different average	standard error
Hypothesis of unequal variances			1.959	130.498	0.014	-0.614	0.04

• Average Scores: The experimental group had an average score of 2.67, while the control group had an average score of 1.73. This indicates that, on average, participants in the experimental group who utilized the Merge Cube achieved higher scores in their understanding of geological phenomena related to plate tectonics compared to the control group.

• Standard Deviation: The standard deviation reflects the dispersion of the data around the mean. In this study, the experimental group exhibited a standard deviation of 1.462, whereas the control group had a standard deviation of 1.982. This suggests that the scores of the experimental group were more consistent around the mean than those of the control group, indicating a greater uniformity in understanding geological phenomena among the experimental participants.

These results imply that Utilizing the Merge Cube has positively impacted the comprehension of geological process associated with plate tectonics. Participants in the experimental group demonstrated improved understanding. The outcome of Levene's examination ($p = 0.207$) shows that there is no discernible difference between the two groups' variances. This implies that the application of the Merge Cube did not influence the variability of the data concerning understanding geological phenomena linked to the formation of mountain ranges and plate tectonics. Consequently, both the experimental and control groups exhibited similar levels of dispersion in their data (Table 6).

Table 6. Descriptive statistics for the 2 experimental and control groups

	Headcount	Minimum	Maximum	Mean	Standard Deviation
Experimental group results	69	0	2	1.19	0.692
Control group results	67	0	2	1.03	0.960

Student's t-test ($p = 0.015$): The p-value indicates a significant difference between the two study groups, leading to the rejection of the null hypothesis (H0). The significance of the difference between the means demonstrates a statistically significant improvement in understanding phenomena related to plate tectonics, including collision, magmatism, and metamorphism, attributable to the use of the Merge Cube and augmented reality. This suggests that these tools enhance learners' comprehension of these complex and abstract concepts.

Recognizing the inherent difficulty in grasping these phenomena, it is essential to highlight that plate tectonics is a complex field of geology characterized by dynamic processes and extensive timescales. Concepts such as plate collision, magmatism, and metamorphism can be particularly abstract and challenging to visualize or conceptualize when relying solely on theoretical descriptions or traditional teaching methods.

The integration of the Merge Cube and augmented reality provides a more immersive and interactive learning experience. It allows students to visually and tangibly explore these phenomena. The 3D visualization of plate movements, subduction and obduction processes, volcanic eruptions, and rock transformations can significantly enhance understanding by offering a more concrete and realistic representation of these geological concepts.

3.1.3. Performance Test for Improved Analysis

To compare the effect of using the Merge Cube on the analysis of geological phenomena related to plate tectonics, in particular subduction, obduction and collision, as well as the dimensions of space and time, we can examine the differences between experimental group and control group. Here is a comparison based on the data provided (Table 7).

Table 7. Results of the student test

results	Levene's test		t-test				
	F	Sig.	T	ddl	Sig. bilateral	Different average	standard error
Hypothesis of equal variances	3.110	0.304	-3.139	134	0.002	-0.935	0.298
Hypothesis of unequal variances			-3.125	121.31	0.0043	-0.935	0.299

• Mean: The experimental group's average score was 1.19, whereas the control groups were 1.03.

This indicates that, on average, participants in the experimental group who used the Merge Cube obtained slightly higher scores in analyzing geological phenomena related to plate tectonics, including subduction as well as the spatial and temporal dimensions involved, compared to the control group.

• Standard Deviation: The standard deviation quantifies the dispersion of data around the mean. In this analysis, the experimental group exhibits a σ of 0.692, whereas, the group under control shows a standard deviation of 0.969. This suggests that the scores of the experimental group are less dispersed around the mean, indicating greater consistency in their analysis of geological phenomena.

The results of Levene's test (Table 8) indicate that the use of the Merge Cube did not affect the variability of the data between the studied groups. In other words, both the groups utilizing the Merge Cube and those in the control group exhibited similar levels of dispersion in their data regarding the analysis of geological phenomena related to the formation of mountain ranges and plate tectonics.

Conversely, the p-value from the student's t-test was 0.002. which is below the commonly accepted significance threshold (e.g., 0.05). Since this result shows a substantial difference between the two research groups, the null hypothesis (H0) is rejected. In essence, there is a statistically significant improvement in the analysis of phenomena associated with plate tectonic such as collision, magmatism, and metamorphism attributable to using augmented reality and the Merge Cube.

The results indicate that the improvement in factual knowledge, such as memorizing definitions or basic concepts (e.g., rock types or subduction stages), is limited. This trend can be attributed to the nature of AR, which prioritizes interactivity and dynamic visualization, often less suited for rote memorization. This finding aligns with the conclusions of Shen and Tsai (2023), who observed that AR primarily enhances lower to mid-level cognitive processes, such as application and interpretation, but has a lesser impact on pure memorization.

The interactive immersion enabled by the Merge Cube allows students to explore complex 3D geological models, making abstract concepts like seismic foci or Benioff zones more accessible. By manipulating these models, students develop a deeper understanding of geodynamic phenomena. This observation is consistent with the work of Cao and Yu (2023), who demonstrated that AR significantly improves the comprehension of complex concepts through its visual and immersive approach, enhancing cognitive engagement and the ability to connect concepts.

The analysis of phenomena such as subduction and magmatism showed significant gains in the AR group, indicating that interactive manipulation helps students formulate hypotheses and interpret causal relationships between various geological processes. This trend is supported by the study of Lespita, et al. (2023), which highlights that integrating AR in a problem-based learning context fosters the development of critical thinking and analytical skills in natural sciences.

4. DISCUSSION AND CONCLUSION

Firstly, it is noted that the effect of using the Merge Cube on lower cognitive levels, such as knowledge acquisition, appears to be relatively modest. This suggests that the Merge Cube alone may not significantly enhance the recall of geological facts related to how mountain ranges are formed. On the other hand, the Merge Cube appears to have a greater effect on higher cognitive levels, such as comprehension and analysis of geological concepts. Immersion in a three-dimensional virtual environment allows learners to explore geological processes interactively, manipulate variables, and observe the outcomes of their actions. This fosters critical thinking and a deeper understanding of the mechanisms and concepts involved in the formation of mountain ranges and associated phenomena.

This outcome can be interpreted through the lens of Edgar Dale's classification, which emphasizes the importance of manipulation and context in learning. The use of the Merge Cube falls under the category of direct manipulation and concrete experience. Learners actively engage with geological models and find themselves in a concrete situation where they can explore geological concepts hands-on. This immersive pedagogical approach can significantly enhance their understanding of geology.

Given the results concerning academic performance, we can confidently affirm the validity of hypothesis H1 of our research. We conclude that the use of the Merge Cube has substantially improved students' comprehension of geological concepts related to mountain formation. This technology has notably elevated learners' levels of knowledge, understanding, and analytical skills. Additionally, the Merge Cube facilitated the development of more accurate and detailed mental representations of geological phenomena. Learners were able to visualize various geological structures, such as plate movements, in real time, thereby enhancing their patio-temporal understanding of geological processes.

Moreover, while objective measures were employed to assess student performance, it is crucial to acknowledge that other situational and individual factors may also influence the results. Variables such as a student's prior experience in geology, interest in the subject, and motivation could affect the effectiveness of the Merge Cube's usage. Furthermore, this study primarily evaluated the immediate impact of the Merge Cube on student performance. Investigating the long-term effects of this educational intervention would be valuable in determining whether the observed improvements are sustainable and whether they contribute to better retention of geological knowledge.

It's also important to keep in mind that the sample size for this study was somewhat small, which may have limited how widely the results may be applied. Furthermore, because to the short duration of the trial, we were unable to assess the Merge Cube's long-term effects on the performance of geology students. Finally, to further deepen this analysis, it would be relevant to conduct longitudinal studies to assess the long-term impact of AR on students' knowledge retention and analytical skills, while also exploring its effects across different age groups and educational levels.

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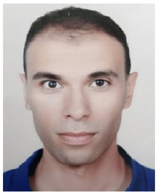
BIOGRAPHIES

Name: **Mouhammed**
Surname: **El Mokhtari**
Birthday: 17.05.1973
Birthplace: El Jadida, Morocco
Bachelor: Plant Physiology, Faculty of Sciences, Chouaib Doukkali University, El Jadida, Morocco, 1996
Master: Educational Technology and Pedagogical Innovation, Faculty of Educational Sciences, Mohamed V University, Rabat, Morocco, 2023
Doctorate: Student, Multidisciplinary Laboratory in Education Sciences and Training Engineering, Normal Higher School (ENS), Hassan II University, Casablanca, Morocco, Since 2024
The Last Scientific Position: Researcher, Higher Normal School (ENS), Hassan II University, Casablanca, Morocco, Since 2005
Research Interests: Didactics Sciences, Teaching and Learning Biology and Geology, TICE, New Teaching Technologies



Name: **Mohamed**
Surname: **El Atlassi**
Birthday: 05.05.1978
Birthplace: Casablanca, Morocco
Bachelor: Chemical Engineering, Faculty of Sciences and Technology, Hasan II University, Mohammadia, Morocco, 2001
Master: Teaching and Training Professions in Physical and Chemical Sciences, Higher Normal School (ENS-C), Hassan II University, Casablanca, Morocco, 2014
Doctorate: Didactics of Sciences, Faculty of Sciences Ben M'sick, Hassan II University, Casablanca, Morocco, 2021
The Last Scientific Position: Prof., Didactics of Sciences, Higher Normal School (ENS), Hassan II University, Casablanca, Morocco, Since 2023
Research Interests: Didactics Sciences, Training Engineering, Pedagogy
Scientific Publications: 5 Papers

Name: **Soukaina**
Surname: **Smouni**
Birthday: 06.10.1994
Birthplace: Casablanca, Morocco
Bachelor: Earth and Life Sciences Teaching, Higher Normal School, Cadi Ayyad University, Marrakech, Morocco, 2016
Master: Earth and Life Sciences Teaching, Higher Normal School, Cadi Ayyad University, Marrakech, Morocco, 2019
Doctorate: Student, Multidisciplinary Laboratory in Education Sciences and Training Engineering, Higher Normal School (ENS), Hassan II University, Casablanca, Morocco, Since 2022
The Last Scientific Position: Lecturer, Earth and Life Sciences, Middle School, Morocco, Since 2018
Research Interests: Didactics Sciences, Teaching and Learning Geology, TICE, Difficulties in Earth Sciences, Obstacles

Name: **Brahim**
Surname: **Nachit**
Birthday: 23.02.1972
Birthplace: Casablanca, Morocco
Bachelor: Applied Mathematics, Faculty of Sciences Ben M'sick, Hassan II University, Casablanca, Morocco, 2004
Master: Training Engineering and Didactics of Sciences, Faculty of Sciences Ben M'sick, Hassan II University, Casablanca, Morocco, 2017
Doctorate: Didactics of Mathematics, Hassan II University, Casablanca, Morocco, 2014
The Last Scientific Position: Prof., Didactics of Mathematics, Higher Normal School (ENS), Hassan II University, Casablanca, Morocco, Since 2019
Research Interests: Didactics Sciences, Training Engineering, Pedagogy
Scientific Publications: 40 Papers