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Dissecting human anatomy learning process through anatomical education with augmented reality: *AEducAR 2.0*, an updated interdisciplinary study

Irene Neri[1] | Laura Cercenelli[2] | Massimo Marcuccio[3] | Simone Lodi[1] | Foteini-Dionysia Koufi[1] | Antonietta Fazio[1] | Maria Vittoria Marvi[1] | Emanuela Marcelli[2] | Anna Maria Billi[1] | Alessandra Ruggeri[1] | Achille Tarsitano[4,5] | Lucia Manzoli[1] | Giovanni Badiali[4,5] | Stefano Ratti[1]

[1]Cellular Signalling Laboratory, Anatomy Center, Department of Biomedical and Neuromotor Sciences (DIBINEM), University of Bologna, Bologna, Italy

[2]eDIMES Lab-Laboratory of Bioengineering, Department of Medical and Surgical Sciences (DIMEC), University of Bologna, Bologna, Italy

[3]Department of Educational Science "Giovanni Maria Bertin", University of Bologna, Bologna, Italy

[4]Department of Biomedical and Neuromotor Sciences (DIBINEM), University of Bologna, Bologna, Italy

[5]Department of Maxillo-Facial Surgery, IRCCS Azienda Ospedaliero-Universitaria di Bologna, Bologna, Italy

Correspondence
Giovanni Badiali, Department of Biomedical and Neuromotor Sciences (DIBINEM), University of Bologna, 40126 Bologna, Italy.
Email: giovanni.badiali@unibo.it

Stefano Ratti, Cellular Signalling Laboratory, Anatomy Center, Department of Biomedical and Neuromotor Sciences (DIBINEM), University of Bologna, 40126 Bologna, Italy.
Email: stefano.ratti@unibo.it

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Abstract

Anatomical education is pivotal for medical students, and innovative technologies like augmented reality (AR) are transforming the field. This study aimed to enhance the interactive features of the *AEducAR* prototype, an AR tool developed by the University of Bologna, and explore its impact on human anatomy learning process in 130 second-year medical students at the International School of Medicine and Surgery of the University of Bologna. An interdisciplinary team of anatomists, maxillofacial surgeons, biomedical engineers, and educational scientists collaborated to ensure a comprehensive understanding of the study's objectives. Students used the updated version of *AEducAR*, named *AEducAR 2.0*, to study three anatomical topics, specifically the orbit zone, facial bones, and mimic muscles. *AEducAR 2.0* offered two learning activities: one explorative and one interactive. Following each activity, students took a test to assess learning outcomes. Students also completed an anonymous questionnaire to provide background information and offer their perceptions of the activity. Additionally, 10 students participated in interviews for further insights. The results demonstrated that *AEducAR 2.0* effectively facilitated learning and students' engagement. Students totalized high scores in both quizzes and declared to have appreciated the interactive features that were implemented. Moreover, interviews shed light on the interesting topic of blended learning. In particular, the present study suggests that incorporating AR into medical education alongside traditional methods might prove advantageous for students' academic and future professional endeavors. In this light, this study contributes to the growing research emphasizing the potential role of AR in shaping the future of medical education.

KEYWORDS
3D printing, anatomical education, augmented reality, blended learning, human anatomy, learning process, medical students

Irene Neri and Laura Cercenelli equally contributed as first authors to this work.

Giovanni Badiali and Stefano Ratti equally contributed as last authors to this work.

INTRODUCTION

Acquiring extensive skills in human anatomy is a central feature of medical education. Indeed, it is recognized that having a deep knowledge of the different anatomical regions and their connections and especially gaining experience on the anatomical/pathological variants that exist in the human body grant future physicians better surgical and clinical performances once they start their professional career.[1–3] Therefore, developing an effective method for teaching human anatomy to medical students has been a long-time goal. In recent years, gross anatomy education has been experiencing a paradigm shift: the advancement of novel technological tools allows students to explore anatomical structures in a three-dimensional (3D) way, providing immersive and interactive learning experiences that are difficult to replicate in traditional classroom settings and therefore introducing a new method to approach human anatomy.[4,5] Augmented reality (AR) is a technology that allows the fusion of digital content into the real world. When applied to the anatomical/medical field, AR enables the user to interact and deeply engage with the different anatomical structures by overlaying new information on top of 3D, tangible anatomical models.[6–8] Moreover, 3D printing is becoming a widely used technology to produce patient-specific simulators for medical education and surgical training.[9–12] AR potential in human anatomy teaching is becoming increasingly evident. Indeed, AR is proving to be an effective tool to place side by side human body dissection, which remains the gold standard for gross anatomy teaching.[13] Clearly, human body dissection can and should not be entirely replaced by technology because it not only permits a direct approach to the human body, but it also allows medical students to experience their very first patient–physician relationship.[14,15] However, the implementation of AR in human anatomy teaching can be a helpful strategy to overcome some of the difficulties related to human body dissection, such as the scarcity of bodies received through body donation programs, the difficulty of accessing a clear, separate view of the different anatomical structures, and, last but not least, the problems that can derive from an eventual emotional involvement.[16,17] Indeed, the medical community is pushing forward the implementation of new technologies like AR in medical education.[18] Many studies have been performed to test the efficacy of AR in teaching human anatomy, demonstrating its overall potential.[19,20] It has been widely demonstrated that AR is able to enhance the educational experience of medical students by providing an immersive and interactive learning experience.[21–24] For example, a study performed on first-year medical students outlined the potential of AR systems for increasing students' 3D understanding of topographic anatomy.[25] Another interesting study reported how an AR system (REFLECT), that superimposes anatomical visualizations over user's body, was able to enhance learning.[26] Recently, a study tested an innovative AR-based tool called *AEducAR* (anatomical education in augmented reality) consisting of virtual information projected with AR on tangible 3D-printed anatomical models.[27] The learning experience with the *AEducAR* prototype revealed that it represents not only a valid educational tool that provides an anatomical knowledge acquisition comparable to traditional textbooks, but also enhances medical students' learning motivation and enthusiasm. However, no study has so far investigated the educational effects of AR applied to human anatomy learning. Indeed, by considering this aspect, it is possible to better understand the quality of the learning experience, its impact on students, and its alignment with broader educational goals. Considering that human anatomy education represents the foundation of medical knowledge, it is reasonable to affirm that studying this aspect applied to human anatomy learning can serve as a model for evaluating the potential impact of AR on general medical education. When it comes to the learning process, pedagogical aspects such as students' background, physical environment, and learning preferences should be taken into consideration. In particular, exploring the pedagogical aspects of AR in medical education could help to better understand the learning process associated with the use of this technology, and enable medical educators to make informed decisions about its integration into medical education, which could ultimately lead to better outcomes.[28] Under this light, the present study was conceived as an interdisciplinary approach to investigate the basic pedagogical aspects related to the use of AR in human anatomy learning. In particular, this study presents *AEducAR 2.0*, an optimized version of the *AEducAR* tool implemented with more interactive aspects, which was tested by a classroom of medical students. In *AEducAR 2.0*, the focus was placed on three aspects: (1) the assessment of the learning outcome, (2) the exploration of students' background, and (3) the assessment of students' perception of the *AEducAR 2.0* experience and AR in general. The learning outcome was evaluated with specifically designed quizzes that were accessible at the end of each activity, whereas the exploration of student's background and the assessment of their perception of the experience were performed through specifically designed questions contained in a questionnaire that participants filled in at the end of the *AEducAR 2.0* experience. Moreover, to delve deeper into students' background, specifically designed interviews were given to willing participants. In this way, the present *AEducAR 2.0* study differentiates from its predecessor, which did not involve interactive parts and focused exclusively on evaluating learning outcomes and participants' satisfaction. The addition of interactive moments, allowing students to engage in practical actions, and especially the focus given to students' backgrounds represent the novelty of the *AEducAR 2.0* study. Indeed, the aim of the present study has been both to explore the effects of interactive features on students' learning outcomes and activity perceptions and to investigate if students' backgrounds could have an impact on their performance and activity evaluation.

MATERIALS AND METHODS

AEducAR 2.0 tool

The development phase of the *AEducAR* tool has been extensively described in a previous study.[27] In brief, the *AEducAR* tool is based on the projection of virtual information with AR on 3D-printed skulls. The decision to produce and use 3D-printed models and not real skulls was based on two main reasons: (1) 3D-printed models are reproducible and durable, on the contrary, real skulls are limited in quantity and are subject to wear and tear; and (2) 3D-printed models eliminate the ethical concerns that regard the use of human material. In this second version (*AEducAR 2.0*), the educational tool was optimized and further developed to add the following major improvements:

- Implementation of a "guided-learning" approach, by introducing intuitive navigation buttons (next/back) and dialog boxes with messages to guide the learner in the various steps of the AR-based experience;
- Implementation of a virtual "testing phase" at the end of each AR-based learning experience; and
- Implementation of an interactive activity ("Place & Check" app, detailed below).

The new tool was structured in two parts to be experienced sequentially by the learner: (1) "Track & Explore" app; and (2) "Place & Check" app, which are detailed below. Both parts were built as separate, independent Android apps for mobile devices, to be used on a tablet device (Samsung Galaxy Table S5E). Of note, it is possible to deploy the two *AEducAR 2.0* apps on any Android device.

Track & Explore app

As preliminary step, the *AEducAR* target-tracking system can recognize the 3D-printed skull through the tablet's camera (via a markerless Model Target Tracking function provided by Vuforia Engine software), and the digital contents are shown on the tablet's screen, superimposed on the 3D-printed skull, in the appropriate location (Figure 1). Once the skull shape recognition is achieved, the virtual-to-real skull model registration can be checked at any time by clicking the *Show/Hide Target* button. The app starts with an explorative learning phase of the anatomical regions of interest. The exploration is subdivided into three macro-topics: "ocular nerves & muscles," "ocular movements," and "facial bones" (Figure 1). To facilitate the learning process, for the "ocular nerves & muscles" topic, the virtual content is organized according to a tree structure in which each nerve is the "parent" of all the muscles innervated by it (Figure 1A). Similarly, at each AR-displayed ocular movement, the corresponding ocular muscle involved in the movement is displayed on the screen with the associated name (Figure 1B). Details of the implemented learning content are reported in Table 1 for the three macro-topics. Of note, a selection of the content has been applied based on: (1) technical reasons: the chosen anatomical structures could be fully appreciated using the *AEducAR* tool; and (2) didactic relevance: the chosen anatomical structures were the ones that more frequently captured the attention, basing on the experience made during anatomy classes and laboratories with the students of the previous years.

As in the previous version of *AEducAR* tool, the 3D models of eye anatomy (eyeball, pupil, orbital muscles, and optical nerve) were selected from the Unity Asset Store (https://assetstore.unity.com/packages/3d/characters/eye-anatomy-animated-100727, accessed on December 20, 2021), while facial bony structures were obtained from real patient imaging segmentation and further mesh refinement using MeshMixer software (Autodesk Inc., San Rafael, CA, USA). Interactable check boxes were added to turn on/off the rendering of each virtual anatomical structure. Each check box is associated with the name of the anatomical structure which is turned on/off. After completing the explorative phase, the tool guides the learner to proceed with the testing phase to evaluate the acquired knowledge on the covered topics. This phase consists of five consecutive multiple-choice questions (Quiz 1) in which the student is asked to recognize the anatomical structure displayed on the 3D-printed skull via AR (Figure 2). The questions included in Quiz 1 and each question's correct answer are reported in Supplementary Material S1.

Place & Check app

This second app is focused on facial mimic muscles. Similar to the "Track & Explore" app, a preliminary AR-based explorative phase, showing the location of the different muscles on the 3D-printed skull, is provided by the tool (Figure 3A). The detailed implemented

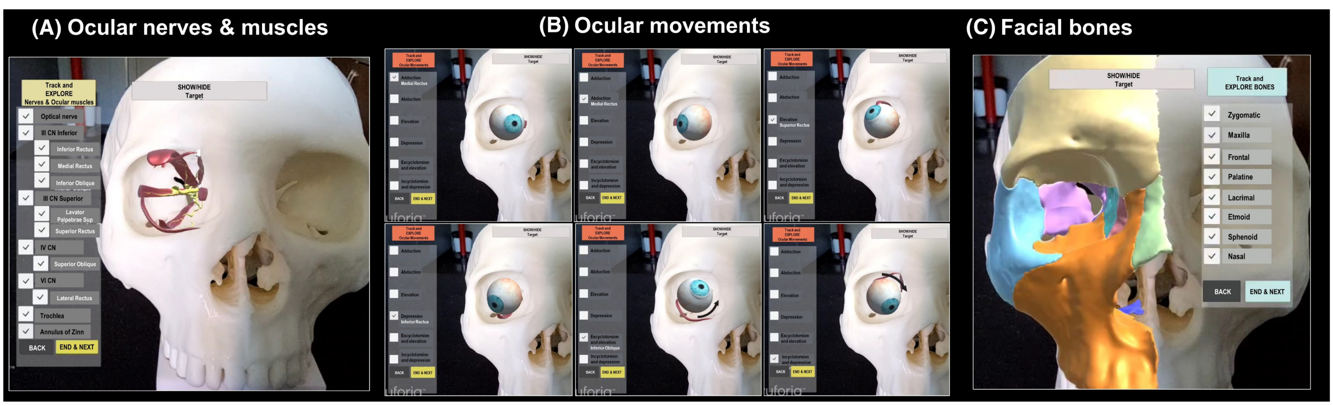

FIGURE 1 Representative images of the "Track & Explore" app for the implemented three macro-topics: (A) ocular nerves & muscles; (B) ocular movements; and (C) facial bones.

TABLE 1 Track & Explore app: anatomical parts selected as virtual content for the AR learning experience.

Macrotopics	Virtual content (anatomical part)
Ocular nerve and muscles	Optical nerve Inferior branch of oculomotor nerve • Inferior rectus • Medial rectus • Inferior oblique Superior branch of oculomotor nerve • Levator palpabrae superioris • Superior rectus Cranial nerve • Superior oblique Abducens nerve • Lateral rectus Trochlea Annulus of Zinn
Ocular movements	Adduction (medial rectus) Abduction (lateral rectus) Elevation (superior rectus) Depression (inferior rectus) Excyclotorsion and elevation (inferior oblique) Incyclotorsion and depression (superior oblique)
Facial bones	Zygomatic Maxilla Frontal Palatine Lacrimal Ethmoid Sphenoid Nasal

learning content for this app is reported in Table 2. Also in this case, the 3D models of the facial mimic muscles were selected from the Unity Asset Store (https://assetstore.unity.com/packages/3d/characters/animated-facial-muscles-ar-vr-153185#description, accessed on March 10, 2022). Then, the students are guided to a "hands-on" learning phase in which they are asked to place physical replicas of the facial muscles directly on the 3D-printed skull and then check their position via AR (Figure 3B). The physical replicas of the facial mimic muscles were produced by material jetting 3D-printing technology, using the J720 Dental 3D printer (Stratasys Ltd., Eden Prairie, MN). This printing process allows to printing of multi-material and multi-color parts, including gradients and graphic textures, with high resolution and surface finish. Each printed part was identified with a label, from A to H (Table 2), and provided with an adhesive tape for their attachment on the 3D-printed skull.

After placement, the positioning of each printed muscle can be checked with the AR software by clicking the *Check* button. In this phase, thanks to the target-tracking system, the digital image of the muscle appears in its correct position on the skull. In this way, the student can check if the chosen position for the muscle was right or not. Moreover, in the verification phase, the student is also given information on the muscle functionality (see the informative box appearing under the *Check* button, Figure 3B). Finally, also for this app, the tool guides the learner to proceed with the testing phase, consisting of three consecutive multiple-choice questions (Quiz 2) in which the student is asked to recognize the virtual muscle displayed on the 3D-printed skull via AR (Figure 4). The questions included in Quiz 2 and each question's correct answer are reported in Supplementary Material S1.

Overall study design

During the second semester of 2021/2022 and 2022/2023 academic years, 130 second-year students at the Bologna International School of Medicine and Surgery (BOMS) voluntarily enrolled in this study. The students were informed of the possibility of participating in this study during the human anatomy course. Students were introduced to the activities right before starting them and did not know what the examined topics would be. For this second *AEducAR* tool trial, the anatomical region of the splanchnocranium was chosen. In particular, the focus was placed on the orbit zone (maintaining the approach chosen for the first *AEducAR* tool trial[27]) and on the facial bones and mimic muscles. Of note, the chosen topics were not covered during the anatomy classes attended by the students until that moment. After each of the two parts of the *AEducAR 2.0* laboratory, students were asked to answer a quiz evaluating the knowledge acquisition. Both quizzes were designed to assess the basic level of the cognitive process. In particular, according to the 2001 revision of Bloom's taxonomy,[29] the quizzes were designed to evaluate factual knowledge and memory. At the end of the activities, the students were asked to answer an anonymous questionnaire to assess their perception of the experience. Moreover, 10 students accepted to be interviewed to further investigate their perception of the *AEducAR* 2.0 activity. Of note, the enrolled students were organized into groups of four people. Each person had a separate workstation consisting of a 3D-printed skull, 3D-printed models of the mimic muscles, a tablet, and a smart stylus for interaction with the tablet screen. Before the start of each AR learning experience, the tablet screen recording was activated to be able to collect the quizzes' scores of the virtual testing phases.

AEducAR 2.0 workshop description

The activity was structured in two separate moments:

1. Phase 1: learning experience with "Track & Explore" app. This phase featured a 3D-printed skull and the AR software. The students were able to appreciate and study different anatomical structures of the splanchnocranium. As described in the previous section, this explorative phase for the implemented three macro-topics ("ocular nerves & muscles," "ocular movements," and "facial bones") was guided by checkboxes that, when clicked on, showed the different structures. The students were then subjected to Quiz 1 session to evaluate the acquired knowledge on the covered topics. An example of the "Track

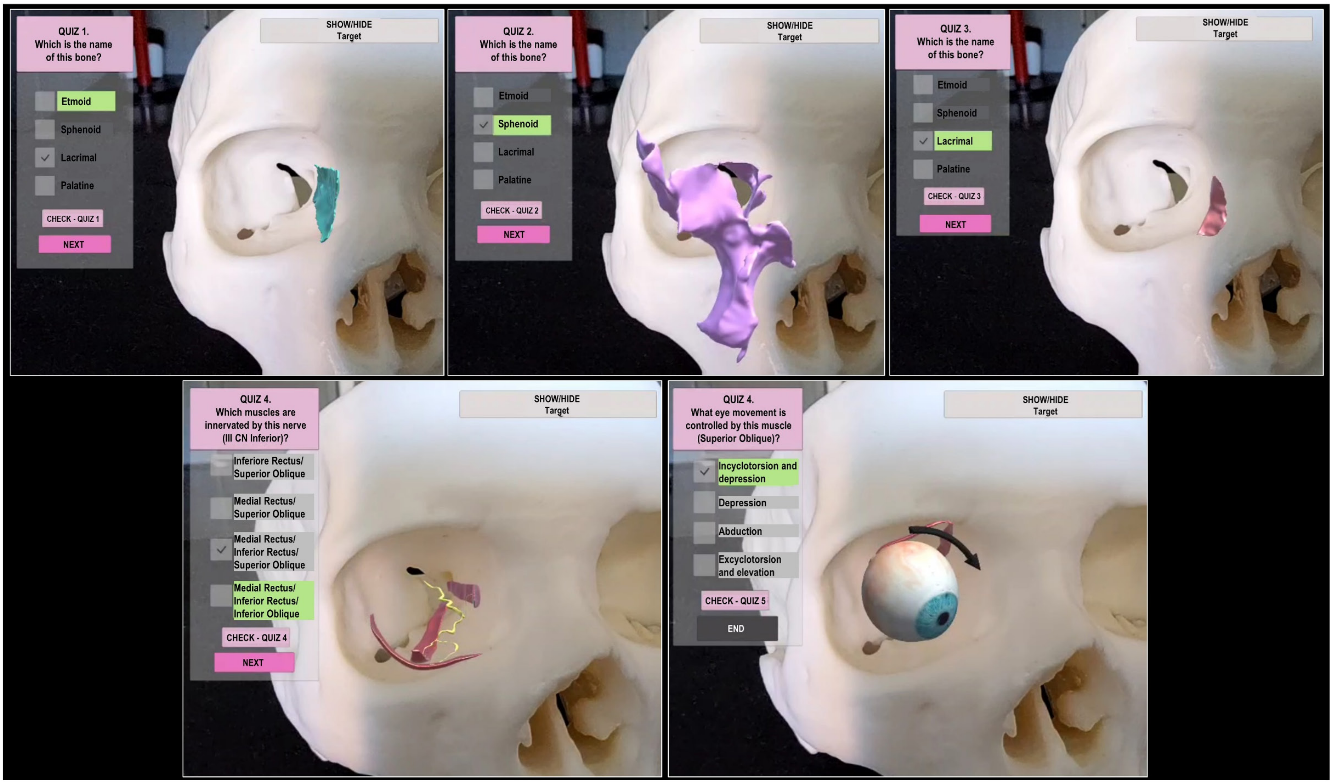

FIGURE 2 Representative images of the implemented multiple-choice questions for the "Track & Explore app" (Quiz 1 session). By pressing *Check* button, the correct answer is displayed (highlighted in green).

& Explore" phase is reported as video extracts of the screen recordings in Video S1.

2. Phase 2: learning experience with "Place & Check" app. This part featured a 3D-printed skull, 3D-printed models of the mimic muscles named from A to H (Table 2), and the AR software. As described in the previous section, the activity was subdivided into two phases: an explorative part similar to the one in the "Track and Explore" part showing the location of the different muscles on the 3D-printed skull via AR and an interactive part in which the students were asked to place the 3D-printed muscles directly on the 3D-printed skull and then check their position via AR. Finally, the students were subjected to Quiz 2 session. An example of the "Place & Check" phase is reported as video extracts of the screen recordings in Video S2.

Courses of medicine and surgery at the University of Bologna

The University of Bologna offers four Medicine and Surgery courses: three Italian courses (Bologna, Ravenna, and Forlì campus), with lessons held in Italian, and one International course (Bologna campus), with lessons held entirely in English. The International course has been active since 2017 and its primary aim is to attract a diverse and global student body, creating also additional opportunities for exchange programs and research collaborations. Indeed, more places are reserved for non-European students in the International course compared to the Italian course (e.g., 20 of 117 places vs. 10 of 374 places for Bologna campus). The Italian and the International courses are both structured on a 6-year program, granting comprehensive theoretical and practical training, and allowing students to identify the future specialization area that aligns best with their abilities and interests. Moreover, both courses offer a robust and up-to-date curriculum, structured with classroom lectures, elective courses, and laboratories. For both the Italian and International courses, the 6 years of Medical School are structured in the following way:

- The first year is dedicated to the fundamental concepts of the medical profession, acquiring primary knowledge of biochemistry, physics, tissue, and molecular organization of organs.
- The second year focuses on the morphology and normal functioning of organs through the integration of anatomy, physiology, and biochemistry.
- From the third to the fifth year, the emphasis shifts to acquiring clinical skills through integrated courses in diagnostics, clinical practice, surgery, pathological anatomy, and pharmacology.
- The sixth year is dedicated to the development of clinical reasoning skills.

Unlike the Italian course, the International curriculum is organized by systems and apparatuses rather than by discipline (e.g.,

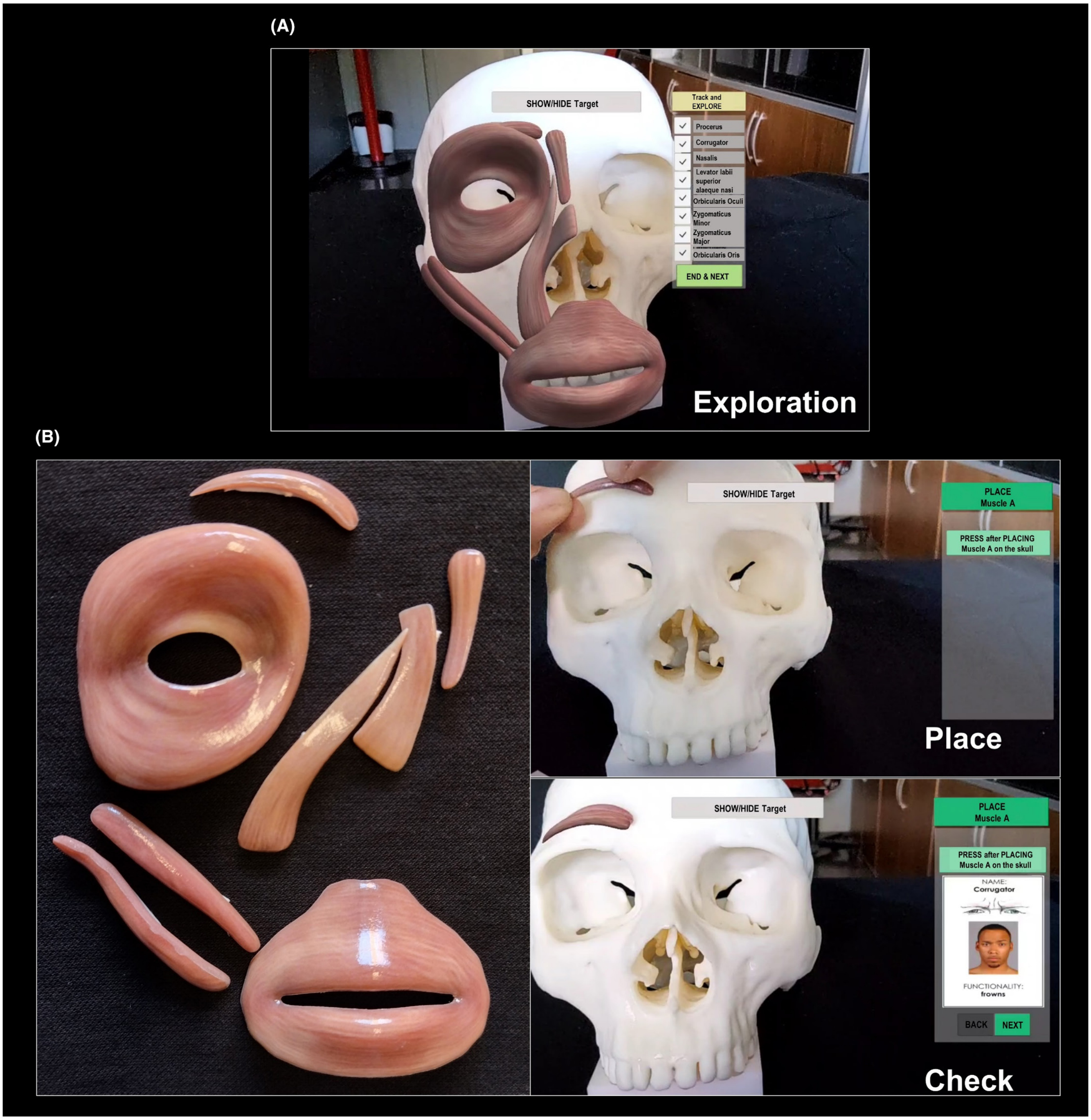

FIGURE 3 Representative images of the "Place & Check" app for the AR-guided learning experience on facial mimic muscles: (A) the preliminary explorative phase; and (B) the "hands-on" learning phase requiring to place 3D-printed muscles on the skull phantom and then check them in AR view.

the Integrated Course "Cardiovascular and respiratory systems" includes the anatomy, the physiology, and the semeiotics courses) and includes mandatory practical activities (including didactic laboratories) starting from the first year.

For the present study, the International Course of Medicine and Surgery has been chosen. The reason behind this choice relies on the will to test the *AEducAR 2.0* tool on an international pool of students with eventual differences derived from students' previous school experiences and therefore have a heterogeneous group of participants.

Human anatomy course description and student demographics

The gross anatomy experience at the Medicine and Surgery course of the University of Bologna takes place during the second year of 6 total years of Medical School. The curriculum is presented in five integrated modules: (1) cardiovascular and respiratory systems (2) musculoskeletal system and movement (3) gastrointestinal system, nutrition, and metabolism, (4) genito-urinary and reproductive systems, and (5) nervous system and sensory organs. These modules are integrated with the physiology and semiotics course. Students spend 120 hours following anatomy theoretical classes, 34 hours participating in didactic laboratories with anatomical models, and 34 hours attending dissection laboratories on body donors. During the dissection classes, the University of Bologna adopted near-peer teaching (NPT) approach with senior medical students teaching and assisting junior students. The NPT program allows junior students to be introduced to human body dissection by their senior colleagues creating a comfortable and encouraging educational environment. Furthermore, the NPT approach allows the management of such a large number of students organized into small groups, guaranteeing high-quality anatomical education.[30] At the end of each integrated module, students are tested through oral examinations. Students involved in *AEducAR 2.0* attended the experience during the second semester in 2021 and 2022. Students' demographic data are shown in Table 3. Gender, age, and nationality frequency are reported in Supplementary Material S4.

TABLE 2 "Place & Check" app: facial mimic muscles selected for the AR learning experience, and the corresponding label for each 3D-printed part.

Topic	Virtual content (anatomical part)	Label on the 3D-printed part
Facial mimic muscles	Procerus	A
	Corrugator	B
	Nasalis and Levator	C
	Labii superioris alaeque nasi	D
	Orbicularis oculi	E
	Zygomaticus minor	F
	Zygomaticus major	G
	Orbicularis oris	H

Questionnaire design and analysis

An anonymous "feedback" questionnaire was administered to the participants at the end of the workshop. The questionnaire consisted of a first part collecting general demographic information and a second part, exploring students' background and activity perception, that included a total of 11 questions, hereby referred to as Q1–Q11, divided into one binary question (Q1), one multiple choice question (Q2), seven Likert 5-point scale questions (Q3-Q7 and Q9–Q10), and two open-answer questions (Q8 and Q11). The meaning of each point of the Likert scale (1 = Strongly disagree, 2 = Disagree, 3 = Neither agree nor disagree, 4 = Agree, and 5 = Strongly agree) was explained to the students at the moment the questionnaire was handed to them. Regarding student's background information, the focus was placed on two aspects: whether the student had previous experience with AR and the study method that the student used to prepare for previous anatomy exams. This choice was made because both the impact of past experience and study method on motivation and performance have been documented.[31–33] The questionnaire is reported in Supplementary Material S2. SPSS statistical package, version 25.0 (IBM Corp., Armonk, NY, USA), was used to statistically analyze the collected data and the two multiple-choice quiz results. One-way ANOVA, linear regression analysis, and Pearson correlation coefficient were performed. Only *p*-values <0.05 were considered statistically significant. Moreover, frequency was calculated for every answer. Finally, multiple-choice quiz results were also reported as mean values and standard deviation. GraphPad Prism, version 8.0 (GraphPad Software, Boston, MA, USA), was used to graphically visualize the quiz results and the questionnaire's answers. The internal consistency of the emerged themes in four Likert statements (Q6, Q7, Q9, and Q10) was established by calculating Cronbach's alpha (α coefficient). The α coefficient of 0.60 and above was considered as acceptable internal reliability. To be eligible for statistical analysis,

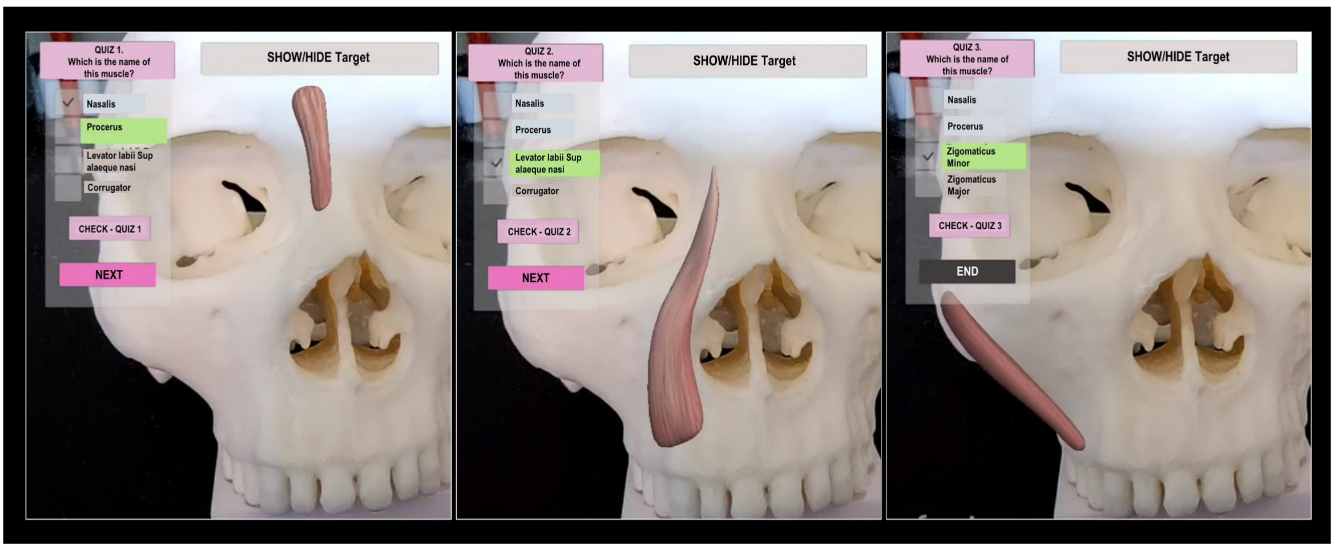

FIGURE 4 Representative images of the implemented multiple-choice questions for the "Place & Check" app (Quiz 2 session). By pressing *Check* button, the correct answer is displayed (highlighted in green).

TABLE 3 Demographic information of the students at the University of Bologna participating in the workshop.

Demographics	Participants
Gender	
Female	73
Male	57
Other	0
Age	
19–23	110
24–28	13
Other	4
Not specified	3
Nationality	
Italian	79
Other	47
Not specified	4
	Total participants = 130

the gender, nationality, and specific answers (Q1, Q2, and Q8) had to be codified. Supplementary Material S3 reports a table with the codebooks of the questions involved. Additionally, the multiple-choice quiz results were normalized using the following formula:

$$\frac{\text{Achieved score} - \text{Minimum score}}{\text{Maximum score} - \text{Minimum score}}$$

Missing questions were reported as off-scale values (−1) and therefore were not included in the calculations. Of note, Q11 was not included in the statistical analysis due to the small percentage of answers received (less than half of the participants) but was qualitatively described to investigate students' sentiment about the activity. Authors employed thematic analysis to understand and interpret data.[34] Using the Nvivo12 software (QSR International, Melbourne, Australia), each characteristic of a text was coded and answers were assigned to four categories (1 = very negative, 2 = moderately negative, 3 = moderately positive, and 4 = very positive) through a process of constant comparison.[35] Finally, a word cloud reporting the 100 most frequent words was created. Words were stemmed in common groups to normalize the analysis, according to natural language processing.[36]

Interview design and analysis

Upon invitation, 10 students accepted to be interviewed to further investigate their perception of the activity. The interviews were performed right after the anonymous questionnaire administration and lasted approximately 15 minutes each. Given the exploratory nature of this stage of the research, the interviews were conducted using a semi-structured approach, favoring a non-directive approach. With the students' consent, the interviews were audio-recorded. The audio recordings were transcribed *verbatim*, and the transcriptions underwent qualitative content analysis divided into two stages:

1. a comprehensive reading of the interviews to identify internal coherence in the development of the content;
2. coding of the text using identified codes, integrating a deductive and inductive approach.

The findings were presented by reorganizing fragments of the transcriptions into a coherent text around the main emerging themes, aiming to highlight similarities and differences among the students' statements. In this way, the data could be interpreted as an initial conceptual/cognitive map of the main themes related to the use of the AR tool *AEducAR 2.0* in the field of anatomical education.

The *AEducAR 2.0* study, including neither personal nor clinical data, received approval from the University of Bologna School of Medicine bioethical board (protocol number 0122477, 05.23.22). The study was conducted in agreement with EU-GDPR and the Helsinki Declaration. All data were collected anonymously without any possibility to identify the students. Students' participation was voluntary and without any compensation (Helsinki Declaration, art. 25). Students were given full explanation of the aims and contents of the anonymous questionnaires (Helsinki Declaration, art. 26).

RESULTS

Quizzes' results and analysis

Of 130 participants, it was possible to collect quizzes' results from 109 students for Quiz 1 and 107 students for Quiz 2. Indeed, 21 and 23 screen recordings resulted to be partially corrupted for the "Track & Explore" and the "Place & Check," respectively, and therefore were excluded from the analysis. The cause of this problem has been linked to technical problems leading to issues with the tablets' storage. Overall, students were able to totalize a high score in both the "Track & Explore" Quiz 1 and the "Place & Check" Quiz 2 (Figure 5).

To display the frequency distribution of the results of Quiz 1 and Quiz 2, a cross-tabulation was created using the normalized scores (Figure 6). The cross-tabulation showed that most students (92 of 130) are placed in the bottom-right part of the table, indicating a globally satisfactory performance in both quizzes. On the other hand, a small minority of students totalized a medium–low/low score (15 of 130). Of note, due to the technical problems previously explained, 27 cases were excluded from the cross-tabulation (cases in which it was not possible to collect the screen recording for one or both quizzes).

Questionnaires' results

All the 130 participants submitted the anonymous questionnaire. The frequency tables calculated for the analyzed questions are reported in Supplementary Material S4. Regarding the general demographic information, 56% of participants identified themselves as female, while 44% identified themselves as male. Moreover, 61%

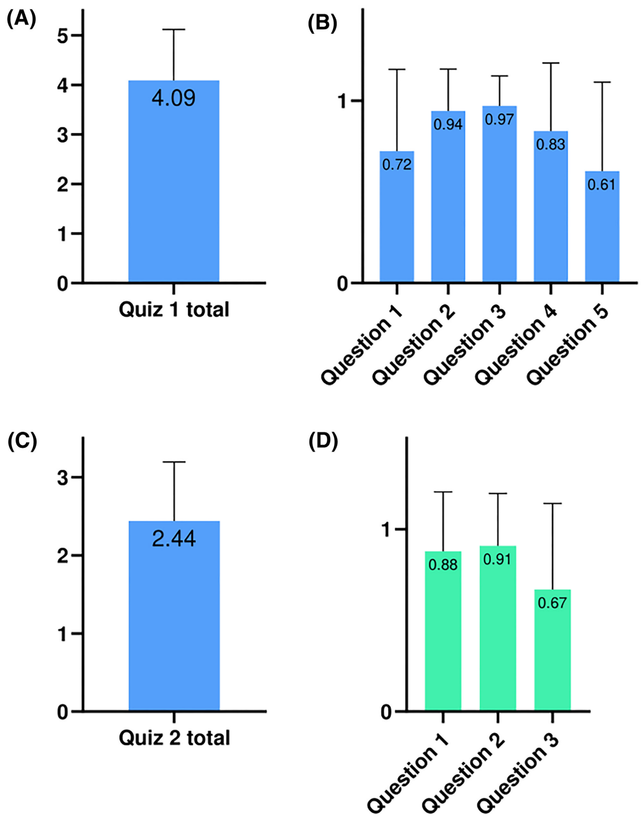

FIGURE 5 Multiple-choice quizzes' results. (A) Mean score for Quiz 1 (109 answers examined). (B) Mean score for Quiz 1 divided per question (5 total questions/1 point per question). (C) Mean score for Quiz 2 (107 answers examined). (D) Mean score for Quiz 2 divided per question (3 total questions/1 point per question). Error bars indicate the standard deviations.

declared to be Italian, while 36% declared to come from another country (3% of the participants did not declare their nationality). Finally, the mean age of the participants was 21.8 years. Figure 7 recapitulates the answers' frequencies for Q1, Q2, and the seven 5-point Likert-scale questions (Q3, Q4, Q5, Q6, Q7, Q9, and Q10). Q1 investigated whether students had prior experience with AR or not. Of 58 students, 25% declared they have had at least one other experience using AR, while 75% declared they never experienced AR before. Q2 investigated what study method the students were used to when preparing for the anatomy exams. 27% of the participants declared they prepared the anatomy exams using books, atlas, and notes, 15% declared they use web apps and notes, 52% declared they use everything listed in the prior two options, 2% declared they use books, atlas, notes, and other sources, 1% declared they use web apps, notes, and other sources, and, finally, 4% of the participants declared to use everything listed in the first two options plus other sources. The 5-point Likert scale questions had the goal to assess the students' perception of the *AEducAR 2.0* activity and of the utility that AR could have in medical education and professional practice. Overall, students positively evaluated both the *AEducAR 2.0* experience and the utility of AR for medical students and professionals. 80% of the students declared to have enjoyed the *AEducAR 2.0* experience (45% strongly agreed and 35% agreed). 92% of the students declared that they would like to have similar experiences in other anatomy modules (73% strongly agreed and 19% agreed). 94% of the students declared to think that AR technology could help them to better understand anatomical structures while preparing for the anatomy exams (79% strongly agreed and 15% agreed). 95% of the students declared to think that AR might improve their knowledge in their future medical career (65% strongly agreed and 30% agreed). 89% of the students declared to think that AR might improve their practical skills in their future medical career (59% strongly agreed and 30% agreed). 63% of the students declared to think that medical doctors will frequently use AR in their professional practice (24% strongly agreed and 39% agreed). Finally, 74% of the students declared to think that AR might facilitate the use of new devices directly on the patients in their future professional practice (34% strongly agreed and 40% agreed).

The two open-answer questions had the aim of collecting any suggestions on how the *AEducAR 2.0* could be improved (Q8) and general comments on the experience (Q11). The topics that emerged in Q8 answers are summarized in Figure 8A. Briefly, 35% of the participants suggested to improve the experience general procedure in a minor (13%) or major (22%) way. 4% of the participants suggested improving the "Track & Explore" part in a minor (3%) or major (1%) way. 2% of the participants suggested to improve the quiz structure in a major way. 7% of the participants suggested minor improvements in the AR tracking system. 7% of the participants suggested minor improvements in the graphics resolution of the digital content. 40% of the participants suggested to improve the prototype hardware/software in a minor (10%) or major (30%) way. Finally, 5% of the participants suggested a minor (1%) or major (4%) improvement of the 3D-printed models. Examples of how the answers were classified are provided in Supplementary Material S3. From the constructivist grounded qualitative analysis of Q11, positive sentiment toward the activity was the most frequently expressed (42% very positive and 43% moderately positive). Here is a sample of the open-ended answers falling into this category: "*It was the easiest and fastest anatomy teaching that I ever witnessed*." However, the analysis revealed that a small percentage of the responders expressed a negative sentiment (8% moderately negative and 7% very negative). Here is a sample of the open-ended answers falling into this category: "*In my opinion virtual reality experiments are more effective than augmented reality experiences if the only resource available is a tablet (take the complete anatomy app as an example) because it allows you to zoom in to see the precise anatomical relations between structures and move around the model to have different point of view*." Figure 8B reports the world cloud displaying words' frequencies in the answers to Q11.

Questionnaires' analysis

The first analyses that were performed on students' answers to the anonymous questionnaire were related to the concept of "didactic

(A) **Quiz 1 Score Normalized * Quiz 2 Score Normalized Crosstabulation**

Count

		Quiz 2 Score Normalized				
		,00	,33	,67	1,00	Total
Quiz 1 Score Normalized	,00	0	0	0	1	1
	,20	0	0	1	0	1
	,40	0	2	1	1	4
	,60	1	5	4	11	21
	,80	0	3	11	18	32
	1,00	0	0	15	29	44
Total		1	10	32	60	103

(B)

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Quiz 1 Score Normalized * Quiz 2 Score Normalized	103	79,2%	27	20,8%	130	100,0%

FIGURE 6 Cross-tabulation of the normalized results to Quiz 1 and Quiz 2. (A) Cross-tabulation shows the distribution of the totalized scores into low (orange), medium–low (yellow), medium–high (green), and high (blue). (B) Case processing summary. The excluded cases represent the students from whom it was not possible to collect the score totalized in one or both quizzes.

fit." "Didactic fit" refers to how well a particular educational material or method matches the learning style, background knowledge, and skills of the student.[37] In other words, it refers to the degree of alignment between a learning resource and the needs, goals, and abilities of the learner. "Didactic fit" is an important concept in education because it can impact students' engagement, motivation, and learning outcomes. Therefore, it was hypothesized that (1) the students' performances might have been influenced *a priori* by their eventual previous experiences with AR and/or by their preferential learning style and (2) the presence or absence of prior experience with AR might have influenced students' experience evaluation. To test hypothesis (1), one-way ANOVA was performed on the following variables:

- Quiz 1 score or Quiz 2 score and answers to Q1
- Quiz 1 score or Quiz 2 score and answers to Q2 (codified)

For every analyzed case, the results were not statistically significant (data reported in Supplementary Material S5). Therefore, the presence or absence of students' prior experience with AR and/or students' preferential learning styles were not correlated with the quizzes' outcome. To test hypothesis 2), one-way ANOVA was performed on answers to Q3 and answers to Q1. The result was not statistically significant (data reported in Supplementary Material S5). Therefore, having had or not prior experiences with AR was not correlated with students' enjoyment of the activity.

One-way ANOVA was also performed on Quiz 1 score, Quiz 2 score, or Q3, and gender or nationality. For every analyzed case, the results were not statistically significant (data reported in Supplementary Material S5). Therefore, neither gender nor nationality influenced the students' results for the quizzes.

To have additional information on the possibility of the quizzes' results or experience enjoyment being influenced by other variables, a linear regression analysis was performed. The only two variables that correlated were the two quizzes' scores (adjusted R square = 0.04), indicating that no external variables linked to students' background, their perception of the *AEducAR 2.0* activity, or their general perception of AR influenced the quizzes' totalized scores.

Finally, with the aim of investigating students' perception of AR potential in their future careers, Cronbach's alpha (α coefficient) was calculated among the answers to Q6, Q7, Q9, and Q10. The calculated α coefficient was 0.61, therefore the internal consistency of this group of answers to 5-point Likert scale questions was considered moderate (data reported in Supplementary Material S6). Among the four analyzed questions investigating students' perception of AR potential in their future careers, Q7, Q9, and Q10 focused on the practical aspect of this matter. Therefore, to investigate if the answers to these questions were significantly correlated, Pearson correlation coefficient was calculated. Indeed, the correlation among the answers to Q7, Q9, and Q10 was significant with a p-value <0.01 (Figure 9).

Interviews' analysis

The interviews allowed to cover and deepen several important aspects related to the use of the augmented reality device *AEducAR*

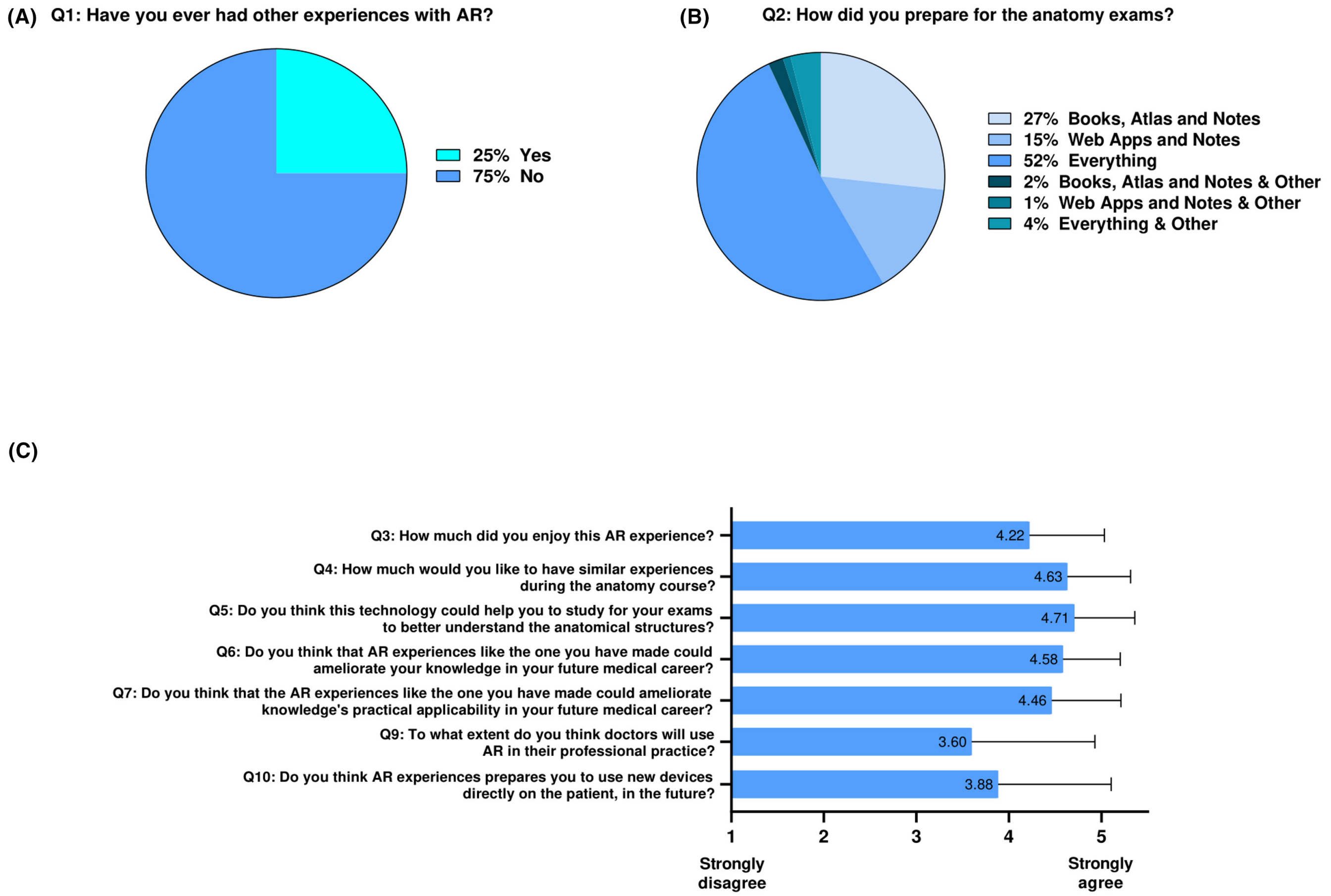

FIGURE 7 Anonymous questionnaires' results. (A) Q1 investigating the presence of any previous experience with AR; (B) Q2 investigating the students' usual study sources; and (C) mean values of 5-points Likert-scale questions investigating the students' perception of the activity; error bars indicate the standard deviations.

2.0 in the field of anatomical education. In particular, the aspects that the interviews aimed to further explore were the following:

1. The use of technology for the study of human anatomy.
2. *AEducAR 2.0's* positive and negative aspects.
3. The relationship between *AEducAR* and another teaching strategy: the dissection room.
4. The future of AR in the medical education and profession.

Regarding the first aspect, "the use of technology for the study of human anatomy," the interviews pointed out that many students had prior experience using technology for studying and found them useful. Students especially declared that on-line anatomy atlases were *"convenient, fast and intuitive,"* and helped *"understanding spatial relationships between organs."* However, students also recognized the complementary nature of traditional resources (e.g., *"Some [paper] atlases are very clear, clearer than the three-dimensional ones. However, sometimes we can't understand a concept well, can't fix it properly: that's when we use the [online] ones that are faster [...] compared to an atlas that you have to scroll through: in my opinion, they are complementary"*) and some students found computer tools complicated and preferred studying in a traditional manner. Regarding the second aspect, "*AEducAR* 2.0 positive and negative aspects," the interviews revealed that students strongly appreciated the support that the *AEducAR* tool can provide to study. In particular, features that were often mentioned to help the learning process were visualization and concretization (e.g., *"[The AEducAR tool is] very useful to allow you to personally engage with what you are studying... it allows you to see it in front of you"*). Indeed, the importance of the interactive component of the *AEducAR 2.0* experience, specifically the Place & Check activity, was the most appreciated and emphasized (e.g., *"Beautiful, [...] useful, especially [...] because [...] with passive methods, it is more difficult to study. If you also have to work with your hands [...] it helps you, the things remain more impressed in your memory"*; *"The added value was the practical aspect of actually attaching [the structures]. Because when I have to do something practical, I have to position them myself, then memorize and fix their location, order, and level. It was very, very, very motivating, much more stimulating because [...] it is a different kind of review. When I am studying from a book, I can cover the image or close the book and repeat. In this case, I am the one who has to position the structure, so it's about developing my knowledge and saying, 'Let's see if I've truly understood!'"*). For what concerns the third aspect, "the relationship between *AEducAR* and another teaching strategy: the dissection room," the interviews pointed out several elements. First, the students underlined that the dissection room experience is pivotal

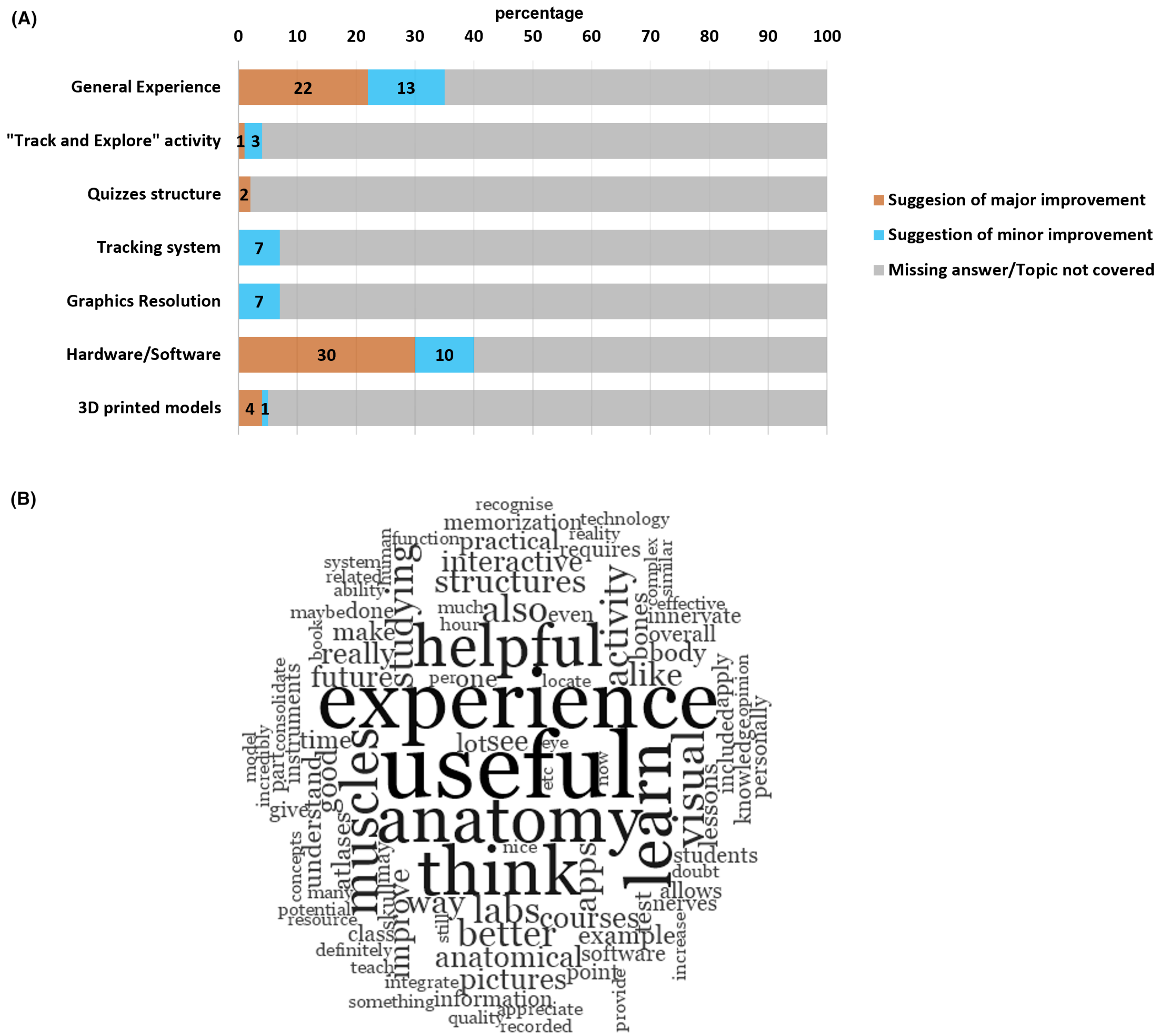

FIGURE 8 Open-answer questions results. (A) Students' suggestions on what to improve in the *AEducAR 2.0* experience emerged from the answers to Q8. Different bar colors represent the answer classification scale explained in Supplementary Material S2 (orange = 1, blue = 2, and gray = 0). (B) Word cloud graph of the most used words in students' answers to Q11. The word cloud displays the 100 more frequent words grouped using a stemming algorithm.

in the study of human anatomy and constitutes a *unicum* that could never be substituted by the *AEducAR* tool because it gives the opportunity of having a comprehensive vision of the anatomical structures (e.g., *"The dissection of body donors allows a more comprehensive view, in the sense that [...] you can see all the structures simultaneously"*), it allows a *"real experience"* (e.g., *"[Seeing the anatomical structures] 'in vivo' provides a certain type of added value"*) that helps the learning process (e.g., *"Having something physical in front of you leaves a stronger impression, there's more impact"*) and also has a great psychological value (e.g., *"[The dissection room experience gives the opportunity to feel] great gratitude towards those who have donated their bodies to us for learning purposes"*). On the other hand, students declared that the dissection room activities also have limitations, such as the impossibility of fully appreciating the anatomical structures (e.g., *"One thing that is lost in human body dissection is, for example [...] muscle tone. Even colors are lost"*). Therefore, students also spontaneously highlighted that *AEducAR* and the dissection room could be complementary experiences in human anatomy education (e.g., *"[There could be] an integration because both experiences provide a realistic help"*; *"[It would be] perfect to integrate AEducAR and dissection"*). Finally, concerning the fourth aspect, "The future of AR in the medical education and profession," the interviews revealed that students believe AR and new technologies in general to be the *"future of medicine"*. In this regard, some students pointed out that implementing AR tools such as *AEducAR* in medical education could be important to familiarize with this technology and *"be ready"* to use it in future medical practice (e.g., *"All these tools are interesting to use, especially*

Pearson Correlation between Q7, Q9 and Q10

		Q7: Do you think that the AR experiences like the one you have made could ameliorate knowledge's practical applicability in your future medical carrier?	Q9: To what extent do you think doctors will use AR in their professional practice?	Q10: Do you think AR experiences prepares you to use new devices directly on the patient, in the future?
Q7: Do you think that the AR experiences like the one you have made could ameliorate knowledge's practical applicability in your future medical carrier?	Pearson Correlation	1	,294**	,291**
	Sig. (2-tailed)		,001	,001
	N	130	119	123
Q9: To what extent do you think doctors will use AR in their professional practice?	Pearson Correlation	,294**	1	,341**
	Sig. (2-tailed)	,001		<.001
	N	119	119	115
Q10: Do you think AR experiences prepares you to use new devices directly on the patient, in the future?	Pearson Correlation	,291**	,341**	1
	Sig. (2-tailed)	,001	<.001	
	N	123	115	123

**. Correlation is significant at the 0.01 level (2-tailed).

FIGURE 9 Pearson correlation coefficient between answers to Q7, Q9, and Q10. The correlation is significant with a *p*-value <0.01.

because nowadays, even in medicine, surgery, and diagnostics, artificial intelligence is becoming more prevalent. So, getting familiar with them starting from education [is important]. Then, when you already have some level of confidence with this type of technology, it is nice").

DISCUSSION

AEducAR 2.0 represents the follow-up of the first *AEducAR* study, conceived as a pilot experience to test an innovative tool for human anatomy education that combines virtual information projected using AR with real, tangible 3D-printed anatomical models.[27] In this follow-up, the tool's interactive aspects were expanded, and the learning outcomes and answers to an anonymous questionnaire administered to the medical students who participated in the activity were analyzed. Moreover, *AEducAR 2.0* represents the first study investigating the pedagogical aspects behind AR implementation in human anatomy education. In particular, the present study explores the whole learning process through the analysis of students' background, performance, perception of the activity and AR future applications, and, ultimately, learning outcome. The *AEducAR 2.0* experience was designed through synergic and translational work among anatomists, maxillofacial surgeons, biomedical engineers, and educational scientists of the University of Bologna. The heterogeneity of this team, already consolidated thanks to the first *AEducAR* experience and enriched for this second study by the presence of educational scientists, was pivotal to obtain a comprehensive understanding of this study's objectives and challenges. The results of the quizzes, administrated to evaluate the achieved theoretical learning, were high for both the "Track & Explore" experience and for the "Place & Check" experience, remarking that the *AEducAR* prototype represents an efficient learning tool for the study of human anatomy. Indeed, the previous *AEducAR* study was able to demonstrate that the use of this prototype to study human anatomy was as efficient as using traditional learning sources such as anatomy atlas.[27] The efficiency and effectiveness of AR-based learning methods were proved by several studies in the anatomical field and others.[38–43] In this study, a deeper analysis performed to investigate the frequency distribution of the results, confirmed that most students totalized a medium–high/high score in both quizzes, showing that students possess both good theoretical and practical skills. When it comes to innovative technologies applied to education, addressing participants' satisfaction is important to evaluate the general learning outcome. Indeed, students' motivation and engagement are pivotal factors in the learning process and AR is proving to be effective in enhancing both.[44,45] For this reason, this study was also focused on students' evaluation of the experience through the administration of an anonymous questionnaire. Overall, the results confirmed that students enjoyed the experience (79%). Moreover, they declared an interest in having similar experiences also for other anatomy modules (92%). In addition, the questionnaire aimed to investigate the students' perception of AR in medical education/practice. Students declared to find AR a helpful tool for studying (94%) and for their future medical career (95%). Students also declared to find AR helpful in improving their practical skills in their future medical career (90%), believe that AR will be frequently used in the future by medical doctors (63%), and believe that in the future AR could be useful to learn how to use new devices directly on patients (74%). All these results suggest that students appreciated this *AEducAR 2.0* experience and, in accordance with the results of other studies, have a generally positive perception of AR and its growing importance in the medical field both at the educational and professional levels. Finally, the questionnaire's aim was also to collect students' comments and suggestions on the experience. When asked what they would improve about the activity to increase its applicability and effectiveness, most students answered they would modify the hardware/software of the prototype, for example by adding new functions and improving the tracking system. This of course not only highlights the actual limitations of *AEducAR* prototype but also suggests that students are really interested in the potential of this technology. In the open comments section, students praised the *AEducAR 2.0* experience's innovative side, the possibility of directly interacting with the study material, and the opportunity to visualize the anatomical structures dynamically. Indeed, students' feedback is pivotal for having a collaborative relationship, with the goal of improving the human anatomy teaching method. Most of the studies regarding AR-based methods to teach human anatomy focus on students' learning outcomes and experience evaluation, often comparing AR-based methods to traditional ones.[19,46] Indeed, these aspects are important to understand the efficacy of AR as teaching tool and to evaluate if the new generations of students would find a greater benefit in the stable implementation of AR in didactics. However, the learning process is not only defined by learning outcome, engagement, and motivation. The learning process is a complex mechanism that involves a wide variety of aspects such as students' background, attention, comprehension, and physical environment.[47–49] All of these aspects determine the "didactic fit" of an educational method.[37] Under this light, another aim of this study was to investigate if the *AEducAR 2.0* tool was able to even all these aspects, therefore evaluating its "didactic fit." To test this hypothesis, we first investigated if the students' background information that was collected through the anonymous questionnaire (gender, nationality, having had other AR experiences before, and preferential learning sources) impacted the learning outcome and students' enjoyment. One-way ANOVA tests revealed that none of these variables influenced quizzes' results or experience enjoyment. Moreover, a linear regression was performed to evaluate if quizzes' results or experience enjoyment might be influenced by any other variable such as students' perception of AR utility. Also in this case, no specific variable influenced the investigated aspects. However, the quizzes' results were correlated. This data can be explained by the fact that a person's score on a test is likely to be consistent across multiple tests due to the construct being measured (e.g., knowledge) being a stable trait.[50] Therefore, it is possible to affirm that the *AEducAR 2.0* prototype could efficiently meet the different students' needs, leveling their differences, and constituting an inclusive experience. Another aspect on which the focus has been placed was to test the reliability of students' answers to the questions asked to express their perception of AR potential in their future medical careers (Q6, Q7, Q9, and Q10). The reliability of a series of questions is measured by calculating the Cronbach's alpha, or α coefficient, between the questions of interest. The calculated α coefficient for the questions regarding students' perception of AR utility in their future careers was 0.61, therefore the reliability of these questions was considered moderate. Even though this result indicates the necessity of further examinations and potential revisions, given the explorative nature of this study, the measured internal consistency between the four analyzed questions can be considered acceptable. A further focus was placed specifically on Q7, Q9, and Q10. In particular, these three questions shared the common aspect of investigating students' perception of the future potential practical aspects of AR: Q7 investigated the perception of whether AR could be helpful to transpose theoretical knowledge into practical skills, Q9 investigated the perception of the extent of AR use in medical doctors' professional practice, and Q10 investigated the perception on whether AR could be helpful to learn how to use new devices directly on patients. To test if the answers to these three questions were correlated, the Pearson correlation coefficient (PCC) was calculated. PCC quantifies the degree of linear relationship between two continuous variables. The result of this analysis was that answers to Q7, Q9, and Q10 are correlated in a statistically significant way, with a p-value <0.01. These data suggest that students' general perception of AR practical applicability in their future medical career is high. This result could imply that the future generation of medical doctors sees potential benefits and usefulness of using AR technology in their work. Indeed, this might lead to an increased adoption and development of AR tools not only for medical education but also for medical professional training and patients' diagnosis and treatment. The constructivist-grounded qualitative analysis of Q11 revealed that the general sentiment toward the *AEducAR 2.0* activity was positive. Understandably, students also declared that the technology should be improved, but the experience was perceived as enjoyable and useful. Finally, the interviews were able to uncover many interesting and important aspects of students' perception of the *AEducAR 2.0* experience and, in general, of AR applied to medical education and training. First, the interviews pointed out that students often refer to technological tools, especially online sources, while studying human anatomy. Nevertheless, students also declared that traditional resources such as anatomy atlases and notes remain key features of the learning process and therefore suggested an implementation of technological resources to the traditional ones, rather than a substitution. Overall, these results are in line with the trend observed in the related scientific literature. Indeed, even though the increasing availability and accessibility of online resources have significantly impacted the way students approach learning, previous research also emphasizes the value of learning experiences offered by traditional resources.[51] Second, the interviews were able to deepen the understanding of the positive and negative aspects of the *AEducAR 2.0* experience. A positive aspect was that students particularly enjoyed interacting with 3D models. Indeed, students affirmed that the innovative aspect of this study, specifically the Place & Check app, offered them an interactive and engaging way to explore human anatomy by allowing direct interaction with the new 3D-printed models. Moreover, students affirmed that the Place & Check app enhanced their understanding and appreciation of the subjects treated, making it a valuable tool for learning. Therefore, students' positive feedback on this aspect of the study highlights the importance of incorporating interactive aspects in anatomy education. In fact, interactive learning environments are proved to enhance students' learning outcome and engagement.[52] Additionally, tactic memory (also known as haptic memory) is proven to enhance learning through multisensory associations and its efficacy has been extensively tested in human anatomy education[53–55] and in professional medical training.[56] Third, the interviews gave the opportunity to delve into the interesting and important topic of human body dissection in anatomy education and to compare the dissection room experience to *AEducAR*. Most students affirmed that body donor dissection remains the gold standard for approaching human anatomy in a practical way. Indeed, human body dissection is currently the only method that allows students to appreciate the complexity of the human body in a complete, 3D, and realistic way, allowing for hands-on learning and a deeper understanding of anatomical relationships.[57,58] Moreover, students underlined also the great psychological value of the dissection room experience. This last aspect has been investigated by a recent study testing graphic medicine applied to the topic of body donation, exploring students' emotions, and underlining the importance of the psychological aspects of dissection room experiences.[59] On the other hand, students declared that human tissue dissection also presents limitations, such as the impossibility of fully appreciating the anatomical structures. In this regard, students highlighted the possibility of *AEducAR 2.0* and body donor dissection to be complementary experiences. Indeed, this aspect that emerged from the interviews supports the educational approach of blended learning. Blended learning refers to an educational approach that combines traditional instruction with digital learning activities and constitutes a hot topic in medical education because it offers the advantage of combining the benefits of both traditional and digital learning methods.[60] Under this light, combining human body dissection with *AEducAR* laboratories has an exciting potential. Finally, the interviews also revealed that students believe AR to be the future of medicine and declared that implementing AR methods in medical education could not only benefit students' learning process and outcome but also help them familiarize with the technology to better perform in future AR experiences. Indeed, AR applied to medical education has the potential of providing hands-on experiences, enhancing the understanding of complex medical concepts, and developing critical and practical skills. Ultimately, this could prepare medical students to navigate the challenges of their profession with greater proficiency, confidence, and patient-centered care.[61]

LIMITATIONS OF THE STUDY

In the presented *AEducAR 2.0* experience, one limitation was related to the inconvenience of having lost some video recordings while using the application. This translated into the inability to analyze 27 screen recordings of the 260 (2 per participant). Indeed, this issue reduced the pool of analyzed learning outcomes. Additionally, during the academic year 2021/2022, wearing face masks in class was still mandatory in Italy due to the Covid-19 pandemic. For this reason, the quality of the interviews' audio recordings was affected due to muffled speech, making it difficult to capture conversations and verbal interactions accurately. Moreover, face masks limited the ability to accurately observe facial expressions and non-verbal communication, which are important aspects of social behavior.[62] A further limitation of this study has been that, although the questionnaire aimed to gauge participants' familiarity with AR, it did not distinguish between varying levels of experience, potentially conflating brief exposures with more comprehensive engagement. Indeed, this oversight may have affected the results of this study. Another limitation is that the results of this study might be partially affected by the explorative approach that was followed. Indeed, including more learning topics and augmenting the difficulty of the knowledge assessment method could significantly improve the results of this study. Finally, the interviews' results are to be considered not representative due to the limited number of participants.

CONCLUSION

Building upon the success of its predecessor, the *AEducAR 2.0* study expanded the tool's interactive features and conducted an explorative analysis of learning outcomes, some aspects of students' background, and students' perception of the activity. With its explorative approach to the pedagogical aspects of implementing AR in anatomy education, the present work represents a first-time product in the field. The results of the study demonstrated that the *AEducAR 2.0* prototype is an effective learning tool for studying human anatomy. Students achieved high scores in the quizzes assessing theoretical knowledge, indicating good theoretical and practical skills. Additionally, most students reported enjoying the *AEducAR 2.0* experience and expressed interest in similar experiences for other anatomy modules. Moreover, they recognized the potential of AR in medical education and practice, perceiving it as a helpful tool for studying, improving practical skills, and envisioning its future use by medical professionals. The study also explored various aspects related to the learning process, including students' backgrounds, perception of AR utility, and their preferred learning sources. It was found that the *AEducAR 2.0* experience catered to the diverse needs of students, leveling their differences, and creating an inclusive learning environment. Moreover, students' perception of AR's practical applicability in their future medical careers was high, indicating a positive outlook on the technology's potential benefits. Finally, through interviews, students emphasized the importance of incorporating interactive and tactile elements, such as the direct interaction with 3D models offered by the *AEducAR 2.0* experience. While acknowledging the gold standard of human body dissection, students saw the potential for *AEducAR 2.0* and body donor dissection to complement each other. Therefore, the aspect of blended learning, which combines traditional teaching methods with digital learning activities, emerged as a promising educational approach. Overall, *AEducAR 2.0* demonstrated its efficacy in enhancing anatomy education and received positive feedback from students, contributing to the growing body of research supporting the implementation of AR-based methods in medical education and training. Nevertheless, further studies are still needed to better assess AR potential in medical education. In this light, the future perspectives of this study are to analyze deeper aspects of the cognitive process and to raise the cognitive load of the activity. Indeed, both actions would provide more precise information into how learners assimilate, retain, and apply complex information, thereby adding relevant insights into how AR implementation in human anatomy learning could be more effective and impactful.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

ORCID

Irene Neri https://orcid.org/0000-0002-8251-0893
Laura Cercenelli https://orcid.org/0000-0001-7818-1356
Giovanni Badiali https://orcid.org/0000-0001-9833-9800
Stefano Ratti https://orcid.org/0000-0002-6258-5345

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AUTHOR BIOGRAPHIES

Irene Neri, M.Sc., is Ph.D. candidate of the Cellular Signalling Laboratory, Anatomy Center, Department of Biomedical and Neuromotor Sciences (DIBINEM), School of Medicine at the University of Bologna in Bologna, Italy. She is a member of the Italian association of Anatomy and Histology (SIAI). Her research interests include glioma microenvironment, mitochondrial neurogastrointestinal encephalomyopathy (MNGIE), chronic intestinal pseudo-obstruction (CIPO), and social/pedagogical aspects of medical education.

Laura Cercenelli, M.Sc., Ph.D., is a biomedical engineer and adjunct professor of Computer Science in the Department of Biomedical and Neuromotor Sciences (DIBINEM), School of Medicine at the University of Bologna in Bologna, Italy. Her research interests include sensors and devices for cardiac function monitoring; digital technologies applied to medicine: 3D modeling, 3D printing, virtual and augmented reality applied to surgery for pre-operative planning, intraoperative guidance and training, and design of personalized surgical instruments and implants. She has been working for 6 years at eDIMES Lab, an in-hospital laboratory of the University of Bologna focused on advanced digital technologies for supporting clinical research, practice, and medical education.

Massimo Marcuccio, M.Sc., Ph.D., is a full professor of experimental pedagogy in the Department of Educational Science "Giovanni Maria Bertin" at the University of Bologna, Bologna, Italy. His research interests include the uses of assessment, impact assessment, models for evaluating the effectiveness of educational systems, models for evaluating innovations in a school context, mixed-methodological approach, measurement of educational conceptions, competence in learning to learn, and transfer of learning.

Simone Lodi, M.Sc., is a biomedical engineer and full-time dissection room technician in the Anatomy Center, Department of Biomedical and Neuromotor Sciences (DIBINEM), School of Medicine at the University of Bologna in Bologna, Italy. He specializes in dissection room equipment, audio-video recording and editing, and digital data management, and has also worked on augmented reality in robotic surgery as fellow researcher.

Foteini-Dionysia Koufi, M.Sc., is a chemist and Ph.D. candidate at the Cellular Signalling Laboratory, Anatomy Center, Department of Biomedical and Neuromotor Sciences (DIBINEM), School of Medicine of the University of Bologna, Italy. She is a member of the Association of Greek Chemists (AGC), Italian Association of Cell Culture (IACC), and the Brainstorming Research Assembly for Young Neuroscientists (BraYn). Her research focuses on studying the pathological mechanisms of rare neurological disorders such as adult-onset autosomal dominant leukodystrophy (ADLD).

Antonietta Fazio, M.Sc., Ph.D., is a postdoctoral fellow in the Cellular Signalling Laboratory, Anatomy Center, Department of Biomedical and Neuromotor Sciences (DIBINEM), School of Medicine at the University of Bologna in Bologna, Italy. She is a member of the Italian Association of Anatomy and Histology (SIAI) and the Italian Association of Histochemistry (SII). Her research interests include cellular signaling and molecular mechanisms in doxorubicin-induced cardiotoxicity and collagen VI-related dystrophies.

Maria Vittoria Marvi, M.Sc., Ph.D., is a postdoctoral fellow in the Cellular Signalling Laboratory, Anatomy Center , Department of Biomedical and Neuromotor Sciences (DIBINEM), School of Medicine at the University of Bologna (Italy). She is a member of the Italian Association of Anatomy and Histology (SIAI), the Italian Association of Histochemistry (SII), and member of the Brainstorming Research Assembly for Young Neuroscientists (BraYn). Her research is focused on studying the signaling transduction pathways of the lipid-dependent processes in neuro-oncological diseases and, specifically, in glioblastoma.

Emanuela Marcelli, M.Sc., is a biomedical engineer and associate professor of Industrial Bioengineering at the Department of Specialized, Diagnostic, and Experimental Medicine (DIMEC), School of Medicine at the University of Bologna in Bologna, Italy. She is head of the eDIMES Lab, an in-hospital laboratory focused on advanced digital technologies for supporting clinical research, practice, and medical education, at the University of Bologna. From 2015 to 2020, she was Deputy Director of the Department of Experimental Diagnostic and Specialty Medicine (DIMES) of the University of Bologna. Her research interests include cardiac devices, and sensors for cardiac function monitoring, and artificial organs. In the last 6 years, she has gained experience in coordinating research activities regarding advanced technologies based on simulation, virtual and augmented reality, 3D modeling, and 3D printing to support pre-operative planning and intraoperative guidance in surgery, as well as to improve the quality of teaching in medical education.

Anna Maria Billi is associate professor of human anatomy in the Department of Biomedical and Neuromotor Sciences (DIBINEM), School of Medicine at the University of Bologna, Bologna, Italy. She is a member of the Italian Association of Anatomy and Histology (SIAI) and the Italian Association of Histochemistry (SII). Her research activity is conducted in the field of gross anatomy dissection and includes the study of the incidence of anatomical variants of clinical-surgical interest and the conception of innovative medical teaching methods.

Alessandra Ruggeri, D.D., is associate professor of human anatomy in the Department of Biomedical and Neuromotor Sciences (DIBINEM), School of Medicine at the University of Bologna, Bologna, Italy. She is Exchange Coordinator for Erasmus+ and Overseas Exchanges of in- and out-going students for Medicine and Surgery, Dentistry School, and Dental Hygiene School. She is member of the Italian Association of Anatomy and Histology (SIAI) and the Italian Association of Histochemistry (SII). Her research interests include the analysis of ultrastructural aspects and interactions between oral tissue and biomaterials for dentistry practice, anatomical identification, and analysis of anatomical variants of clinical and surgical interest, and innovative medical education and training.

Achille Tarsitano, M.D., is associate professor of maxillo-facial surgery in the Department of Biomedical and Neuromotor Sciences (DIBINEM), School of Medicine at the University of Bologna, Bologna, Italy. He is head of the Oral and Maxillo-Facial Surgery Unit at IRCCS Azienda Ospedaliero Universitaria of Bologna, Italy. He is the chief of the Head and Neck oncology Board at IRCCS Azienda Ospedaliero Universitaria of Bologna. He is a member of the European Association for Cranio-maxillofacial Surgery, of the Italian Society of Maxillo-Facial Surgery (SICMF), and a founder member of Associazione Italiana di Oncologia Cervico-Cefalica (AIOCC). His research interests include Maxillo-facial surgical oncology, head and neck reconstruction, computer-assisted surgery, 3D printing, and technological medical innovations and devices for precision in surgery.

Lucia Manzoli, M.D., is full professor of human anatomy in the Department of Biomedical and Neuromotor Sciences (DIBINEM), School of Medicine at the University of Bologna, Bologna, Italy. She is head of the Department of Biomedical and Neuromotor Sciences (DIBINEM) and the Anatomy Center of the University of Bologna. She is a member of the Italian Association of Anatomy and Histology (SIAI), the Italian association of Histochemistry (SII), the Bologna Society of Medicine and Surgery, and the Academy of Sciences of Bologna Institute. Her research interests include cellular signaling and molecular mechanisms in rare diseases and cancer, technological medical innovations and devices for precision medicine tested and developed on body donors, and creative and innovative medical education and training.

Giovanni Badiali, M.D., Ph.D., is associate professor of maxillo-facial surgery in the Department of Biomedical and Neuromotor Sciences (DIBINEM), School of Medicine at the University of Bologna, Bologna, Italy. He is a member of the Italian Society of Maxillofacial Surgery (SICMF), the European Association for Cranio-Maxillofacial Surgery (EACMFS), the Italian Society for the Study and Treatment of Cleft Lip-Palate and Cranio-Maxillofacial Malformations (SILPS), the Italian Association of Aesthetic and Functional Surgery of the Face (AICEF), the Italian Digital Biomanufacturing Network (IDBN), and the Italian Society of Orthodontics (SIDO). His research interests include augmented reality in the surgical field, computer-assisted surgery, and 3D printing and planning for surgery.

Stefano Ratti, M.D., Ph.D., is full professor of human anatomy in the Department of Biomedical and Neuromotor Sciences (DIBINEM), School of Medicine at the University of Bologna, Bologna, Italy. He is head of the Cellular Signalling Laboratory and curator of the Anatomical Waxes Museum "Luigi Cattaneo" at the Anatomy Center of the University of Bologna. He is president of the "Graphic Medicine Italia" association and a member of the Italian Association of Anatomy and Histology (SIAI), the Italian Association of Histochemistry (SII), the Bologna Society of Medicine and Surgery, and the Neuro-Oncology Board of the Institute of Neurological Sciences of Bologna (Bellaria Hospital, Bologna). His research interests include cellular signaling and molecular mechanisms in rare diseases and cancer, technological medical innovations and devices for precision medicine tested and developed on body donors, and creative and innovative medical education and training.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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