Received: 21 February 2024 | Accepted: 29 February 2024

DOI: 10.1002/ca.24155

EDUCATION

CLINICAL ANATOMY WILEY

Personalized strategies for academic success in learning anatomy: Exploring metacognitive and technological adaptation in medical students

Mónica Stambuk-Castellano[1] | Anna Carrera[2] | R. Shane Tubbs[3,4,5,6,7] | Carlos Alario-Hoyos[8] | Enric Verdú[2] | Joe Iwanaga[3,4,5,9] | Francisco Reina[2]

[1]Department of Computer Science, School of Engineering, Pontificia Universidad Católica de Chile, Santiago, Chile

[2]Clinical Anatomy, Embryology and Neuroscience Research Group (NEOMA), Medical Sciences Department, Faculty of Medicine, Universitat de Girona, Girona, Spain

[3]Department of Neurosurgery, Tulane Center for Clinical Neurosciences, Tulane University School of Medicine, New Orleans, Louisiana, USA

[4]Department of Neurology, Tulane Center for Clinical Neurosciences, Tulane University School of Medicine, New Orleans, Louisiana, USA

[5]Department of Structural & Cellular Biology, Tulane University School of Medicine, New Orleans, Louisiana, USA

[6]Department of Neurosurgery and Ochsner Neuroscience Institute, Ochsner Health System, New Orleans, Louisiana, USA

[7]Department of Anatomical Sciences, St George's University, True Blue, Grenada

[8]Telematics Engineering Department, Universidad Carlos III de Madrid, Leganés, Spain

[9]Department of Oral and Maxillofacial Anatomy, Graduate School of Medical and Dental Sciences, Tokyo Medical and Dental University, Tokyo, Japan

Correspondence
Francisco Reina, Clinical Anatomy, Embryology and Neuroscience Research Group (NEOMA), Medical Sciences Department, Faculty of Medicine, Universitat de Girona. Girona, Spain.
Email: francisco.reina@udg.edu

Funding information
National Research and Development Agency of Chile; MCIN/AEI

Abstract

Personalization of learning is an educational strategy rooted in metacognition and is significant in academic training. This is especially true in medical contexts. This study explored the relationship between the metacognitive profile of students of human anatomy, the classification of questions according to their difficulty, and the anatomical domain. It also covered the integration of educational technologies to create personalized learning environments. The identification of metacognitive profiles ("Active", "Pragmatic", "Theoretical", and "Reflective") has been highlighted as a critical influence on students' responses to different pedagogical approaches. Personalized adaptation based on these profiles has shown potential for improving grades and increasing student satisfaction and engagement with learning. The results revealed variations in student performance in relation to different pedagogical approaches, learning units, and evaluation modalities. The "Experience" evaluation modality, personalized according to metacognitive profiles, level of competence, and learning objectives, resulted in higher average scores. However, there was significant variability in the results. Those findings confirm the effectiveness of metacognitive adaptation in improving academic performance. Furthermore, they provide a solid basis for formulating personalized and effective pedagogical strategies in medical education. They recognize the influence of metacognitive profiles on student performance and contribute to advancing medical pedagogy.

KEYWORDS
competence level, educational technologies, learning anatomy, metacognitive profile, personalized learning

1 | INTRODUCTION

The study of human anatomy is essential for training medical professionals and other health science disciplines. It provides an accurate and deep understanding of the body, a prerequisite for the ongoing study of pathophysiology, pathological anatomy, and semiology (Venturelli, 1997; Heredia-Escorza & Sánchez-Aradillas, 2013). Much research supports its importance in medical educational programs (Latarjet et al., 2019; Moore et al., 2013; Williams, 2018). Those seeking to become medical professionals and specialists in various medical disciplines develop practical skills and refine their clinical skills through the study of anatomy (Araujo Cuauro, 2018; Cárdenas-Valenzuela, 2020; Rodríguez et al., 2021; Turney, 2007).

Anatomy provides a solid foundation for understanding the structure, function, and relationships of the different systems and organs to each other (Latarjet et al., 2019; Latarjet & Liard, 2004). In their learning, students acquire detailed knowledge through dissection, the use of anatomical models, and advanced imaging technologies (Iwanaga, Loukas, et al., 2021; Iwanaga, Singh, et al., 2021). Those three approaches are invaluable for those looking to specialize in medical-surgical disciplines (Ordóñez Aguilar, 2023; Quelca Choque, 2022). In the surgical setting, an accurate understanding of the locations and spatial relationships of anatomical structures is essential for carrying out procedures safely and efficiently (Arráez-Aybar et al., 2010; Cheung et al., 2021; Kumar & Singh, 2020). According to McHanwell et al. (2021), surgeons with solid anatomical knowledge are better prepared to prevent injury to crucial organs and structures during surgical interventions, thereby reducing patient risks.

In addition, hands-on learning of human anatomy motivates and guides students toward its clinical application (González Pulido, 2023; Sbayeh et al., 2016). Students feel more stimulated and engaged in anatomy when they visualize how this knowledge directly translates into medical practice. It allows for more effective diagnosis and treatment of diseases (Fagalde & McNulty, 2023; Smith et al., 2022; Triepels et al., 2018). The learning process in anatomy is the first opportunity for medical students to establish contact with patients.

However, despite its relevance, the traditional teaching of human anatomy has been subject to criticism (González La Nuez & Suárez Surí, 2018; Romero-Reverón, 2020). Hall et al. (2018) point out that students face difficulties because of the content overload they must assimilate rapidly. Moreover, McBride and Drake (2018) observe a current trend toward reducing the time dedicated to laboratory practice in anatomy curricula, thereby demonstrating inaccurate anatomical modeling and mockups. That approach limits opportunities for direct observation of actual structures. Finally, there was a debate following a symposium entitled, "Do we really need cadavers anymore to learn anatomy in undergraduate medicine?" (Dharmasaroja, 2019; McMenamin et al., 2018).

Alzate-Mejía and Tamayo-Alzate (2019) identify challenges such as the lack of memory strategies and underdeveloped visuospatial skills in initial anatomy learning. Teaching approaches that do not delve into anatomical interrelationships and their pathological implications are included among those challenges. Faced with this, teachers seek to modify learning approaches through educational technologies (Araujo Nasayo & García Valbuena, 2022; Vargas Gutiérrez, 2022) to provide themselves with adequate teaching resources (Chan et al., 2019; Estai & Bunt, 2016; Harrell et al., 2021). Even so, a considerable number of such resources cannot address the individual needs of students and support their self-regulation in learning (Hamilton et al., 2021; Osorio & Zolano, 2022; Robles Melgarejo, 2022; Simó & Domènech-Casal, 2018; Simón Medina et al., 2023; Tibán & del Rocío, 2023).

Standardized and passive teaching practices often overlook individual differences among students, which affect their motivation and understanding (Suárez-Escudero et al., 2020). Therefore, it is essential to recognize that each student has unique characteristics, metacognitive processes, and rhythm of assimilation (Montoya Villena & Pinedo Pichilingue, 2022; Valdivieso Cavagnari, 2020). Flavell (1977, 1979) introduced metacognition as the key to mastering and regulating cognitive processes, allowing students to self-regulate their learning to become autonomous learners.

Valdez (2022) calls attention to the merit of identifying anatomy students' metacognitive processes and learning styles to overcome obstacles to learning and the lack of terminological understanding. Vargas Lujan (2023) highlights adapting methods to meet individual needs and promote deeper learning by identifying learning styles to personalize the learning experience (Suárez-Escudero et al., 2020; Valderrama Wong, 2022). Merrill (2013) promotes student curiosity through pedagogical activities. Those activities promote interest and self-knowledge and encourage active use of acquired knowledge. Educators should encourage student-centered approaches, with active techniques and technologies, to improve the understanding of anatomy and its application (Cheung et al., 2021; McHanwell et al., 2021; Zibis et al., 2021). This personalized approach, called "personalized education," empowers students and improves their clinical preparation (De Oliveira et al., 2022; García et al., 2021).

Does the personalized adaptation of learning based on metacognitive profiles affect the performance of human anatomy students in the "Respiratory System" and "Digestive System" learning units? This study aims to answer this research question.

The primary approach in this study was to analyze the effect of the personalized adaptation of learning. We considered learning based on the metacognitive profiles of medical undergraduates in human anatomy. This was done by adapting questions to the complexity and the domain using educational technologies to improve academic performance in the "Respiratory System" and "Digestive System" learning units.

2 | METHODS

2.1 | Teaching and learning context of anatomy

The study used a qualitative approach and an applied field research methodology. Two pedagogical intervention designs mediated by educational technologies were analyzed, with learning environments personalized according to each student's metacognitive characteristics and the questions' domain and difficulty. The pedagogical interventions were conducted in the human anatomy course in the undergraduate medical studies program at the University of Girona (UdG).

The study focused on the "Respiratory System" and "Digestive System" learning units in "Introduction to the Study of Medicine: The Study of the Structure and Function of the Human Body II" (hereafter, IMSF II). These learning units are taken up during the second semester of the first year of training. They address the study of the development, morphology, structure, and function of the cardiovascular, respiratory, and digestive systems at the cellular, tissue, organ, and systems levels.

Human anatomy is taught at the University of Girona (UdG) during the first 2 years via four subjects. The evaluation scale ranges from 1 to 10 as part of the European Credit Transfer and Accumulation System used in the European Higher Education Area.

2.2 | Participants and sampling

The IMSF II course at the UdG comprised 91 first-year medical students, of whom 78% (71 students) agreed to participate in the study. From there, they were assigned to the experimental group. The remaining 22% (20 students) decided not to participate and were assigned to the control group. In addition to participating in the two pedagogical interventions analyzed in the present study, the experimental group also took the evaluation tests the teachers scheduled to pass the course. The control group only completed the scheduled evaluations of the regular IMEF II course. The study was conducted during March, April, and May 2023.

2.3 | Study design

The study design was quasi-experimental with an independent variable (learning unit and modality) and a dependent variable (academic performance). Modality was divided into "Experience" (experimental group) and "Traditional" (control group). The former referred to the two pedagogical interventions designed for this study and the latter to the IMSF II course evaluations.

For the "Experience" modality, two interventions were described based on the different student metacognitive profile types and the difficulty of the questions in the "Respiratory System" and "Digestive System" learning units. In the first experience, a questionnaire categorized by level of mastery and difficulty according to Bloom's taxonomy was created with 150 questions about the "Respiratory System." In the second experience, 150 questions about the "Digestive System" were created, categorized by level of mastery and difficulty, along with four personalized learning paths based on the metacognitive profile of each student. Figure 1 shows the proposed research design.

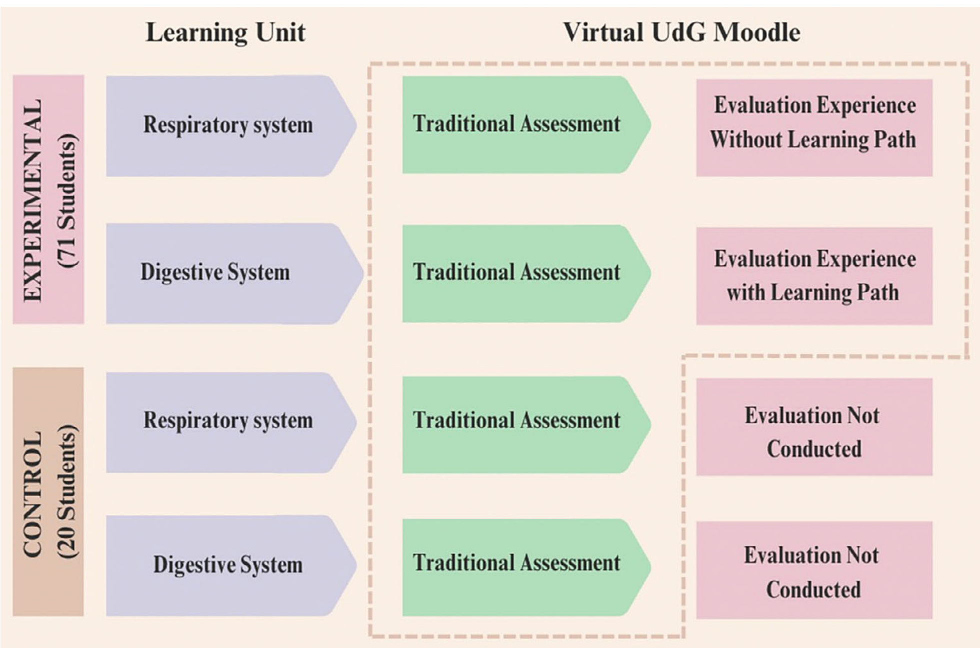

FIGURE 1 Procedural outline of the research design.

The phases of the study design are described in detail below.

Phase 1: Two questionnaires were given to establish the metacognitive profiles of the IMSF II course students regarding knowledge and self-regulation. The questionnaires used were the Metacognitive Awareness Inventory (Schraw & Dennison, 1994) and an instrument validated by Jaramillo and Osses (2012). They were administered to the 71 students in the experimental group through a survey management platform. The theoretical proposal was to categorize metacognitive profiles concerning the assessment's mastery level. This was based on analyses and interpretations of works carried out by various authors, including Bloom (1977), Kolb (1999), Alonso and Gallego (2000), Osses Bustingorry and Jaramillo Mora (2008), Marcén (2008), Osses-Bustingorry et al. (2018), Pastén (2021), and Medina et al. (2023). The components associated with metacognition included metacognitive knowledge (such as learning styles), self-regulation of cognitive processes (planning, monitoring, and evaluation), and mastery of questions.

Students in the experimental group also answered two feedback questionnaires at the end of each learning experience. One assessed the usefulness of the questions based on their level of mastery and difficulty. The other measured satisfaction with the personalization experience. Both questionnaires contained 14 mixed questions (Likert scale and open-ended).

The proposal regarding these associations between the four metacognitive profiles of the student and the level of mastery in the evaluation is shown in Table 1.

Phase 2: Based on the learning objectives of the IMSF II course, the questions were grouped into four categories: identify, understand, apply, and analyze. According to Bloom's cognitive taxonomy, these categories correspond to the levels of mastery of the questions. The latter two levels of the taxonomy were not applied because they pertain to a deeper level of understanding and clinical decision-making, which medical students acquire in more advanced courses (Altamirano & Javiera, 2017; Castañeda et al., 2021; Díaz Flores, 2014). The questions were classified into three levels of difficulty: easy, medium, and difficult. Three hundred questions relating to the respiratory and digestive systems were prepared. They included true/false, multiple choice, short answer, and clinical application. They were reviewed and validated by three expert UdG teachers with substantial experience (>25 years) in human anatomy.

A discrepancy analysis technique was used to ensure the accuracy and quality of the questions. The experts independently evaluated the 150 questions from each learning unit and classified them into levels of mastery and difficulty. Discrepancies among their classifications were identified. The expected concordance was calculated at 0.92; the three experts agreed on the assigned classifications for 138 of the 150 questions analyzed. Additionally, an agreement analysis was applied using Cohen's kappa coefficient to measure the agreement among the experts about the taxonomic level of the questions. The result of this analysis was 0.84, indicating good to excellent agreement in the classification of questions per Bloom's taxonomy for human anatomy.

Phase 3: Once the metacognitive profiles of the 71 students in the experimental group had been evaluated and the taxonomic level and difficulty of the questions identified, the information obtained in phases 1 and 2 was cross-referenced. From this classification, and based on what is defined in Table 1, the students were distributed as follows in the four metacognitive profiles according to the level of

TABLE 1 Associations according to metacognitive profile with the level of mastery of the questions based on the metacognitive profiles and processes [adapted from Bloom, 1977; Kolb, 1999; Alonso & Gallego, 2000; Osses Bustingorry & Jaramillo Mora, 2008; Marcén, 2008; Osses-Bustingorry et al., 2018; Pastén, 2021; Medina et al., 2023].

		Definitions
Profile I (active)	ST	Students who engage in new experiences: They are enthusiastic about new things and prefer a practical and participatory approach to the learning process.
	ML	They can respond better to questions at the level of identification and understanding in Bloom's Taxonomy.
	QT	The question they want to answer with learning is directed at the "why".
Profile II (pragmatic)	ST	Students who look for the best way to do things, make decisions, and solve problems. They prefer the practical, application-oriented approach to learning.
	ML	They tend to perform better with questions about the level of identification and understanding in Bloom's Taxonomy.
	QT	The question they want to answer with learning is directed at the "why".
Profile III (theoretical)	ST	Students who make logically based theoretical observations through sequential thinking. They prefer an analysis-oriented approach to the learning process.
	ML	They can work better with questions about the level of identification and understanding in Bloom's Taxonomy.
	QT	The question they want to answer with learning is directed at the "why".
Profile IV (reflective)	ST	Students who collect information and subsequently analyze it in detail. They observe and thoroughly analyze their experiences from different perspectives. They prefer the analytical and reflective approach to learning.
	ML	They can work better with questions at the level of the analysis in Bloom's Taxonomy.
	QT	The question they want to answer with learning is directed at the "why".

Abbreviations: ML, level of mastery; ST, student type; QT, question type.

mastery of the questions: eight students from the Active Profile, 17 from the Pragmatic Profile, 20 from the Theoretical Profile, and 26 from the Reflective Profile.

Phase 4: Once the groups were formed, two types of intervention experiences were designed on the Moodle learning platform (Diaz Pérez & Colorado Aguilar, 2020), the official UdG tool for learning in a virtual environment. The design criterion was to create questionnaires and learning paths appropriate for each metacognitive profile according to the level of competence and the learning objectives in each knowledge unit. The conceptual bases supporting the proposal of the learning paths are presented in Table 2. The proposed design focused on the constructivist approach and Flavell's theory (Flavell, 1977,

TABLE 2 The design of learning paths is based on the metacognitive profile for which it is intended and depends on the level of competence the student must achieve.

Profile type		Respiratory system competency levels	Digestive system competency levels
Profile I (active)	BL	Describe the respiratory system in its entirety, including its structure and function, as well as the morphology of the lungs. Pay particular attention to the details of their surfaces, lobes, and anatomical landmarks.	Describe the basic anatomical structure of the digestive system, relating its different segments to the functions they fulfill.
	IL	Synthesize the morphology, course, and topographic relationships of the respiratory tract, including the trachea and main bronchi with the purpose of understanding and systematizing the function of the respiratory system.	Comprehensive description of the human digestive system, including the morphological characteristics of its segments, anatomical relationships, vascularization, and innervation.
	AL	Identify the anatomical and structural components that make up the right and left pulmonary hilus in a precise and detailed manner, understanding their importance in circulation and pulmonary function.	Identify the different segments of the digestive tract in the different diagnostic imaging scans.
Profile II (pragmatic)	BL	Identify the relationship between the lung segments and the walls of the mediastinum.	Define the topographic regions in the surface anatomy of the abdomen, identifying the projection of the elements that are part of the abdominal cavity in them.
	IL	Locate the anatomical structures of the mediastinum according to their topographic systematization.	Understand the anatomy of the arrangement of the abdominal viscera in the peritoneal cavity. Identify the supracolic and infracolic spaces.
	AL	Identify the main macroscopic details of the laryngeal mucosa and interpret them in basic laryngoscopy images.	Understand the arrangement of the different segments of the digestive tract in relation to the three-dimensional arrangement of the abdominal peritoneum. Define the *bursa omentalis* and peritoneal pouches.
Profile III (theoretical)	BL	Describe the morphology of the larynx and its fibrocartilaginous skeleton.	Understand the anatomy of the bile duct in relation to its function in digestion.
	IL	Describe the embryonic development of the tracheo-bronchial tree and the formation of the larynx.	Establish the origin and functional meaning of the bile secretion, relating its characteristics to its function during digestion.
	AL	Describe the morphology and arrangement of the pleura. Understand the functional significance of the pleural space.	Relate the anatomy of the bile duct to the symptoms of pathological processes that occur in the pancreas, duodenum, or liver.
Profile IV (reflective)	BL	Define bronchopulmonary segmentation and understand its topographical arrangement.	Classify the elements of the abdominal cavity in relation to their peritoneal, retroperitoneal, and secondarily retroperitoneal locations.
	IL	Understand the radiological projection of the bronchopulmonary segments and explain its application.	Detail the formation of the anal canal and cloaca, relating this process to defects of the rectourethral or rectovaginal septum.
	AL	Analyze bronchopulmonary segmentation in depth, evaluating its clinical implications and its relevance in medical and diagnostic procedures.	Describe the mechanisms of the embryonic development of the abdominal cavity, formation of the digestive tube and its annexed glands. Analyze the findings of the main malformations of the abdominal segment of the digestive tract.

Note: For the respiratory and digestive system learning units, examples of specific knowledge objectives grouped by themes are shown for each profile and level.
Abbreviations: AL, advanced level; BL, beginner level; IL, intermediate level.

1979). Four learning paths were designed based on knowledge of the objectives in the "Respiratory System" and "Digestive System" learning units. The learning paths were related to the levels of competency and cognitive domains the student is expected to achieve during instruction (Castrillón Rivera et al., 2020; Fowler, 2002; Hertzog & Dixon, 1994; Martins et al., 2020).

2.4 | Data analysis

To evaluate the effect of the personalized learning environment (metacognitive profile—learning paths) on each student's academic performance, *t*-tests of dependent population means (paired) were used. The data analyzed were the grades obtained in the "Respiratory System" and "Digestive System" tests applied to the 71 students in the experimental group and the grades obtained in the study program exam. The differences according to the type of test within each learning unit ("Respiratory System" and "Digestive System"), and the differences in performance between them, were assessed. Likewise, the differences between learning units were analyzed regarding students' perceptions of the questions' usefulness and satisfaction with the experience.

Independent *t*-tests of means (unpaired) of the scores in each learning unit ("Respiratory System" and "Digestive System") were used to establish descriptive results by group ("Experimental" and "Control"). The Levene test was used to assess the assumption of homogeneity of variances of the dependent variables in each group ("Experimental" and "Control"). The Shapiro–Wilks test was used to verify the compliance of the dependent variables with the normality assumption in both learning units. Finally, Cohen's d was applied to estimate the size of the effects. All statistical analyses were performed using R v3.6.3 (R Core Team, 2020).

3 | RESULTS

The differences in the students' performances in the "Experience" test and the "Traditional" test and the perception of the level of usefulness of the questions according to group (Experimental vs. Control) are shown in Table 3. Compliance with the assumption of normality of the dependent variables in both learning units, the "Respiratory System" and "Digestive System," was evaluated using the Shapiro–Wilk test. The residuals were normally distributed for the performance of the control group ($W = 0.96$, $p = 0.5$) in the "Respiratory System" but not for the experimental group ($W = 0.937$, $p < 0.001$). With the "Digestive System," evidence of compliance with the assumption was obtained in both the control group ($W = 0.92$, $p = 0.09$) and the experimental group ($W = 0.99$, $p = 0.8$). Regarding the perception of the level of usefulness of the questions, no evidence was obtained that the residuals were normally distributed in the "Respiratory System" unit ($W = 0.87$, $p = 0.01$ in the control group and $W = 0.88$, $p < 0.001$ in the experimental group) or the "Digestive System" ($W = 0.85$, $p = 0.004$ in the control group and $W = 0.87$, $p < 0.001$ in the experimental group).

The results of the Levene test indicated that the performance variances were equal between the groups, as were the variances of perception of level of usefulness in both learning units ($p > 0.05$) for the "Respiratory System." No evidence was obtained of homogeneity of variances between the groups regarding performance in the "Digestive System" learning unit ($p = 0.02$). The Welch *t*-test was used to evaluate these differences. It is less restrictive and does not assume that the group variances are equal.

The results of the *t*-test of the student's scores in the "Traditional" test in the "Respiratory System" learning unit indicate that the experimental group showed significantly lower performance than the control group (t (89) = −2.79, $p = 0.01$, 95% CI [−1.79, −0.3]). However, the effect size was medium ($d = 0.71$). In the "Digestive System" learning unit, there were no statistically significant differences in the performances of the groups in the "Traditional" test, according to the results of the Welch *t*-test (t (24.74) = −0.07, $p = 0.94$, 95% CI [−0.74, 0.69]), and the effect size was not significant ($d = 0.02$). Regarding the perception of the level of usefulness of the questions, no differences were observed between the groups or in the "Respiratory System" learning unit (t (89) = −1.36, $p = 0.18$, 95% CI [−0.74, 0.14], $d = 0.34$) or the "Digestive System" learning unit (t (89) = −0.56, $p = 0.58$, 95% CI [−0.57, 0.32], $d = 0.14$).

TABLE 3 Descriptive statistics by experimental group and control group.

	Control group					Experimental group				
	Mean	SD	Mean	Min.	Max.	Mean	SD	Mean	Min.	Max.
"Respiratory" unit										
Traditional grade	6.04	1.62	6.35	2.90	8.90	4.99	1.44	5.40	3.30	7.10
Experience grade						5.10	1.48	5.55	4.20	7.80
Utility level question	3.85	0.88	4.00	2.00	5.00	3.55	0.87	4.00	1.00	5.00
Experience satisfaction level						3.59	0.84	4.00	2.00	5.00
"Digestive" unit										
Traditional grade	6.06	1.46	6.53	3.78	8.35	6.04	1.04	5.98	4.20	8.50
Experience grade						6.36	1.14	6.29	4.30	9.20
Utility level question	3.9	0.79	4.00	2.00	5.00	3.77	0.91	4.00	2.00	5.00
Experience satisfaction level						3.89	0.78	4.00	2.00	5.00

TABLE 4 Descriptive statistics per "respiratory system" and "digestive system" learning unit for the experimental group.

	Mean	SD	Mean	Min.	Max.
"Respiratory" unit					
Traditional test grade	4.99	1.44	5.40	1.30	7.10
Experience grade	5.10	1.48	5.55	1.20	8.80
Utility level question	3.55	0.87	4.00	1.00	5.00
Experience satisfaction level	3.59	0.84	4.00	2.00	5.00
"Digestive" unit					
Traditional test grade	6.04	1.04	5.98	3.20	8.50
Experience grade	6.36	1.14	6.29	3.30	9.20
Utility level question	3.77	0.91	4.00	2.00	5.00
Experience satisfaction level	3.89	0.78	4.00	2.00	5.00

The descriptive statistics per learning unit ("Respiratory System" and "Digestive System") for the experimental group show that the average performance in the "Experience" test was higher than that of the "Traditional" test in both units under analysis, especially in the "Digestive System." Likewise, at a descriptive level, the usefulness of the questions asked was perceived as greater and the level of satisfaction was greater for the intervention in the "Digestive System" unit than the "Respiratory System" unit. These results are shown in Table 4.

The results of the Shapiro-Wilks test indicate that the residuals were distributed normally for performance in the population of the "Digestive System" learning unit ($W = 0.99$, $p = 0.94$ in the "Experience" test, and $W = 0.99$, $p = 0.8$ in the "Traditional" test). In the "Respiratory System" learning unit, there was no evidence of compliance with the assumption of normality in the distribution of performance ($W = 0.95$, $p = 0.01$ in the "Experience" test and $W = 0.93$, $p < 0.001$ in the "Traditional" test). Regarding the perception of the usefulness of the questions, no evidence was obtained of compliance with the assumption of normality in the distribution in either the "Respiratory System" learning unit ($W = 0.88$, $p < 0.001$) or the "Digestive" learning unit ($W = 0.87$, $p < 0.001$). For the dependent variable of satisfaction with the experience, the residuals were normally distributed in neither the "Respiratory" learning unit ($W = 0.87$, $p < 0.001$) nor the "Digestive" learning unit ($W = 0.85$, $p < 0.001$).

Concerning the effect of the intervention on the students' performances in the two learning units, the paired samples *t*-test in the "Respiratory System" unit offered evidence of a marginally significant difference in performance between the "Traditional" test and the "Experience" test (t (70) $= -1.82$, $p = 0.07$, 95% CI [−0.23, 0.01]). The effect size was not significant ($d = 0.08$). In the "Digestive System" learning unit, there were significant differences in the students' scores between the "Traditional" test and the "Experience" test (t (70) $= -7.33$, $p < 0.001$, 95% CI [−0.41, −0.23]). The effect size was small ($d = 0.28$).

When the performances in the two learning units in each test were compared, the scores on the "Traditional" test were significantly higher in the "Digestive" learning unit than the "Respiratory" learning unit (t (70) $= -6.32$, $p < 0.001$, 95% CI [−1.37, −0.71]), with a large effect size ($d = 0.82$). The scores were also significantly better in the "Digestive" than in the "Respiratory" in the "Experience" test (t (70) $= -7.86$, $p < 0.001$, 95% CI [−1.57, −0.93]), also with a large effect size ($d = 0.93$).

As for the perceived level of usefulness of the questions, the differences between the "Respiratory System" and "Digestive System" learning units were marginally significant (t (70) $= -1.69$, $p = 0.1$, 95% CI [−0.49, 0.04]) with a small effect size ($d = 0.25$). Students in the "Digestive System" academic unit expressed greater satisfaction with the experience than those in the "Respiratory System" (t (70) $= -2.41$, $p = 0.02$, 95% CI [−0.54, −0.05]), with a small effect size ($d = 0.36$).

4 | DISCUSSION

This study answers the research question as to whether the personalized adaptation of learning based on metacognitive profiles affects the performances of human anatomy students. The control and experimental groups were compared quantitatively on the "Respiratory System" and "Digestive System" learning units. To this end, two pedagogical interventions in human anatomy were designed and implemented in which various educational technologies were used to personalize learning environments. This personalization considered the metacognitive profiles of the students, the domain according to Bloom's taxonomy, and the difficulty level of the questions.

The learning process in a human anatomy course involves more than memorizing structures. It includes understanding relationships, their integration with other disciplines, and their application in clinical practice (Brunstein, 2014). Evaluation of performance during the first years of medical undergraduate studies is usually traditional. It is largely based on the transfer of content and information, often without promoting a constructivist approach to learning (Bernal-García et al., 2022; Hernández-Huaripaucar & Calmett, 2020; Santos Hernández et al., 2020). To promote new didactic approaches in the teaching and learning of human anatomy, this study provides a methodological base from which it can be demonstrated that the understanding of metacognitive profiles and the personalization of learning can influence student performance and the quality of education positively.

In terms of the educational implications, our results highlight the importance of considering the context and purpose of the assessment when an appropriate learning modality and path is selected. In the analysis of the grades obtained by the students in the two evaluation modalities ("Experience" and "Traditional") for the two learning units ("Respiratory System" and "Digestive System"), the "Experience" modality stands out as accounting for the higher grades in the "Digestive System" learning unit. The results of the effect of the intervention on student performance and the paired samples *t*-test for the "Digestive System" learning unit revealed significant differences in the student's grades between the "Traditional" test and the "Experience" tests. Students who answered the questions in the "Experience" modality showed better academic performances. The "Experience" modality presented four learning paths designed according to the metacognitive profiles of the students, the level of mastery, and the difficulty of the questions. In contrast, in the "Experience" modality for the "Respiratory System" learning unit, the effect of the intervention on the students' performance differed only slightly between the "Traditional" and "Experience" tests, with marginal significance. That is, academic performance in the "Experience" test for the "Respiratory System" learning unit was not better than the grades obtained in the "Traditional" test.

The "Respiratory System" unit for the "Experience" modality was not designed with learning paths. However, the questions given to the students were classified by level of mastery and difficulty without differentiating their metacognitive profiles. These results raise relevant questions about personalizing learning in different contexts to optimize academic performance. They also highlight the importance of continued research to refine personalized teaching strategies supported by empirical data, particularly in highly complex academic disciplines.

Personalization of health learning involves adapting training to the individual needs of students. This is achieved through competency-based approaches, educational technology, formative assessment, a student-centered approach, and curricular flexibility. Together, these enable more competent and prepared professionals to be trained to address the complexities of the current healthcare field (Goldenberg et al., 2021; Tzenios, 2020). In this sense, our study addresses four types of metacognitive profiles based on the stated personal learning characteristics and, in turn, identifies the metacognitive processes of medical students. In this way, the "Experience" modality, designed from the assignment of four learning paths based on the metacognitive profiles and the mastery and difficulty of the "Respiratory System" and "Digestive System" questions, allowed the "Reflective" students to benefit from a learning path that contained questions at the analysis mastery and high difficulty levels. The "Active" students performed better on the learning path designed with identification-comprehension mastery and low-to-medium difficulty questions. The "Theoretical" students achieved better grades when the learning path gave them application-analysis mastery and high-difficulty level questions. Those more "Pragmatic" students who adapted better to different contexts and educational approaches benefited from the learning path that gave them application mastery and medium-high difficulty level questions. These observations are consistent with research demonstrating how metacognitive preferences affect students' relationships with instruction and learning (Delgado Martínez & Mahecha Fontecha, 2021; Kwarikunda et al., 2022; Valdez, 2022). The application of the four metacognitive profile classifications "Active," "Pragmatic," "Theoretical," and "Reflective" is a relevant contribution to the research because it provides a perspective for analyzing students' responses to different learning paths. These profiles, supported by the educational psychology literature (Corva, 2022; Hong et al., 2020), suggest that students vary in their preferences and metacognitive strategies throughout their teaching and learning histories, and this can influence their academic performances positively (Montoya Villena & Pinedo Pichilingue, 2022; Solórzano-Restrepo & López-Vargas, 2019). Considering the metacognitive profiles of the students opens the possibility of designing more effective teaching strategies. By adjusting questions based on mastery and difficulty, a more personalized learning experience is achieved. These facts, theoretically supported by the level of competence of the students and the learning objectives of the human anatomy course, can generate a valuable tool for improving academic performance (Calle Sánchez & Vanegas Jaramillo, 2021; Coll Salvador et al., 2023).

In summary, our study has explored how the metacognitive profiles of students and the adaptation of questions according to their level of mastery and difficulty improve academic performance. Not least, we also explored how educational technologies can be used to design personalized learning environments to that end, in this case for studying human anatomy in medical courses. The findings reveal a connection among pedagogical approaches, metacognitive profiles, and question classification and show how those factors influence student performance in the "Respiratory" and "Digestive" areas. Identifying distinct metacognitive profiles adds depth to our understanding of how students approach learning. Furthermore, personalization based on the metacognitive profile affected student performance significantly. The differences in the evaluation modalities highlight the effectiveness of the "Experience" modality concerning the metacognitive profile and the adaptation of learning paths. These results emphasize the adaptation of teaching and assessment strategies based on individual preferences and needs. If addressed, it will lead to greater student engagement and satisfaction.

5 | CONCLUSIONS

The present study has focused on analyzing the relationship between the metacognitive profiles of the students and the classification of questions according to their level of difficulty and mastery in anatomical understanding. It has also examined the integration of educational technologies to create personalized learning environments for medical students learning about the human anatomical system. A detailed analysis of the results revealed differences in student performance related to the pedagogical approaches used, the metacognitive profiles of the students, and the strategic categorization of questions based on their complexity and scope.

The metacognitive profiles identified ("Active," "Pragmatic," "Theoretical," and "Reflective") offer a unique perspective for understanding how students respond to different approaches to teaching and how their preferences and learning strategies influence their performance. Personalized adaptation based on these profiles has shown the potential to improve grades and increase student satisfaction and engagement with learning.

The "Experience" assessment modality, designed to align learning paths with metacognitive profiles and question classification, affected student performance positively in comparison to the "Traditional" modality. However, there was also greater variability in the "Experience" modality scores, which suggests that students respond differently to this modality depending on their metacognitive strategies and their individual adaptation to the designed learning routes.

In conclusion, the present study has valuable pedagogical implications. It has demonstrated that adapting teaching and assessment strategies according to individual characteristics such as metacognitive profiles improve the quality of learning and increases student engagement. Medical education benefits from considering these differences and implementing personalized approaches that respond to students' individual needs and preferences. This study contributes to medical education by providing a framework for designing personalized and effective learning environments in human anatomy.

6 | LIMITATIONS

This article focuses on a study that investigated the personalized adaptation of learning in the context of human anatomy, specifically in the "Respiratory System" and "Digestive System" units. Despite its valuable contributions, the study had some limitations that require consideration and critical analysis.

One limitation concerns the control of external variables that could influence student achievement. Aspects such as the time dedicated to studying, student motivation, and learning conditions should be discussed or controlled. This lack of control for external variables makes it difficult to attribute the results solely to personalized adaptation of learning and leaves open the possibility of influences from unexamined factors.

The study focused on short-term academic performance in the "Respiratory System" and "Digestive System" learning units. However, how these interventions could influence long-term learning and whether the benefits are sustainable need to be considered. Long-term learning and knowledge retention are important aspects of education. Therefore, a long-term follow-up analysis is needed to assess the effects of personalized adaptation strategies fully.

The study focused on grades as a measure of student achievement. Other dimensions of learning, such as the deep understanding of concepts or applications to real clinical situations, need to be addressed. Measuring performance solely through grades could present a limited view of the effects of interventions on the learning process; a more thorough understanding of those effects is needed.

In summary, it is essential to consider these limitations when interpreting the results and considering their applicability to other educational contexts, notwithstanding the significant contributions of this study. The limitations cited offer opportunities for future research to address them and provide a more complete understanding of the personalized adaptation of learning in human anatomy and medical education.

7 | FUTURE WORK

Based on the conclusions derived from this study and its limitations, several directions are opened for future research aimed at expanding and enriching our understanding of the interaction between the metacognitive profiles of students and the personalization of learning environments. First, to increase the findings' external validity, a more extensive and more diverse sample of medical students from different institutions and educational contexts could be considered. This would allow for a more substantial generalization of the results and the identification of more robust patterns in the relationship between metacognitive profiles and academic performance. Second, since metacognitive processes are complex, future research could investigate further segmentation and analysis of the metacognitive profiles. This could involve identifying subgroups within existing profiles or including new and emerging profiles. A third approach could be to adopt a longitudinal perspective. That would provide a deeper understanding of how metacognitive profiles and learning personalization evolve, potentially allowing for changes in learning preferences and strategies to be observed as student's progress in their training. Fourth, extending the analysis to other academic fields would be worthwhile. Doing so could reveal whether the relationships between metacognitive profiles and personalization of learning are generalizable or specific to certain fields. It would provide a broader perspective on how to adapt educational strategies to different contexts. Fifth, one could explore how external factors such as the teacher's teaching style, group dynamics, and institutional characteristics interact with metacognitive profiles and personalization of learning. This would also contribute to a greater understanding of the complex interactions that influence learning. Finally, the possibility of collaborating with fields such as cognitive psychology, educational neuroscience, and artificial intelligence would enrich our understanding of the cognitive, emotional, and technical aspects of learning personalization based on metacognitive profiles.

ACKNOWLEDGMENTS

Our gratitude goes out to the researchers from the Clinical Anatomy, Embryology and Neuroscience (NEOMA) research group and the participating students and teachers from the Introduction to the Study of Medicine: Study of the Structure and Function of the Human Body II at the University of Girona, Spain. The authors also sincerely thank those who donated their bodies to science so that anatomical

research could be performed. Results from such research can potentially increase humankind's overall knowledge and improve patient care. Therefore, these donors and their families deserve our highest gratitude (Iwanaga, Loukas, et al., 2021; Iwanaga, Singh, et al., 2021).

FUNDING INFORMATION

This work received support from the National Research and Development Agency of Chile (ANID/Programa de Becas/DOCTORADO NACIONAL/2020-21200443). Partial support was also received from the H2O Learn project (PID2020-112584RB-C31), funded by MCIN/AEI/10.13039/50110001103.

ORCID

Mónica Stambuk-Castellano https://orcid.org/0000-0002-5631-117X
Anna Carrera https://orcid.org/0000-0003-3265-2778
R. Shane Tubbs https://orcid.org/0000-0003-1317-1047
Carlos Alario-Hoyos https://orcid.org/0000-0002-3082-0814
Enric Verdú https://orcid.org/0000-0002-0816-1146
Joe Iwanaga https://orcid.org/0000-0002-8502-7952
Francisco Reina https://orcid.org/0000-0002-2664-2277

REFERENCES

Alonso, C., & Gallego, D. (2000). Cuestionario Honey-Alonso de estilos de aprendizaje CHAEA. www. aprender. org. ar/aulas/avadim/recursos/chaea1.rtf (01.12. 2008).

Altamirano, C., & Javiera, F. (2017). *Factores asociados para el logro de aprendizajes significativos en la Asignatura de Anatomía Humana I, con los estudiantes de primer año, de la Carrera de Medicina en la Facultad de Ciencias Médicas*, Universidad Nacional Autónoma de Nicaragua (UNAN-Managua), 2016.

Alzate-Mejía, O. A., & Tamayo-Alzate, O. E. (2019). Metacognición en el Aprendizaje de la Anatomía. *International Journal of Morphology*, *37*(1), 7–11.

Araujo Cuauro, J. C. (2018). Aspectos históricos de la enseñanza de la anatomía humana desde la época primitiva hasta el siglo XXI en el desarrollo de las ciencias morfológicas. *Revista Argentina de Anatomía Online*, *9*(3), 87–97.

Araujo Nasayo, D., & García Valbuena, C. G. (2022). *Desarrollo de la motivación hacia el aprendizaje y la comprensión de la anatomía del cuerpo humano, en estudiantes del grado séptimo dentro del área de ciencias naturales, a través del uso de la realidad aumentada en las Instituciones Educativas Rurales Simón Bolívar y Guamales* [Master's thesis, Universidad del Norte]. 1–139.

Arráez-Aybar, L. A., Sánchez-Montesinos, I., Mirapeix, R. M., Mompeo-Corredera, B., & Sañudo-Tejero, J. R. (2010). Relevance of human anatomy in daily clinical practice. *Annals of Anatomy-Anatomischer Anzeiger*, *192*(6), 341–348.

Bernal-García, M., Quemba-Mesa, M., Silva-Ortiz, S., & Pacheco-Olmos, B. (2022). Laboratorios tradicionales versus nuevas tecnologías para el estudio de anatomía humana en estudiantes de medicina: Revisión sistemática y meta análisis. *International Journal of Morphology*, *40*(1), 30–36.

Bloom, B. S. (1977). *Taxonomía de los objetivos de la educación*. El Ateneo.

Brunstein, J. U. A. N. (2014). *Experiencias de los académicos acerca de Enseñar, Aprender y Evaluar Anatomía Humana* (Doctoral dissertation), Pontificia Universidad Católica de Chile, Santiago de Chile. 60(2), 1–312.

Calle Sánchez, M. C., & Vanegas Jaramillo, A. (2021). *DoctoLab: Estrategias metacognitivas y de aprendizaje desde la neuroeducación para el mejoramiento del rendimiento académico de los estudiantes de primero y segundo semestre de Medicina de la Universidad CES* (pp. 1–110). Medellín.

Cárdenas-Valenzuela, J. (2020). Historia de la Anatomía en Chile Parte II. El Alma Mater. *International Journal of Morphology*, *38*(4), 1074–1089.

Castañeda, L., Main, G., & Benzi, P. (2021). *Desarrollo de competencias académicas específicas para el aprendizaje de la Anatomía Humana* (p. 39). Adriana Emilia Ortolani-Hector Santiago Odetti.

Castrillón Rivera, E. M., Morillo Puente, S., & Restrepo Calderón, L. A. (2020). Diseño y aplicación de estrategias metacognitivas para mejorar la comprensión lectora en estudiantes de secundaria. *Ciencias Sociales y Educación*, *9*(17), 203–231.

Chan, A. Y. C. C., Ten Cate, O., Custers, E. J., van Leeuwen, M. S., & Bleys, R. L. (2019). Approaches of anatomy teaching for seriously resource-deprived countries: A literature review. *Education for Health*, *32*(2), 62–74.

Cheung, C. C., Bridges, S. M., & Tipoe, G. L. (2021). Why is anatomy difficult to learn? The implications for undergraduate medical curricula. *Anatomical Sciences Education*, *14*(6), 752–763.

Coll Salvador, C., Díaz Barriga Arceo, F., Engel Rocamora, A., & Salinas Ibáñez, J. M. (2023). Evidencias de aprendizaje en prácticas educativas mediadas por tecnologías digitales. *RIED. Revista Iberoamericana de educación a Distancia*, *26*(2), 9–25.

Corva, M. A. (2022). *Estudio longitudinal sobre los Estilos de Aprendizaje en estudiantes de Medicina* [Master's thesis, Universidad FASTA, Mar del Plata]. 1–47.

De Oliveira, V. F., Ramos, A. P., Tomaz, J. F. M., dos Reis, M. C., da Silva Pereira, E., Gondim, V. J. T., Santana, R. D., Alexandria, A. R., & Albuquerque, V. H. C. (2022). A brief review on innovative anatomy learning technologies for medical and health students education. *Recisatec-Revista Científica Saúde E Tecnologia*, *2*(4), e24121.

Delgado Martínez, J. L., & Mahecha Fontecha, M. A. (2021). *Relación entre los estilos de aprendizaje, según el modelo de programación neurolingüística (PNL) y el desarrollo de la capacidad metacognitiva en estudiantes de dos centros educativos de Huila y Bogotá, Colombia* [Doctoral dissertation]. Corporación Universitaria Minuto de Dios, 1–190.

Dharmasaroja, P. (2019). Do we not really need cadavers anymore to learn anatomy in undergraduate medicine? *Medical Teacher*, *41*(8), 965–966. https://doi.org/10.1080/0142159X.2018.1548760

Díaz Flores, O. (2014). *Estrategias de aprendizaje que facilitan aplicar el conocimiento en la materia anatomía humana en las diversas licenciaturas que conforman la Facultad de Medicina de la Benemérita Universidad Autónoma de Puebla* [Master's thesis]. 1–84.

Diaz Pérez, M., & Colorado Aguilar, B. (2020). Estudio para realizar la acción tutorial a través de un sistema de gestión de aprendizaje en Moodle para el nivel de secundaria. *MLS Educational Research (MLSER)*, *4*(1), 41–56. https://doi.org/10.29314/mlser.v4i1.260

Estai, M., & Bunt, S. (2016). Best teaching practices in anatomy education: A critical review. *Annals of Anatomy-Anatomischer Anzeiger*, *208*, 151–157.

Fagalde, M. C., & McNulty, M. A. (2023). Determining baseline anatomy knowledge among professional allied health students. *Anatomical Sciences Education*, *16*(2), 334–347.

Flavell, J. H. (1977). *Cognitive development*. Englewood Cliffs.

Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive–developmental inquiry. *American Psychologist*, *34*(10), 906–911.

Fowler, B. (2002). La taxonomía de Bloom y el pensamiento crítico. Gabriel Piedrahita U. Foundation Published on September 1–4.

García, L. S., Zuñiga, J., & Perez-Trejos, L. E. (2021). Las tecnologías e-learning y TIC en el aprendizaje a largo plazo de la anatomía humana en estudiantes del área de la salud: una revisión de la literatura. *International Journal of Morphology*, *39*(2), 396–400.

Goldenberg, D., Kofman, K., Albert, J., Mizrachi, S., Horowitz, A., & Teinemaa, I. (2021). Personalization in practice: Methods and applications. In Proceedings of the 14th ACM international conference on web search and data mining (1123-1126).

González La Nuez, O., & Suárez Surí, G. (2018). Los medios de enseñanza en la didáctica especial de la disciplina Anatomía Humana. *Revista Médica Electrónica*, *40*(4), 1126–1138.

González Pulido, P. F. (2023). *Enfoques de aprendizaje en estudiantes de anatomía* [Master's thesis, Universidad de La Sabana].

Hall, S., Stephens, J., Parton, W., Myers, M., Harrison, C., Elmansouri, A., Lowry, A., & Border, S. (2018). Identifying medical student perceptions on the difficulty of learning different topics of the undergraduate anatomy curriculum. *Medical Science Educator*, *28*, 469–472.

Hamilton, D., McKechnie, J., Edgerton, E., & Wilson, C. (2021). Immersive virtual reality as a pedagogical tool in education: A systematic literature review of quantitative learning outcomes and experimental design. *Journal of Computers in Education*, *8*(1), 1–32.

Harrell, K. M., McGinn, M. J., Edwards, C. D., Warren Foster, K., & Meredith, M. A. (2021). Crashing from cadaver to computer: Covid-driven crisis-mode pedagogy spawns active online substitute for teaching gross anatomy. *Anatomical Sciences Education*, *14*(5), 536–551.

Heredia-Escorza, Y., & Sánchez-Aradillas, A. L. (2013). Teorías del aprendizaje en el contexto educativo. *Editorial Digital Tecnológico de Monterrey*, *38*(2), 1–306.

Hernández-Huaripaucar, E. M., & Calmett, R. M. Y. (2020). El Aprendizaje Basado en Problemas (ABP) como estrategia didáctica innovadora en la enseñanza de la Anatomía Humana. *Horizonte de la Ciencia*, *10*(19), 165–177.

Hertzog, C. Dixon, R.A. (1994) "Metacognitive development in adulthood and old age" en Metcalfe, J. y Shimamura A. (Eds.) *Metacognition: knowing about knowing* MIT Press (227–251).

Hong, W., Bernacki, M. L., & Perera, H. N. (2020). A latent profile analysis of undergraduates' achievement motivations and metacognitive behaviors, and their relations to achievement in science. *Journal of Educational Psychology*, *112*(7), 1409–1430.

Iwanaga, J., Loukas, M., Dumont, A. S., & Tubbs, R. S. (2021). A review of anatomy education during and after the COVID-19 pandemic: Revisiting traditional and modern methods to achieve future innovation. *Clinical Anatomy*, *34*(1), 108–114.

Iwanaga, J., Singh, V., Ohtsuka, A., Hwang, Y., Kim, H. J., Moryś, J., Ravi, K. S., Ribatti, D., Trainor, P. A., Sañudo, J. R., Apaydin, N., Şengül, G., Albertine, K. H., Walocha, J. A., Loukas, M., Duparc, F., Paulsen, F., Del Sol, M., Adds, P., … Tubbs, R. S. (2021). Acknowledging the use of human cadaveric tissues in research papers: Recommendations from anatomical journal editors. *Clinical Anatomy*, *34*(1), 2–4.

Jaramillo, S., & Osses, S. (2012). Validación de un instrumento sobre metacognición para estudiantes de segundo ciclo de educación general básica. *Estudios Pedagógicos*, *38*(2), 117–131.

Kolb, D. A. (1999). Learning style inventory: Version 3. Hay/McBer Training Resources Group.

Kumar, R., & Singh, R. (2020). Model pedagogy of human anatomy in medical education. *Surgical and Radiologic Anatomy*, *42*, 355–365.

Kwarikunda, D., Schiefele, U., Muwonge, C. M., & Ssenyonga, J. (2022). Profiles of learners based on their cognitive and metacognitive learning strategy use: Occurrence and relations with gender, intrinsic motivation, and perceived autonomy support. *Humanities and Social Sciences Communications*, *9*(1), 1–12.

Latarjet, M., & Liard, A. R. (2004). Anatomía humana. 2a ed. Buenos Aires Ed. Médica Panamericana. [Libro].

Latarjet, M., Liard, A. R., & Pro, E. A. (2019). Anatomía Humana. 5a ed. Buenos Aires, Ed. Médica Panamericana. [Libro].

Marcén, E. (2008). Estilos de aprendizaje (Facultades de Medicina) (No. Book -2020-096). Prensas Universitarias de Zaragoza. 1–140.

Martins, M., Padovez, J., Silva, V., Kobayasi, R., Arantes, F., Zen, P., & Arruda, M. (2020). Relationship between metacognitive awareness and motivation to learn in medical students. *BMC Medical Education*, *20*(1), 1–10.

McBride, J. M., & Drake, R. L. (2018). National survey on anatomical sciences in medical education. *Anatomical Sciences Education*, *11*(1), 7–14.

McHanwell, S., Davies, D. C., Morris, J., Parkin, I., Whiten, S., Atkinson, M., Dyball, R., Ockleford, C., Standring, S., & Wilton, J. (2021). A core syllabus in anatomy for medical students-adding common sense to need to know. *European Journal of Anatomy*, *11*(S1), 3–18.

McMenamin, P. G., McLachlan, J., Wilson, A., McBride, J. M., Pickering, J., Evans, D. J., & Winkelmann, A. (2018). Do we really need cadavers anymore to learn anatomy in undergraduate medicine? *Medical Teacher*, *40*(10), 1020–1029.

Medina, N. S., del Valle Díaz, M. S., Collado, N. R., & Borobia, J. C. (2023). Evaluación del aprendizaje profundo metacognitivo y autodeterminado en estudiantes universitarios. *Retos: Nuevas Tendencias en educación física, Deporte y recreación*, *48*, 861–872.

Merrill, M. D. (2013). Constructivism and instructional design. In *Constructivism and the technology of instruction* (pp. 99–114). Routledge.

Montoya Villena, L. A., & Pinedo Pichilingue, A. A. (2022). *Estrategias metacognitivas y estilos de aprendizaje en estudiantes de segundo año de la escuela de Medicina de una universidad privada de Lima, en el ciclo académico 2021-II* [Master thesis, Universidad Tecnológica] Lima, Perú. 1–178.

Moore, K. L., Dalley, A. F., & Agur, A. M. (2013). Clinically oriented anatomy. *Lippincott Williams & Wilkins*, *62*, 625–683.

Ordóñez Aguilar, J. E. (2023). *Estrategias para mediar, el aprendizaje con sentido, en la docencia universitaria médica* [Master's thesis, Universidad del Azuay], Cuenca, Ecuador. 1–222.

Osorio, M., & Zolano, V. (2022). *Autorregulación del aprendizaje, estrategias metacognitivas de aprendizaje y rendimiento académico en estudiantes de la Facultad de Ciencias de la Educación de la Universidad Nacional Daniel Alcides Carrión-Pasco*, Perú. [Master's Thesis]. 1–102.

Osses Bustingorry, S., & Jaramillo Mora, S. (2008). Metacognición: un camino para aprender a aprender. *Estudios Pedagógicos*, *34*(1), 187–197.

Osses-Bustingorry, S. E., Carrasco-Delgado, L. E., & Gálvez-Nieto, J. L. (2018). Efecto de una estrategia pedagógica sobre el desarrollo metacognitivo de adolescentes chilenos. *Estudios Pedagógicos*, *44*(1), 69–88.

Pastén, L. E. (2021). Pensamiento metacognitivo, y creativo en contextos educativos: Conceptualización y sugerencias didácticas. *Psicologia Escolar E Educacional*, *25*, e220278.

Quelca Choque, H. G. (2022). *Experiencias con Preparaciones Cadavéricas y el Rendimiento Academico de los Estudiantes de Anatomia Humana de la Facultad de Odontología de la UMSA, 2019· 2020 [Doctoral dissertation, Universidad Mayor de San Andrés]* (pp. 1–171). RI-UMSA, Institutional Repository.

R Core Team. (2020). *R: a language and environment for statistical computing*. R Foundation for Statistical Computing https://www.R-project.org/

Robles Melgarejo, H. (2022). Estrategias metacognitivas y el desarrollo de competencias clínicas en internos de obstetricia, en un hospital nacional de Lima, 2022. [Master's thesis, Universidad César Vallejo]. 1–109.

Rodríguez, A. L. L., Barrenechea, A. L. H., González, L. E. M., & Alfonso, Y. L. L. (2021). La educación alimentaria y nutricional desde el proceso de enseñanza-aprendizaje de la Anatomía y Fisiología Humana. *Anatomía Digital*, *4*(2), 30–39.

Romero-Reverón, R. (2020). La enseñanza de la anatomía humana a los estudiantes de medicina de la Generación Z. Briceño-Iragorry L, Urbina Medina H, editores. Colección Razetti. Volumen XXIII. Caracas: Editorial Ateproca, 93-99.

Santos Hernández, E., Pelcastre Neri, A., & Ruvalcaba Ledezma, J. C. (2020). Impacto del enfoque constructivista en el proceso de nivelación de enfermería. *Journal of Negative and No Positive Results*, *5*(1), 91–103.

Sbayeh, A., Qaedi Choo, M. A., Quane, K. A., Finucane, P., McGrath, D., O'flynn, S., O'Mahony, S. M., & O'Tuathaigh, C. M. (2016). Relevance of anatomy to medical education and clinical practice: Perspectives of medical students, clinicians, and educators. *Perspectives on Medical Education*, *5*, 338–346.

Schraw, G., & Dennison, R. S. (1994). Assessing metacognitive awareness. *Contemporary Educational Psychology*, *19*(4), 460–475.

Simó, V. L., & Domènech-Casal, J. (2018). Juegos y gamificación en las clases de ciencia: ¿una oportunidad para hacer mejor clase o para hacer mejor ciencia? *Revista Eletrônica Ludus Scientiae*, *2*(1), 34–44.

Simón Medina, N., Del Valle Díaz, S., Rioja Collado, N., & Cuadrado Borobia, J. (2023). Evaluación del aprendizaje profundo metacognitivo y autodeterminado en estudiantes universitarios. Retos: Nuevas Perspectivas de Educación Física. *Deporte y Recreación*, *48*, 861–872.
Smith, C. F., Freeman, S. K., Heylings, D., Finn, G. M., & Davies, D. C. (2022). Anatomy education for medical students in the United Kingdom and Republic of Ireland in 2019: A 20-year follow-up. *Anatomical Sciences Education*, *15*(6), 993–1006.
Solórzano-Restrepo, J., & López-Vargas, O. (2019). Efecto diferencial de un andamiaje metacognitivo en un ambiente e-learning sobre la carga cognitiva, el logro de aprendizaje y la habilidad metacognitiva. *Suma Psicológica*, *26*(1), 37–45.
Suárez-Escudero, J. C., Posada-Jurado, M. C., Bedoya-Muñoz, L. J., Urbina-Sánchez, A. J., Morales, J. L. F., & Bohórquez-Gutiérrez, C. A. (2020). Enseñar y aprender anatomía. *Acta Médica Colombiana*, *45*(4), 1–8.
Tibán, S., & del Rocío, C. (2023). *Estrategia didáctica basada en el aprendizaje por descubrimiento para el fortalecimiento del pensamiento crítico en estudiantes de Bachillerato Técnico* [Master's thesis, Universidad Tecnològica Indoamèrica], Ambato, Ecuador. 1–136.
Triepels, C. P. R., Koppes, D. M., Van Kuijk, S. M. J., Popeijus, H. E., Lamers, W. H., Van Gorp, T., Futterer, J. J., Kruitwagen, R. F. P. M., & Notten, K. J. B. (2018). Medical students' perspective on training in anatomy. *Annals of Anatomy-Anatomischer Anzeiger*, *217*, 60–65.
Turney, B. W. (2007). Anatomy in a modern medical curriculum. *The Annals of the Royal College of Surgeons of England*, *89*(2), 104–107.
Tzenios, N. (2020). Clustering students for personalized health education based on learning styles. *Sage Science Review of Educational Technology*, *3*(1), 22–36.
Valderrama Wong, M. J. C. (2022). *Estrategia metodológica para el desarrollo del aprendizaje significativo en el curso de anatomía humana de la carrera de medicina de una universidad privada de Lima*. [Master's thesis, Universidad San Ignacio de Loyola], Lima, Perú. 1–118.
Valdez, J. R. (2022). *Estilos de aprendizaje de alumnos de primer año de medicina: un estudio exploratorio y descriptivo en la asignatura bioquímica médica* [Master's thesis, Facultad de Ingenieria, Universidad Nacional del Comahue], Neuquen, Argentina. 1–267.
Valdivieso Cavagnari, J. A. (2020). *Habilidades metacognitivas y estilos de aprendizaje en los médicos residentes de un hospital de Lima Norte*, 2020. [Master's thesis, Universidad César Vallejo], Lima, Perú. 1–79.
Vargas Gutiérrez, S. C. (2022). *Fortalecimiento de los procesos de enseñanza–aprendizaje, la formación de docentes a través del desarrollo de aplicaciones, software y juegos educativos, participando en los adelantos tecnológicos y las estrategias innovadoras de la Gamificación en las aulas de clase* [Doctoral dissertation, Universidad de Cartagena], Colombia, 1–123.
Vargas Lujan, C. A. (2023). *Estilos de aprendizaje y estrategias metacognitivas en estudiantes de medicina de una universidad privada*, Lima, 2022 [Master's thesis, Universidad César Vallejos], Lima, Perú. 1–95.
Venturelli, J. (1997). Educación Médica. Nuevos enfoques, metas y métodos. *Washington: Organización Panamericana de la Salud*, *53-55*(3), 1–307.
Williams, C. (2018). Student perspectives of an Interprofessional education experience for nurse anesthetist students and physical therapy students in a cadaver-based anatomy review course. *Open Access Library Journal*, *5*(8), 1–15.
Zibis, A., Mitrousias, V., Varitimidis, S., Raoulis, V., Fyllos, A., & Arvanitis, D. (2021). Musculoskeletal anatomy: Evaluation and comparison of common teaching and learning modalities. *Scientific Reports*, *11*(1), 1517.

How to cite this article: Stambuk-Castellano, M., Carrera, A., Tubbs, R. S., Alario-Hoyos, C., Verdú, E., Iwanaga, J., & Reina, F. (2024). Personalized strategies for academic success in learning anatomy: Exploring metacognitive and technological adaptation in medical students. *Clinical Anatomy*, *37*(4), 472–483. https://doi.org/10.1002/ca.24155