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Augmented reality-based teaching-learning tool, and the evolution of conceptions about "human breathing": Fifth-grade basic Tunisian students' case

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ABSTRACT

This study examines how teaching biology to fifth-grade children using modern technologies, such as augmented reality, can help them better understand the concept of human breathability. There are 24 volunteers total, of which 12 make up the experimental group, and the remaining half the control group. The 4-item survey was used as a basis for the methodological course. The investigation yielded two distinct outcomes. On the one hand, we saw a marked shift in the way students understood the function of breathing, the respiratory system's makeup, and the route taken by inspired air. However, engagement with interactive three-dimensional models, breathing process visualization in real time, and the ability to visually explore the interior of the human body prompted students to assimilate knowledge more efficiently. These findings demonstrate how AR provides fresh angles for the appropriation of intricate biological ideas.

Keywords: learner conceptions, evolution of conceptions, digital technology, augmented reality, human breathing

INTRODUCTION

Many argue that because respiration is an abstract concept with many moving parts, and technical scientific terminology, it is difficult for students to understand. Prior studies in science education have shown that pupils frequently have misconceptions that are in direct opposition to accepted scientific theories. These opposing viewpoints, sometimes referred to as misunderstandings, present a difficulty for science educators (Vosniadou & Skopeliti, 2017). Taber (2017) asserts that students' alternative frameworks are views and opinions that diverge from scientific theories. Given this, the development of technology has made the incorporation of technology into education a vital trend that has a big impact on the teaching and learning processes (Ismail & Abdullah Arshah, 2016). AR is one of the most significant advancements in technology-driven education. AR has become a powerful force for change. AR provides learners with exceptional opportunity for immersive engagement and interaction (Chang et al., 2016; Chien et al., 2019; Erbas & Demirer, 2019; Fuchsova & Korenova, 2019; Hung et al., 2017; Yapici & Karakoyun, 2021). Biology instruction using augmented reality (AR) improves both formal and informal learning (Hwang et al., 2016; Lu & Liu, 2015). We are currently trying to identify components of a response to the following questions in relation to AR-related concerns in education. we are currently trying to find answers to the following question: How the use of RA as an educational tool, and aid could-contribute to the evolution of the conceptions of Tunisian fifth grade students regarding their conceptualization of the human breathing mechanism, and the construction of their knowledge.

CONCEPTUAL FRAMEWORK OF STUDY

AR and Education

AR is one of the emerging digital technologies that has generated the greatest interest in the field of education (López-Faican & Jaen, 2020) because it allows interaction between real and virtual space (Madanipour & Cohrssen, 2019). The educational value of AR is closely related to how it is designed, implemented, and integrated into formal and informal learning environments (Petrovich et al., 2018). Considering AR as a conceptual framework rather than a specific technology could prove to be beneficial for educators (Tzima et al., 2019).

Due to its novelty and its potential to create innovative and engaging interfaces, AR can provide a natural incentive for the learning process (Mystakidis et al., 2021). Gopalan et al. (2016) explored the influence of science textbooks enhanced with AR on junior high school students in Malaysia, and referred to a positive relationship between students' engagement, enjoyment, fun and motivation for learning science. Chiang et al. (2014) tested the efficacy of an AR-based mobile learning system for engaging fourth-grade students in Taiwan in natural science research activities. The system guided students to the target ecological zones and displayed the corresponding learning tasks.

The results showed that students using mobile learning with AR showed increased motivation in terms of attention, confidence and relevance. Akçayır et al. (2016) conducted an examination of the effectiveness of an AR-enhanced laboratory manual in science laboratories, specifically among first-year students in Turkey. It follows that AR significantly improved the laboratory skills development of university students. Numerous studies have documented the potential of utilizing AR to enhance students' knowledge acquisition and improve learning outcomes in real-world environments when compared to traditional teaching methods. For example, Ibáñez and Delgado-Kloos (2018) discussed trends in AR applications for science, engineering, technology, and mathematics learning. They also highlighted that AR would be used more in science, technology, engineering and mathematics, well as in increasing spatial ability, practical skills, conceptual understanding and research learning scientist.AR applications have been developed for many areas of education (Martín-Gutiérrez et al., 2015). Some of these AR applications have been used in previous studies (Akçayır et al., 2016; Chiang et al., 2014; Gopalan et al., 2016). Indeed, AR applications fascinate users' responsiveness, enable an operational learning environment and encourage them to focus more on learning (Krüger et al., 2022). AR applications, which are interactively and visually richer than traditional media, appear more attractive and motivating than traditional tools (Shelton & Hedley, 2002).

Learners' Conceptions of Breathing

Based on De Vecchi and Giordan (1991), a conception is an "underlying explanatory model". It is a way of representing the world around us, which can sometimes be erroneous but which appears "simple and coherent". Conceptions are individual, but they can be shared.

They are built on the personal history and sociocultural context of the learner. Conceptions are a "general phenomenon" that all individuals, whether children or adults, are capable of. In this part of the study, we will examine learners' conceptions of human breathing.

According to research carried out on the concept of respiration (Bahar et al., 1999; Liu & Hmelo-Silver, 2009), we see that this concept is very complex and encompasses many dimensions, namely all living beings, from unicellular ones up to the most complex living structures, namely multicellular ones. Scientific evidence has established that respiration and associated concepts vary between species. In previous research, it was indicated that generally students find it difficult to understand the subject of "breathing" (Bahar et al., 1999; Waheed & Lucas, 1992) and they encounter difficulty grasping the correlation between breathing and vital biological functions, such as circulation, which are common to living beings (Songer & Mintzes, 1994).

According to Liu and Hmelo-Silver (2009), since breathing takes place at the cellular level as well as at the organismal level, it is one of the subjects that students struggle to understand. Hmelo et al. (2000) found that students in the 6th year of primary school have problems related to their learning of the human respiratory system. Assaraf et al. (2011) determined that two-thirds of high school students indicated that the fundamental role of both circulatory and respiratory systems is the exchange of CO_2 and O_2. Additionally, they tend to group concepts related to life, including those related to structures such as "cell nucleus, nerves and bones" but they fail to connect them at the microscopic level. Garcia-Barros et al. (2011) determined that children aged 4 to 7 years have limited knowledge about the respiratory system.

This is why the youngest in particular did not identify any of the organs of the respiratory system, while the oldest included the lungs and/or other organs (stomach and heart). Kurt et al. (2013) found that some 4th grade and 5th grade basic learners reduce the process of breathing into a single movement of inhaling. This translates into the following alternative conception: "Inspiration is a must for the continuation of life"

Thinking Explanations and the Concept of Respiration in Scientific History

Throughout history, numerous explanatory registers and models have been proposed to understand the process of respiration in humans, including the mechanistic register, the vitalist register and the physico-chemical vitalist register. The explanatory register refers to the type of knowledge or explanations that are used to understand a phenomenon. In order to identify learners' conceptions of human breathing and their foundations, we will use tools from epistemological analyzes of the concept of breathing. Thus, several biological meanings (several functions) of respiration could be noted in the history of the concept (Astolfi & Peterfalvi, 1997; Giordan, 1987). By referring to the history of the concept of "human breathing", we have been able to identify three possible conceptions. Vitalism is a philosophical tradition in which life is not reduced by physicochemical laws. It considers life as matter animated by a principle or vital force. In Homeric poetry, respiration is presented as one of the criteria of existence, and the manifestation of life in antiquity. Galen (129-217) grants several functions to breathing.

It is the blacksmith's bellows that maintain biological life. He also adds that the air mixes with the blood and that breathing purges the body. Galen's system will last until the 18th century. Vitalist thinking about breathing views the process as being underpinned by a vital force or vital energy.

This approach is not only based on observable and measurable data, but also on hypotheses and theories about the existence of a vital force. In philosophy, mechanism is a materialist conception that approaches all phenomena following the model of cause-and-effect links. Mechanistic philosophy rejects any idea of God or divine intervention in the workings of nature.

It was in 1637 that Descartes in his "discourse on method" conceived the living being as a machine. Harvey's theory of circulation which dates from 1628 "suggests research and erroneous ideas that the lungs are a sort of bellows maintaining the continual movement of the blood" (Giordan, 1987). Mechanistic thinking about respiration views the process as being underpinned by physical and chemical phenomena that can be observed and measured. This approach relies on observation and experimentation to understand the process of respiration and emphasizes the chemical reactions and gas exchanges that occur during respiration.

Physicochemical thinking is defined by Bernard (1865, p 161):

> "Today we distinguish three orders of properties manifest in the phenomena of living beings: physical properties, chemical properties and vital properties [...] This last denomination of vital properties is not itself only provisional; because we call organic properties vital which we have not yet been able to reduce to physico-chemical considerations".

Physicochemical thinking views respiration as a set of biochemical reactions and physical processes that can be described by the laws of thermodynamics. In short, physicochemical thinking interprets respiration as an essential biological function to convert nutrients into usable energy for cells, using oxygen and producing carbon dioxide as a byproduct (Viallard et al., 2001).

RESEARCH METHODOLOGY

General Background

To carry out this research, we opted for a mixed methodology that combines both a qualitative approach and a quantitative approach. To facilitate this study, we developed an AR application named "Arbio" in the context of a course on the human breathing system for fifth-grade students.

Sample

Our target participants are students from the two fifth-grade classes enrolled during the first quarter of the 2022-2023 academic year. The sample was pulled randomly from the 2 classes. This procedure was meant to eliminate bias in the selection of students, thus guaranteeing the representativeness of the sample. It should be noted that students in the experimental group (EG) will follow a course based on activities constructed using AR, while students in the control group (CG) will follow a non-experimental teaching course.

Figure 1. Application's logo (Source: Authors)

Instrument and Procedure

As part of our study, a questionnaire was meant to collect students' knowledge and conceptions about human breathing. This questionnaire consists of four items in Arabic which is the language of instruction. The first item aims to characterize learning conceptions concerning the meaning of breathing, but the remaining four questions are multiple-choice questions. Each of these questions has several propositions, but only one answer is correct.

Data Analysis

First of all, to understand the students' conceptions relating to the theme of human breathing, a qualitative analysis was carried out to capture the students' responses to the first item. They were chosen for their relevance in assessing students' knowledge and perceptions of the subject. Student responses were carefully reviewed and categorized to identify common ideas and common errors.

A quantitative approach was subsequently carried out to evaluate the contribution of the use of AR in the context of teaching sciences to the evolution of students' conceptions. In so doing, appropriate statistical tests were applied to measure changes in students' scientific knowledge and perceptions before and after the application of AR. The incumbent results were analyzed to evaluate the effectiveness of this teaching method.

RESEARCH RESULTS

AR Application

ArBio was designed to help learners develop their ideas on some scientific concepts related to the human respiratory system. The course of human breathing is relatively complicated for primary school students. The use of this technology is a problematic part of the course, which, according to our experience as primary school teachers, is likely to help resolve this conceptual problem. Rather than a simple multimedia support, AR allows learners to immediately return to the passage of the course that poses a problem by simply fact of placing their smartphone on it to see an image materialize in 3D or 2D, which often off-putting for them: The 3D virtual objects were prepared using the Unity 3D platform. We named our application Arbio, with "Ar" for "AR" and "bio" which is a short form for "biology". **Figure 1** shows the application logo made with Photoshop.

This tool ArBio allows us to recognize the page of the student's book on which the legend of the respiratory system is illustrated and thus transform it into 3D presentations. Once learners open the application, they can start interacting with

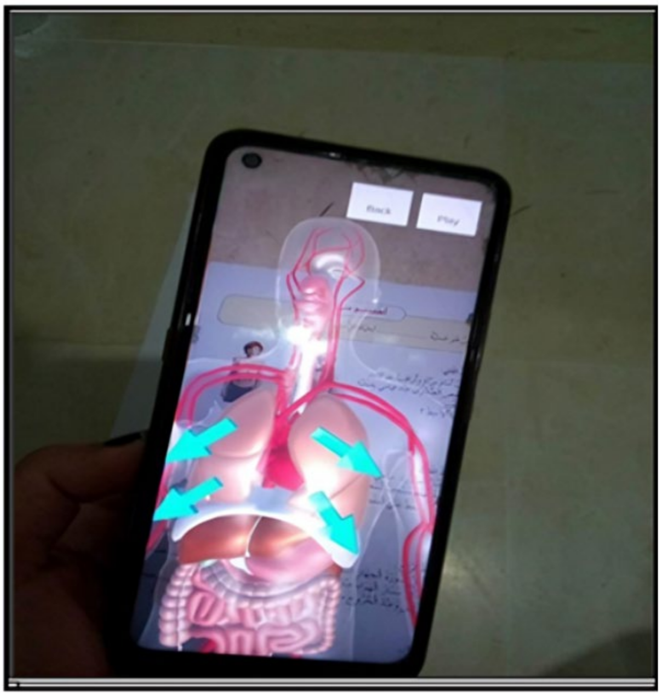

Figure 2. Screenshot describing inspiration-1 (Source: Authors)

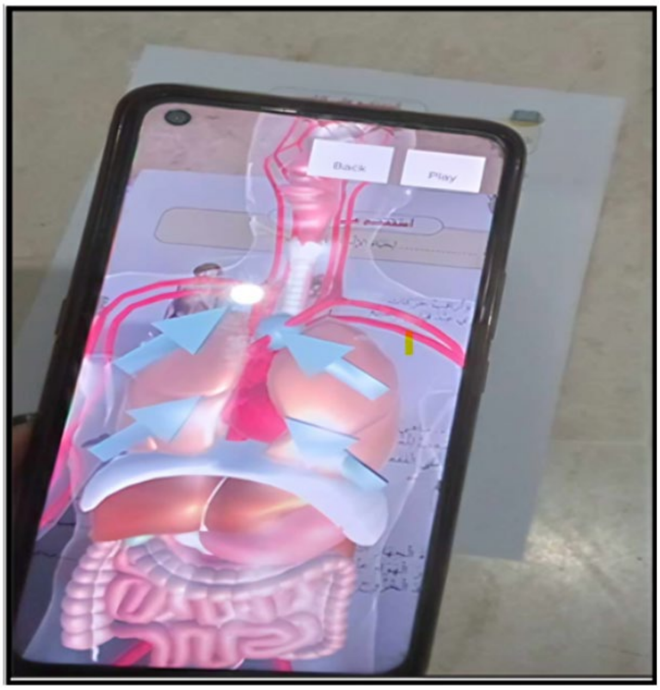

Figure 3. Screenshot describing inspiration-2 (Source: Authors)

virtual objects: The camera will follow the pattern on the book and start displaying the 3D model of the respiratory system. This natural interaction is a unique way that AR can offer to connect real and virtual representations. As to this study, we used six smartphones, one smartphone for every two students. During the experiment, we could observe the interactions closely between the learners and the teacher during the lessons. As observers, we were ready to intervene, if necessary, yet able to objectively observe the effects of AR on learners' conceptions. As part of this experiment, we compared the

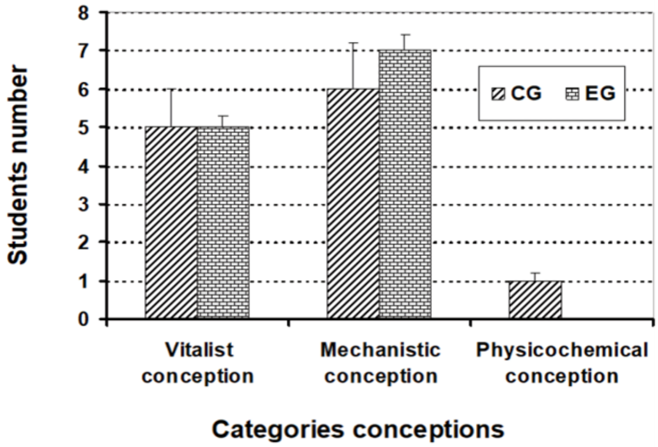

Figure 4. Evolution of students' conceptions of understanding the phenomenon of human respiration for the CG and EG groups (results are the mean ± standard deviation for 24 students) (Source: Authors)

impact of AR use on the evolution of conceptions. We chose to work on a specific subject, namely humans, and set up a two-stage experiment, with a CG and an EG. The EG benefited from the use of an AR application during the learning process while the CG did not. The application uses a target image, as well as a mobile device's camera to display an AR model.

The results of this experiment are presented in **Figure 2** and **Figure 3** using screenshots of the AR application used by the EG.

Post-Test Comparison of the Responses

The main objective of this comparison is to evaluate the effectiveness of AR on the evolution of learners' conceptions. We will therefore examine the statistically significant differences between the responses of the EG and the CG. In so doing, we will analyze the results of the post-tests using the chi-square test to determine whether the differences observed between the responses of the two groups are due to chance or statistically significant.

Evolution of students' conceptions of understanding the phenomenon of human respiration for the CG and EG groups

Question 1. What does breathing mean to you?: The analysis of learners' responses to the first item played a crucial role in categorizing conceptions of breathing into three distinct perspectives. Examining the explanations provided, it is clear that some reflected a vitalist approach, emphasizing a life force or mysterious energy.

Other responses, however, were more from a mechanistic perspective, describing respiration as the result of measurable physical and chemical phenomena. Finally, a set of responses was positioned from a physico-chemical perspective, integrating the biological understanding of respiratory function while recognizing the measurable aspects inherent to the mechanistic concept. Thus, through this process of analysis, it was possible to group the different conceptions according to these three distinct conceptual frameworks (**Figure 4**).

After the experiment, we noted that five students in each CG had referred to vitalist expressions such as "breathing is

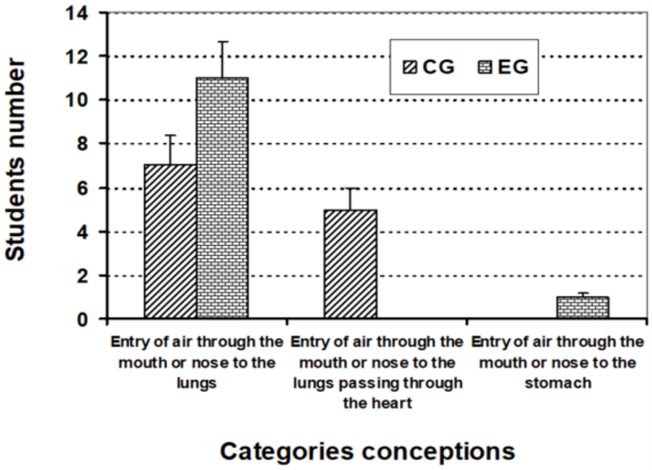

Figure 5. Evolution of students' conceptions of understanding the path of air inspired by the human respiratory system for the CG and EG groups (results are the mean ± standard deviation for 24 students) (Source: Authors)

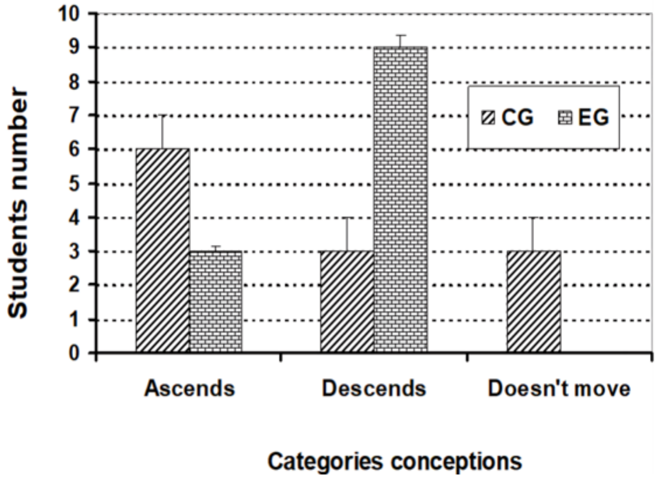

Figure 6. Evolution of students' conceptions of the movement of the diaphragms of human lungs during inspiration for the CG and EG groups (results are the mean ± standard deviation for 24 students) (Source: Authors)

life". This concept emphasizes the vital importance of breathing for the survival and functioning of the human body. Six students from the CG expressed mechanistic conceptions such as "*b*reathing ensures heart function" and "respiration is the absorption of O_2 and the release of CO_2". This concept fits into the mechanical register by emphasizing the gas exchanges that occur during breathing. Additionally, seven students in the EG shared conceptions of this same register. Moreover, one student from the CG expressed a physic-chemical conception, namely, "breathing is having energy".

This concept involves an understanding of how oxygen is used to produce energy in the body, which is a physicochemical explanation. The results of the statistical analysis ($\chi^2_{v=2} = 1.08$; $p > 0.05$) suggest homogeneity in the conceptions of the participants of the two groups, which indicates that there was no significant change in the meaning of breathing after the experiment.

Evolution of students' conceptions of understanding the phenomenon of human respiration for the CG and EG groups

Question 2. Trace the path of the inhaled air: Upstream of learning, we observed that among the choices proposed, the answer concerning the entry of air through the mouth or nose to the lungs was selected by three control participants and three participants from the EG. However, downstream, we found that this answer was chosen by seven control participants and eleventh participants in the EG. The answer (entry of air through the mouth or nose to the heart) was chosen by five students from the CG and no students from the EG. These students might think that breathing corresponds to a supply of air to the ears. Therefore, the answer concerning the entry of air through the mouth or nose to the stomach was chosen by one student from the EG and no students from the CG. The results of the statistical analysis ($\chi^2_{v=2} = 6.88$; $p < 0.05$) indicate that there is a significant difference between the CG and the EG. This means that the intervention of AR had a significant impact on the conceptions of participants regarding the path of inspired air (**Figure 5**).

Evolution of students' conceptions of the movement of the diaphragms of human lungs during inspiration for the CG and EG groups

Question 3. During inspiration, the diaphragm ...: Answer A (the diaphragm ascends) was chosen by nine students in the CG and by eight students in the EG. Answer B (the diaphragm goes down) was chosen by one student in the CG and by one student in the EG. Answer C (the diaphragm does not move) was chosen by two students in the CG and by three students in the EG. Examination of the statistical results ($\chi^2_{v=2} = 7$; $p < 0.05$) reveals that the disparities between the CG and the EG are considered significant. This indicates that AR had a significant impact on students' conceptions. Participants in the EG showed different conceptions than those in the CG regarding the movement of the diaphragm during inspiration (**Figure 6**).

Evolution of students' conceptions of the role of the alveoli in human lungs for the CG and EG groups

Question 4. The pulmonary alveoli allow for ...: Regarding the role of the alveoli, answer A (gas exchanges between air and blood) was chosen by six students in the CG and by six students in the EG. Answer B (to make the heartbeat) was chosen by six students in the CG and by one student in the EG. For these students, breathing is linked to all manifestations of life; the heart being generally considered to be the organ of life par excellence, students combine the two. Answer C (to convey air from the trachea to the alveoli) was chosen by no students in the CG and by three students in the EG. The results of the statistical analysis ($\chi^2_{v=2} = 6$; $p < 0.05$) reveal a significant difference between the CG and the EG. This highlights the effectiveness of AR in changing students' conceptions. By using this immersive technology, participants in the EG were likely exposed to visual and interactive information that promoted a better understanding of the precise role of the alveoli in respiration (**Figure 7**).

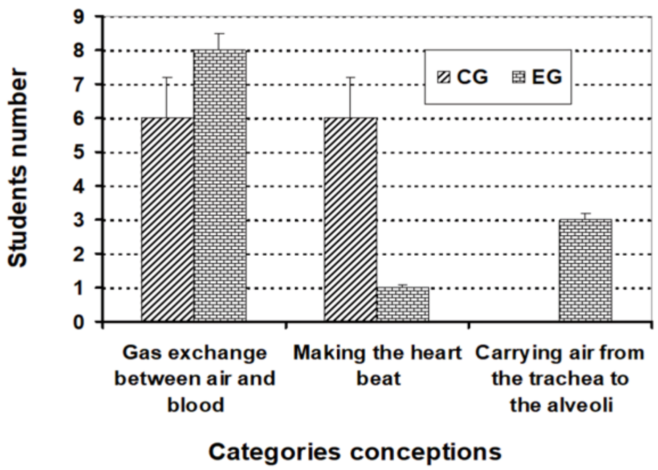

Figure 7. Evolution of students' conceptions on the role of the alveoli in human lungs for the CG and EG groups (results correspond to the mean ± standard deviation for 24 students) (Source: Authors)

DISCUSSION

The effect of AR on participants' conceptions is evident. The significant difference observed between the CG and the EG in understanding the composition of the respiratory system demonstrates the potential of AR as an educational approach to optimize the understanding of complex anatomical concepts. This indicates that immersive interaction with virtual elements had a positive impact on the way learners grasped and integrated this knowledge. Indeed, AR enables learners to observe and interact with invisible mechanisms. It provides structures that guide the learner's attention to relevant information, highlighting dynamic changes in the phenomenon over time and details that might otherwise be overlooked or unavailable (Yoon & Wang, 2013). AR may have the potential to situate students in the development of their conceptual knowledge (Yilmaz et al., 2016). The significant evolution of students' conceptions in the EG compared to the CG may be attributed to the visualization facilitated by AR. Students have the chance to visualize the respiratory organs, which they cannot observe directly, in a three-dimensional manner and from different angles (Rini et al., 2022). Students can better understand information through authentic representations of abstract objects that cannot always be observed in their original everyday form. Furthermore, the effectiveness of AR in improving the understanding of the diaphragm's movement during inspiration is a significant discovery. This specificity attests to the ability of AR to clarify complex anatomical concepts and help learners grasp subtle and essential details. Most studies indicate that the use of AR is beneficial for developing a better spatial perception of anatomy (Ferrer-Torregrosa et al., 2016; Manrique-Juan et al., 2017).

This learning experience allowed us to note that the use of AR enables students to manipulate virtual objects and observe phenomena that are difficult to see in our natural environment. Indeed, primary school students' imagination and spatial visualization abilities are generally very limited (Cai et al., 2014). The AR application was developed using 3D objects as virtual models to represent the learning content, particularly the respiratory system.

The AR 3D object functionality makes the learning process more interactive and exciting. AR is a very promising technology that could transform scientific visualization (Mathur et al., 2023). AR makes it possible to visualize the information and show the 3D models, so students can receive them ready to be perceived and they will not waste time and cognitive effort to interpret them (Midak et al., 2020). Three D virtual objects can be viewed, observed, and manipulated from different perspectives to improve student understanding (Safadel & White, 2018).

The use of an AR application increases the motivation of learners (Delello, 2014; Matcha & Rambli, 2013), allowing them to actively participate in the course (Bai et al., 2013; Cai et al., 2014), to interact with the course content (Bai et al., 2013; Yusoff & Dahlan, 2013), and to be a practical and time-saving tool, which may have contributed to a positive impact on student performance. Although the quantitative results showed a high level of correct responses, the lack of significant differentiation between the two groups indicates that non-technological factors play a crucial role in transforming conceptions. It also demonstrates that teaching must be viewed holistically and supported by a combination of educational approaches to ensure the deep assimilation of knowledge. Besides the significant progress observed, it is important to acknowledge that this study has limitations. The sample used was quite small with only 12 students in each group, which limits the generalization of the results to a larger population. Also, the duration of the experiment was relatively short, which could limit the impact of the application of AR on the evolution of learners' conceptions.

CONCLUSIONS

The objective of this study was to explore the impact of AR on the evolution of learners' conceptions concerning human respiration. After being exposed to AR, the statistical tests indicated a significant evolution in learners' conceptions for most of the questions proposed, notably those addressing the path of the inspired air and the role of breathing.

Indeed, the high proportion of physicochemical conceptions in the EG may indicate a better understanding of the scientific and chemical aspects related to respiration. In fact, interaction with interactive three-dimensional models, real-time visualization of the process of breathing, and the ability to virtually explore the inside of the human body all promoted better assimilation of knowledge.

However, the lack of significant differences between the two groups particularly regarding the question relating to the meaning of breathing indicates that non-technological factors play a crucial role in transforming conceptions. The contributions of this research are multifarious. First of all, the study highlights the effectiveness of AR as a teaching tool for complex scientific concepts, most particularly in biology. It also shows that this technology can help reduce the gap between theoretical abstraction and physical reality, which is essential for understanding biological processes. In light of our results, we make several recommendations for teachers of life and earth sciences. It is advisable to integrate more elements of AR in lessons on digestion and to explore other topics in biology where this technology could be beneficial.

By means of AR, teachers would have the opportunity to establish more immersive and interactive learning environments, making it possible for students to virtually manipulate complex objects and actively observe abstract phenomena. This can promote a deeper understanding and better integration of anatomical and physiological concepts. It is also important to train teachers in the use of AR and provide them with resources adapted to teaching methods.

It would be equally interesting to conduct comparative studies to evaluate the effectiveness of AR compared to other innovative learning methods, such as educational games or educational videos.

Such a comparison will provide a better understanding of the specific advantages and limitations of each approach, in addition to their impact on student learning. Furthermore, it would be useful to focus on the factors that might contribute to the effectiveness of the AR application in the educational context and take into consideration the particularities of the audiences and the learning contexts.

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Ethics declaration: ***Informed Consent:*** All participants involved in this study provided informed consent prior to their participation. They were fully informed about the nature of the research, its purpose, and their right to withdraw at any time. ***Confidentiality:*** The authors ensured the confidentiality of all participant's data. Personal identifiers have been removed, and data were stored securely to protect participants' privacy. ***Compliance with Regulations:*** This research was conducted in accordance with all relevant laws and institutional guidelines. The study was conducted after approval from the regional commission of primary education in the Manouba-Tunisia under reference 2021/12. The authors also obtained consent from the parents of the students. The students were informed about the research and their role in this scientific work. Both classes (experimental group and control group) were taught by the same regular teacher to avoid altering the educational context and creating new variables that could influence the research results. The authors also anonymized the names of the students to maintain the moral and physical integrity of all students participating in the study.

Declaration of interest: The authors declare no conflicts of interest related to this study. Any potential conflicts have been disclosed and managed appropriately.

Availability of data and materials: All data generated or analyzed during this study are available for sharing when appropriate request is directed to corresponding author.

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