Annals of Anatomy 257 (2025) 152339

Contents lists available at ScienceDirect

Annals of Anatomy

journal homepage: www.elsevier.com/locate/aanat

B-learning in human anatomy: Comparative analysis of academic achievement between face-to-face and e-learning modalities

Josep Nebot-Cegarra [a,*], Carlos Nebot-Bergua [b,c,d], Jordi Gascón-Bayarri [a,e,f], Enric Macarulla-Sanz [g,h], Sílvia Ricart [i,j]

[a] Department of Morphological Sciences, Human Anatomy and Embryology Unit, Faculty of Medicine, Autonomous University of Barcelona, Av. Can Domènech, Edifici M, 08193 Cerdanyola del Vallés, Barcelona, Catalonia, Spain
[b] Neonatology Unit, Sant Joan de Déu Barcelona Hospital, Passeig Sant Joan de Déu, 2, 08950 Esplugues de Llobregat, Barcelona, Catalonia, Spain
[c] Neonatology Unit, San Pedro Hospital, Piqueras, 98, 26006 Logroño, La Rioja, Spain
[d] Faculty of Health Sciences, University of La Rioja, Duquesa de la Victoria, 88, 26004 Logroño, La Rioja, Spain
[e] Department of Neurology, Bellvitge University Hospital, Feixa Llarga, s/n, 08907 L'Hospitalet de Llobregat, Barcelona, Catalonia, Spain
[f] Research Group in Neurological Diseases and Neurogenetics, IDIBELL, Av. Gran Via de l'Hospitalet, 199, 08908 L'Hospitalet de Llobregat, Barcelona, Catalonia, Spain
[g] Department of Surgery, Igualada University Hospital, Av. Catalunya, 11, 08700 Igualada, Barcelona, Catalonia, Spain
[h] Department of Experimental Medicine, Faculty of Medicine, University of Lleida, Montserrat Roig, 2, 25008 Lleida, Catalonia, Spain
[i] Pediatrics Department, Sant Joan de Déu Barcelona Hospital, Passeig Sant Joan de Déu, 2, 08950 Esplugues de Llobregat, Barcelona, Catalonia, Spain
[j] Department of Surgery and Medical and Surgical Specialties, Faculty of Medicine and Health Sciences, University of Barcelona, Casanova 143, 08036 Barcelona, Catalonia, Spain

ARTICLE INFO

Keywords:
B-learning
E-learning
Face-to-face learning
Learning in anatomy
Anatomy and medical education
Human anatomy
Multiple-choice exams

ABSTRACT

Introduction: In recent years, modern technologies have become established in most educational fields. Thus, e-learning tends to be an integral part of the learner-centered learning process, with the teacher acting as a facilitator. However, the methodologies used to study the impact of e-learning have been varied and imprecise, making comparison and meta-analysis difficult. This study attempts to overcome these obstacles with a large and homogeneous sample to compare (1) the academic outcomes obtained with face-to-face and e-learning in a blended module of human anatomy and (2) the response attempts (response index) of each student in answering questions specific to each learning modality.

Material and methods: The results of the multiple-choice exams under study were collected. All students (n=1160) were from four consecutive academic years following the same teaching program with a b-learning method: 13 topics were presented face to face by the same lecturers, and six via e-learning with the same online resources. Two variables were compared: (1) the academic grade, based on the score for correct answers and the penalty for incorrect ones, and (2) the response index, based on the number of correct and incorrect answers.

Results: (1) 73.45 % of the examinees passed the test. In the sample as a whole, results were better in face-to-face than in e-learning. In the quartiles ordered by overall academic performance, this superiority was limited to the top half of the higher-performing students. In contrast, lower-scoring students performed better in e-learning. However, these differences were modest ($\leq$ 0.54 points). (2) In proportion, the questions on topics learned face-to-face were the most frequently answered. A strong correlation was observed between the variables in the whole sample and the students with the highest academic scores (first quartile) on the global exam and the questions on topics learned in each modality. In the remaining quartiles, the correlation was also strong in the e-learning content.

Conclusions: (1) Both modalities included in b-learning are academically effective. (2) Proportionally, students take more risks when answering content questions learned in face-to-face classes, and there is a strong correlation between response attempts and academic grades, especially, on the brightest exams and e-learning content.

* Corresponding author.
E-mail addresses: josep.nebot@uab.cat (J. Nebot-Cegarra), carlos.nebot@sjd.es (C. Nebot-Bergua), jordigneuro@bellvitgehospital.cat (J. Gascón-Bayarri), emacarulla@csa.cat (E. Macarulla-Sanz), silvia.ricart@sjd.es (S. Ricart).

https://doi.org/10.1016/j.aanat.2024.152339
Received 15 June 2024; Received in revised form 13 September 2024; Accepted 18 September 2024
Available online 26 September 2024

1. Introduction

Electronic learning (E-learning) based on computers, the Web (Ruiz et al., 2006), and mobile applications (Sonne et al., 2021; Rangel-de Lazaro and Duart, 2023) has been successively introduced due to the continuous development of digital technology.

The terms e-learning and online learning are often used interchangeably. The latter is broader and includes new developments in learning over the Internet, but excludes other offline electronic media (e.g., CDs, DVDs) (Bell and Federman, 2013).

Although it is too early to be certain, it may be that the forced implementation of online teaching during the SARS-CoV-2 virus pandemic was a dynamic factor in the expansion of this methodology by allowing testing with it, even for those teachers most resistant to change (Rajab et al., 2020), and to make it a permanent part of the educational strategy (Böckers et al., 2021; Evans and Pawlina, 2022; Messerer et al., 2023).

Before the pandemic, Bell and Federman (2013) noted that all indicators pointed to the unstoppable growth of e-learning in postsecondary education. This is evidenced by the design of specific plans for its development since the beginning of the century (Bates, 2001) and the increase in publications on online and blended postsecondary learning collected in broad reviews (Aristovnik et al., 2023; Bell and Federman, 2013; Wu, 2015; Hachey et al., 2022; Jeffs et al., 2024).

E-learning has been implemented as a main resource in distance universities. In others, blended learning (b-learning) has allowed face-to-face learning to coexist with e-learning (Kim et al., 2008; Vallée et al., 2020; Sáiz-Manzanares et al., 2022). In educational projects with flipped classrooms, e-learning has been an additional teaching resource for students to study and prepare lessons before classroom discussions (Jesurasa et al., 2017; Sierra-Fernández et al., 2023).

In medical education, online learning and assessment could soon become widespread (Saiyad et al., 2020), due to the pressing demand for more health professionals, especially in less developed countries (Barteit et al., 2020), and the increasing use of the Internet to obtain academic information (Kadam et al., 2018).

In anatomy courses, the pandemic proved to be the main reason (70.97 %) for the increase in e-learning (Abualadas and Xu, 2023). The consequences of restrictions on cadaver donations and their use in teaching during the pandemic have highlighted their importance for learning human anatomy (Brassett et al., 2020; Schulte et al., 2022).

The sudden shift from exclusively face-to-face teaching to online learning that occurred during the last pandemic has revealed some problems related to curriculum planning, student assessment, lack of personal interaction, inequality of individual access to online technology (Rajab et al., 2020), high cost of some multimedia materials, maintenance of Internet platforms, and technological preparedness of users (Vallée et al., 2020; Nuuyoma et al., 2023). On the other hand, it has shown that e-learning has improved access to information and its distribution by eliminating the need for the physical presence of students and teachers at specific times and places (Kemp and Grieve, 2014), with corresponding time savings (Rouleau et al., 2019); has allowed updating of subject matter; has facilitated personalized training, both in terms of pacing and content (customizing the look and feel of the system, adapting its use, setting one's own goals…) (Chin et al., 2019); has opened up the possibility of self-regulated learning (Saiyad et al., 2020), and provided the opportunity of immediate self-assessment (Chin et al., 2019). Although it is known how students interact with online resources, no relationship has been found between levels of engagement, usage, and assessment outcomes (Pickering and Swinnerton, 2019; Ullah et al., 2023). However, educational institutions that used e-learning intensively in the years leading up to the pandemic experienced less learning loss due to the health crisis (De Witte and François, 2023).

Some studies have shown that learning through electronic methods produces better academic results than face-to-face teaching (Kumta et al., 2003; Cook et al., 2008; Voutilainen et al., 2017; Barteit et al., 2020; Shikino et al., 2021), although others attributed this greater effectiveness to use in combination with face-to-face learning (b-learning) (Lehmann et al., 2015; Liu et al., 2016; McDonald et al., 2018; Means et al., 2013; Sheikhaboumasoudi et al., 2018; Vallée et al., 2020; Ødegaard et al., 2021; Sonne et al., 2021; Sáiz-Manzanares et al., 2022; Delafontaine et al., 2023), by adding the advantages of both modalities (Cardoso et al., 2019). In contrast, other authors found better results with face-to-face learning (Khasawneh et al., 2016; Turčić et al. 2023) or no differences in the results obtained by the learning methods (George et al., 2014; Kemp and Grieve, 2014; Wu, 2015; da Costa Vieira et al., 2017; Vaona et al., 2018; Stevens et al., 2019; Abualadas and Xu, 2023; Lien et al., 2023). This disparity has been explained by the difficulty of comparability across studies and meta-analyses due to the heterogeneity of both the learning modalities (Law et al., 2018), assessment approaches (Clunie et al., 2018; Nicoll et al., 2018), methodological reporting bias, and the unsatisfactory sample size of several reviewed articles (Zhang et al., 2024).

In the present study, based on the homogeneous b-learning teaching experience of 1160 second-year undergraduate medical students, the results of the multiple-choice exams of a human anatomy module were analyzed with the following objectives: First, to describe and compare the academic outcomes obtained with face-to-face and e-learning. Second, to assess the impact of minority online content responses on overall academic performance. Third, to describe and compare the response attempts of the students in answering the questions, as incorrect answers were penalized. Fourth, to analyze the correlation between academic grades and response indexes.

2. Material and methods

2.1. Study sample

The results, question by question, of the 1160 multiple-choice exam of the Human Anatomy-Digestive System module taken in four consecutive academic years were compiled. This module was taught in the second year of a bachelor's degree in medicine at the Autonomous University of Barcelona (also known as UAB), Spain.

Table 1 shows the academic and demographic data of the students examined.

2.2. Study design

This study is based on data from the first four academic years of b-learning implementation in the Digestive System module, the only ones in which the program, instructors, online materials, and evaluation criteria were consistent. The main objective was to compare students' academic performance between topics learned online or in lectures. Therefore, the present study focused on the grades of the first multiple-choice test of the module and not on the subsequent make-up test or the practical exam (see Section 2.3.2.2).

2.2.1. The exam

The exam consisted of forty questions, each with one correct answer out of five choices. One point was awarded for each correct answer, and 0.25 points were deducted for each incorrect answer. There was no

Table 1
Demographic and academic data of the students assessed.

Academic year	University entrance cut-off score[a] [b]	Mean age[b]	n	Female %	Male %
2014–2015	12.09	21	312	68.77	31.23
2015–2016	12.15	21	247	68.65	31.35
2016–2017	12.39	21	381	73.75	26.25
2017–2018	12.35	21	220	73.99	26.01

Note: [a] scale from 0 to 14; [b] data from UAB (2024).

penalty for unanswered questions. Examinations with an overall academic grade of ≥5 (on a scale from 0 to 10) were considered passed. The exam questions were mainly aimed at the taxonomic levels of remembering and understanding, and, to a lesser extent, applying and analyzing.

2.2.2. Learning outcome measures

The number of questions on topics learned in the classroom and through e-learning was extracted from the exam questionnaire. The percentages of correct, incorrect, and blank answers were obtained from the automatic correction data of the exams using optical mark readers (ROM).

To compare results between courses, the difference between the percentages of correct and incorrect answers was evaluated, considering that the higher the value, the better the result. The percentage of unanswered questions (blank answers) was also compared.

Two scores were obtained from each student's tests: academic grade and response index. These scores were calculated three times: for the exam as a whole and the questions on the content of each learning modality.

2.2.2.1. Academic grade. The academic grade was calculated using the above evaluation criteria (Section 2.2.1). The formula used to calculate academic grade (*AG*) was:

$$AG = (nca - (nica \text{ x } 0.25)) \text{ x } 10/tnq$$

where *nca* was the number of correct answers, *nica* was the number of incorrect answers, and *tnq* was the total number of exam questions (Table 2). The scale ranged from 0 to 10 points.

2.2.2.2. Response index. To calculate the response index (*RI*), one point was awarded for each correct and incorrect answer. Unanswered questions were not scored. Therefore, since incorrect answers were penalized in the academic grade, this index reflects the risk the student took in answering the questions. The formula used to calculate this variable was:

$$RI = (nca + nica) \text{ x } 10/tnq$$

The scale also ranged from 0 to 10 points.

2.2.2.3. Quartiles. Students from all years were ranked from highest to lowest according to their overall academic grades and divided into four groups: The first quartile included the 25 % of students with the highest grades, the second and third quartiles included the 50 % of students with intermediate grades, and the fourth quartile included the 25 % of students with the lowest ones.

2.2.3. Calculation of the impact of e-learning questions on the total academic grade

There were five questions on topics studied online in 2014–2015 and 2017–2018, and six in 2015–2016 and 2016–2017, representing 12.50 % and 15.00 % of the 40 questions on the exam, respectively (Table 2). In order to highlight the importance of e-learning on the overall academic grade, the percentage of students who needed the points obtained on the e-learning content questions to achieve a passing grade was calculated. For this purpose, the overall academic grade was recalculated by eliminating the points obtained in the e-learning questions.

2.2.4. Statistical analysis

SPSS Statistical package (IBM SPSS Statistics for Windows, version 28.0.1.1. Armonk, NY: IBM Corp) was used to analyze the data. For continuous variables, descriptive statistics were presented as mean, with 95 % confidence interval (CI), maximum and minimum values, and standard deviation.

Student's t-test was used to compare the scores obtained in the face-to-face and e-learning questions in the total sample. Analysis of variance (ANOVA test) was used to analyze the academic grade, response index, and the percentage of correct, incorrect, and blank answers from the face-to-face and e-learning questions, both overall and among the quartiles. This test was used to calculate the 95 % CI of the mean of each grade among the four quartiles. The difference in academic grades on online and face-to-face learning questions was calculated for each student. An analysis of variance with Bonferroni post hoc correction was performed to compare these differences among the four quartiles and the four courses. The Pearson correlation coefficient (r) was used to analyze the association between academic grades and response indexes for the total sample and the quartile subgroups. Statistical significance was set at $p<0.05$.

2.3. Teaching and learning context

2.3.1. Previous training in human anatomy

At UAB, the medical degree is a six-year, 360-credit curriculum according to the European Credit Transfer System (ECTS). The compulsory subjects of human anatomy are taken in the four semesters of the first two years. In the four academic years analyzed, the first semester of the first year was dedicated to the modules General Anatomy and Embryology and Musculoskeletal System (6 ECTS credits); in the second semester, Cardiovascular System, Head and Neck (4 ECTS credits). In the first semester of the second year, the modules Respiratory System and Urogenital System (3 ECTS credits) were taught first, followed by the module Digestive System (3 ECTS credits); the second semester was reserved for Neuroanatomy (4 ECTS credits). Therefore, the students who examined the Digestive System module (the object of this study) had previously studied all human anatomy topics, except Neuroanatomy. The modules of each semester were integrated into independently graded subjects.

Table 2
Number of questions and percentage of answer types for each learning modality.

Academic year	Question topics	Number of questions	Answer type	**Percentage**
2014–2015				
	E-learning topics	5	Correct	52.63
			Incorrect	17.69
			Blank	29.68
	Face-to-face learning topics	35	Correct	67.27
			Incorrect	17.57
			Blank	15.16
2015–2016				
	E-learning topics	6	Correct	70.31
			Incorrect	15.79
			Blank	13.90
	Face-to-face learning topics	34	Correct	60.24
			Incorrect	22.80
			Blank	16.96
2016–2017				
	E-learning topics	6	Correct	62.56
			Incorrect	17.06
			Blank	20.38
	Face-to-face learning topics	34	Correct	67.75
			Incorrect	15.00
			Blank	17.25
2017–2018				
	E-learning topics	5	Correct	69.00
			Incorrect	18.82
			Blank	12.18
	Face-to-face learning topics	35	Correct	61.76
			Incorrect	19.01
			Blank	19.23

2.3.2. Digestive system module

2.3.2.1. Objectives and distribution of teaching. Due to a change in the curriculum, the number of lessons in Anatomy was reduced. The Digestive System module, with 19 topics, was the only one that moved part to the e-learning modality: six topics (31.58 %). The remaining 13 topics (68.42 %) were taught in 21 one-hour classroom sessions. The theoretical content was designed to provide knowledge about the development and anatomy of the digestive system and pharyngeal organs.

The e-learning materials created by the module professors were available to the students on the UAB Virtual Campus, a digital platform that provides a virtual learning environment to support face-to-face studies and host online courses. These resources were five documents and one multimedia. Three documents (text and images) dealt with the anatomy and basic development of the teeth, pharynx, and pharyngeal or branchiogenic organs; one with the topographic anatomy of the peritoneal cavity, and one with the portal venous system of the liver. The interactive multimedia contained illustrated clinical cases in which the student, using an algorithm, answered questions that promoted pathophysiological reflection based on anatomical data. It was estimated that students would need ten hours to complete a productive initial review of the online resources: eight hours for the documents (the same time used in the previous curriculum to teach these topics face-to-face) and two hours for the interactive clinical anatomy multimedia (estimated average time after two students correctly completed all steps).

The anatomical part of all topics included the corresponding practical sessions in the dissection room: five hours divided into three sessions. The objective was to apply the theoretical knowledge to identify and localize anatomical details of the digestive organs and other related structures in the materials used: cadaveric prosections, plastinated organs and sections, CT and MRI scans, and X-rays with and without contrast. For this reason, the course was programmed in such a way as to encourage the students to attend the practical sessions with the topics studied: the online material was published from the beginning and the sessions were convened at least one week after the last lecture.

2.3.2.2. Evaluation. The evaluation of the Human Anatomy-Digestive System module consisted of two parts: A multiple-choice exam (70 % of the final grade), on paper format, with questions designed to assess knowledge of the systematic, topographic, and clinical anatomy of the digestive system and pharyngeal organs, as well as their prenatal and postnatal development (see Section 2.2.1); a practical exam (30 % of the final grade) in which students were required to identify, in writing, and locate, in oral presentations, anatomical details on the same material used in the practical sessions.

3. Results

3.1. Academic results of the analyzed examination

The number of questions on the topics of each type of learning, and the percentages of correct, incorrect, and blank answers are shown in Table 2.

Comparing the results between courses, it can be highlighted that regarding the questions on topics learned through e-learning, the first course in which e-learning was introduced (2014–2015) had the highest percentage of unanswered questions (29.68 %) and also the smallest difference between the percentages of correct and incorrect answers (34.94 percentage points), $p<0.001$. For questions on topics learned face-to-face, the biggest difference between correct and incorrect answers was obtained in the course 2016–2017 (52.76 percentage points), $p<0.001$, and the highest percentage of unanswered questions was in the 2017–2018 course (19.23 %), $p=0.001$. In the 2015–2016 academic year, there was the largest difference between correct and incorrect answers in online content (54.52 percentage points) and the smallest difference in face-to-face content (37.44 percentage points), $p<0.001$.

Of the 1160 students who took the b-learning course exams, 852 (73.45 %) passed them: all those in the first and second quartiles and 94.63 % in the third quartile. The mean overall academic grade was 6.01 (Table 3).

3.2. Descriptive statistics of the academic grades and response indexes

Table 3 shows the descriptive statistics of the academic grades and response indexes, for the entire exam and the groups of questions corresponding to each learning method. The mean of the overall academic grades and the overall response indices across the four courses were: 6.10 and 8.30 (2014–2015); 5.63 and 8.35 (2015–2016); 6.31 and 8.23 (2016–2017); and 5.79 and 8.16 (2017–2018).

3.3. Impact of e-learning questions on the overall academic grade

23.36 % (n=199) of the 852 students who passed the exam needed the points from the minority e-learning content questions to achieve a passing score: 0.59 % (n=5) of quartile 2 and 22.77 % (n=194) of quartile 3.

3.4. Face-to-face versus e-learning: comparison of academic grades

For the sample as a whole, the mean academic grade of the questions on topics learned face-to-face was higher than for e-learning content (Table 3), with a statistically significant difference, $p=0.018$. When the sample was divided into quartiles, the largest difference in overall academic grade, although only 0.54 points, was in the first quartile (the highest grades): the mean academic grades for face-to-face and e-learning content questions were 8.25 (95 % CI, lower limit = 8.17 – upper limit =8.33) and 7.71 (95 % CI, 7.48–7.94), respectively, and this difference was statistically significant, $p<0.001$. In the second quartile, the mean academic grade for face-to-face learning content questions, 6.77 (95 % CI, 6.71–6.82), was significantly higher than that for e-learning, 6.28 (95 % CI, 6.03–6.54), $p<0.001$. In the third quartile, there were no statistically significant differences between the two teaching modes: the mean academic grade of the questions on topics learned face-to-face was 5.51 (95 % CI, 5.45–5.57), and 5.53 for e-learning (95 % CI, 5.25–5.80), $p=0.452$. In the fourth quartile (lowest grades), the mean academic grade for the face-to-face content questions was 3.68 (95 % CI, 3.57–3.78), significantly lower than that for e-learning, 3.97 (95 % CI, 3.70–4.24), $p=0.022$.

3.5. Face-to-face versus e-learning: comparison of response indexes

For the sample as a whole, the mean response index to questions

Table 3
Descriptive statistics of the academic grades and response indexes of the students assessed.

Grades	Mean (95 % CI)	SD	Minimum value	Maximum value
Overall academic grade	6.01 (5.91–6.11)	1.74	1.19	10.0
E-learning academic grade	5.86 (5.71–6.01)	2.61	0.00	10.0
Face-to-face learning academic grade	6.04 (5.93–6.14)	1.81	0.96	10.0
Overall response index	8.26 (8.20–8.33)	1.14	5.00	10.0
E-learning response index	8.00 (7.89–8.12)	2.03	0.00	10.0
Face-to-face learning response index	8.30 (8.23–8.37)	1.16	4.29	10.0

Legend: CI, confidence interval; SD, standard deviation.

about face-to-face learning content was higher than for e-learning. (Table 3), with a statistically significant difference, $p<0.001$. For the first quartile, the differences between the mean response indexes for face-to-face and e-learning content questions were 9.36 (95 % CI, 9.30–9.42) and 8.91 (95 % CI, 8.74–9.08), respectively, $p<0.001$. In the second quartile: 8.49 (95 % CI, 8.40–8.58) and 8.03 (95 % CI, 7.81–8.25), $p<0.001$. In the third quartile: 7.92 (95 % CI, 7.81–8.04) and 7.90 (95 % CI, 7.67–8.13), $p=0.405$. In the fourth quartile: 7.45 (95 % CI, 7.31–7.59) and 7.20 (95 % CI, 6.94–7.46), $p=0.024$. These data show that, in the four quartiles, the mean response index was higher for the questions on topics learned face-to-face than for e-learning ones, and the difference was statistically significant, except for the third quartile. However, in no case did the difference reach half a point.

3.6. Analysis of correlations between academic grades and response indexes

For the sample as a whole, there was a statistically significant positive correlation between overall academic grades and overall response indexes, $r=0.60$. When analyzed by subgroups according to academic performance, this correlation was negative for the fourth quartile, $r=-0.04$, and strong only for the first quartile, $r=0.55$. The correlation coefficients for the second and third quartiles were 0.19 and 0.17, respectively.

When analyzing questions on topics learned through e-learning, a strong positive correlation was observed between academic grade and response index. This correlation became progressively stronger from the fourth, $r=0.43$, to the first quartile, $r=0.63$, and it was significant in all the quartiles and the sample as a whole. In the second and third quartiles, and the whole sample the correlation coefficients were 0.59, 0.55, and 0.59, respectively.

The same analysis using questions from the topics given with face-to-face learning yielded comparable results, with a strong positive correlation between academic grade and response index in the sample as a whole, $r=0.61$, and in the first quartile, $r=0.53$, but not in the fourth quartile, $r=0.03$. Correlation coefficients were 0.24 and 0.19 in the second and third quartiles, respectively.

4. Discussion

4.1. Methodological considerations

Although e-learning has sometimes been a means of access to teaching, it could become a pillar of teaching activity (Ellaway and Masters, 2008) based on general pedagogical principles (Singh et al., 2013), with the focus on the student, and the teacher as facilitator in the autonomous learning process (Koops et al., 2011).

It has been proposed that from now on, research should be based on experimental designs (Bell and Federman, 2013) that focus on understanding the psychological, pedagogical, and technological factors that facilitate online learning (Greenhow et al., 2022). However, there are still discrepancies in its effectiveness compared to other learning modalities (Kumta et al., 2003; Cook et al., 2008; Means et al., 2013; George et al., 2014; Kemp and Grieve, 2014; Lehmann et al., 2015; Khasawneh et al., 2016; Liu et al., 2016; da Costa Vieira et al., 2017; Voutilainen et al., 2017; McDonald et al., 2018; Sheikhaboumasoudi et al., 2018; Vaona et al., 2018; Stevens et al., 2019; Barteit et al., 2020; Vallée et al., 2020; Ødegaard et al., 2021; Shikino et al., 2021; Sonne et al., 2021; Sáiz-Manzanares et al., 2022; Abualadas and Xu, 2023; Lien et al., 2023; Turčić et al. 2023).

Different findings in this regard have been attributed to the imprecision and heterogeneity of the methods used to assess the impact of online resources on learning (Van Nuland and Rogers, 2016; Clunie et al., 2018; Law et al., 2018; Nicoll et al., 2018), with an overemphasis on the assessment of individual student perceptions (Barteit et al., 2020), as well as the lack of prospective studies with large samples that would allow us to more reliably determine the pedagogical value of e-learning (Degerfält et al., 2017).

To avoid some of these shortcomings, the present study was based on the academic results of a large sample of students (n=1160) in the Human Anatomy-Digestive System module of the Bachelor of Medicine degree. They belonged to four consecutive years whose university entrance cut-off scores did not differ by more than 0.3 points, on a scale of 0–14 (Table 1). All followed the same learning method (b-learning), shared the same lecturers, e-learning materials, and evaluation criteria, and demonstrated similar average academic performance across the four courses (see Section 3.2). The introduction of e-learning in this module was primarily motivated by the need to reduce the number of hours allocated to human anatomy in the curriculum. This was the explanation for the implementation of e-learning in anatomy in 22.58 % of the thirty-six medical schools analyzed by Abualadas and Xu (2023). The increasing development of different medical sciences and specialties and non-technical skills has meant that disciplines such as human anatomy have had to reduce their teaching time to incorporate new knowledge (Smith et al., 2022). In most curricula, this reduction in hours has negatively impacted the opportunity for students to see and touch real anatomical structures, an integral part of successful anatomy learning (Cheung et al., 2021).

In our module, moving some of the program's theoretical content to e-learning mitigated the impact of cutbacks in other parts where lecturer presence was considered essential (e.g., most difficult conceptual content or dissection room practices).

The present study shares goals and academic focus of the recent bibliographic review by these authors (Abualadas and Xu, 2023) on the effectiveness of face-to-face and e-learning in anatomy courses. The data they provided confirmed that none of the nineteen recent papers reviewed (only three were published before 2020) had a sample as large and homogeneous as the one in the current research. In two studies, the total number of students was slightly larger, but neither allowed a reliable comparison of the effectiveness of the two methods. In one of them, the two learning methods were not evaluated separately, because the authors wanted to determine whether the previous use of audiovisual resources had improved learning in the face-to-face dissection classes (Choi-Lundberg et al., 2016). In the other study, the students were divided according to the methodology used, so that the comparison was based on grades for heterogeneous groups (Biasutto et al., 2006). This grouping criterion, designed to compare the effectiveness of the learning methods used, was generally used in the rest of the studies examined in the literature review (Abualadas and Xu, 2023); in this way, the effect of the difficulty of the topics was equalized in both groups. In the present study, on the other hand, the influence of academic achievement was fixed. All students were trained using both methods (face-to-face and self-directed e-learning), and the effect of each on academic outcomes was determined based on the grades each student received for answering questions related to topics presented in either format.

4.2. Face-to-face versus e-learning: gaining academic advantage

For the sample as a whole, face-to-face learning was shown to produce better academic grades than e-learning (Table 3). When students were grouped into quartiles based on overall academic performance, there were also statistically significant differences in favor of face-to-face grades for the higher-performing half of the sample (first and second quartiles) and e-learning for the lower-performing students (fourth quartile). Although these results were consistent with those of Khasawneh et al. (2016), Rouleau et al. (2019), and Turčić et al. (2023) that e-learning in higher education was not more effective than the face-to-face modality, they also showed that the magnitude of the difference in mean academic grades was small: a maximum of 0.54 points for the best students (first quartile). This similarity in effectiveness is in

line with other authors who have found that neither modality is better than the other (George et al., 2014; Wu, 2015; da Costa Vieira et al., 2017; Vaona et al., 2018; Lien et al., 2023) and those who reported b-learning as the best means to achieve better academic performance (Means et al., 2013; Lehmann et al., 2015; Liu et al., 2016; McDonald et al., 2018; Sheikhaboumasoudi et al., 2018; Vallée et al., 2020; Ødegaard et al., 2021; Sonne et al., 2021; Sáiz-Manzanares et al., 2022).

In the specific field of anatomy, the same considerations could be made, since in the recent review article by Abualadas and Xu (2023), there was an equal number of papers that emphasized one learning modality over the other (nine each); only one found no difference between the results of online and face-to-face learning.

In line with these results, the use of both modalities was recommended (Böckers et al., 2021), with a thematic distribution adapted to the needs of each university, and an appropriate project to develop a b-learning model (Lam, 2014), which must be open to corrections as the educational program is implemented in a pilot mode (Greenhow, 2022).

4.3. Face-to-face versus e-learning: relationship between the academic grades and response indexes

It has been suggested that students would study more superficially in broad content subjects assessed with multiple-choice tests (Leung et al., 2008), with a consequent impact on learning and understanding of the exam questions (Jakwerth et al., 2003). Knowledge level, risk aversion, and chance have been implicated in decision-making when answering multiple-choice test questions with an error penalty (Espinosa and Gardeazabal, 2010; Vanderoost et al., 2018).

The present study analyzes the relationship between the academic grades obtained in the questions about the topics studied with each learning modality and the number of attempts to answer the corresponding questions, assessed by the response index. This variable was calculated from the number of questions answered correctly or incorrectly, not from the students' opinions expressed on the Linkert scale of a questionnaire (Schulte et al., 2022). Thus, it was found that students took more risks on questions related to topics studied in the face-to-face mode (Table 3). Furthermore, a strong positive correlation between the number of answers and academic achievement was observed in the whole sample and the first quartile (brightest students), both for the overall exam and for questions on topics studied in each modality. For the remaining quartiles, a strong correlation was observed only for the e-learning questions. Since the correlation provides information about the concordance between academic outcomes and the number of answers used, the lower the correlation, the higher the degree of speculation in the choice of answers, an attitude far from the usual one of well-prepared students. However, in a multiple-choice exam with a penalty, the level of knowledge is not the only factor in answering or not a question: strategy also plays a role. For example, students with a good academic background but who are cautious may leave blank questions (Espinosa and Gardeazabal, 2010) that would have been answered with a sufficient level of correctness in an oral or written exam.

4.4. Limitations of the study

To find the educational value of e-learning more reliably, prospective studies with larger samples would be required (Degerfält et al., 2017). Despite the large sample size of students (n=1160), the retrospective nature of the data remains a limitation, as it precluded adjusting the proportion of the number of questions according to research objectives or conducting student satisfaction surveys.

Given that the implementation of e-learning in the module represented a novel experience for both students and lecturers in the years studied, caution was taken in limiting the number of examination questions on the affected topics to five (12.50 %) in the academic years 2014–2015 and 2017–2018, and six (15.00 %) in 2015–2016 and 2016–2017 (Table 2). As the total time dedicated to the face-to-face sessions and the first beneficial encounter with the online material were 21 (67.74 %) and 10 (32.26 %) hours, respectively, the number of questions should have been 27 and 13 for the topics of each learning modality, respectively. The students of the inaugural cohort (academic year 2014–2015), the earliest with a b-learning approach, may have been less prepared for the topics learned by e-learning, as there was the largest proportion of unanswered questions and the smallest percentage difference between correct and incorrect answers (see Section 3.1 and Table 2). It is possible that the students in later years devoted more attention to their study in response to the finding that all these topics, although a minority, would also be evaluated. In fact, in the following academic year (2015–2016), the best results were achieved in the online content part of the exam (Table 2). Despite these potential explanations, the mean academic grade for the e-learning content questions (5.86) was only 0.18 points lower than that for the face-to-face learning (6.04) (Table 3). Additionally, nearly a quarter (23.36 %) of the students who passed would not have succeeded in the test without the points obtained on the questions of e-learning. These data indicated a high level of motivation among the students for the module content. Undoubtedly, the high academic level required for admission to a bachelor's degree in medicine (Table 1) also had a positive effect on the examination outcomes. This factor should be considered in future comparisons.

There is no consensus on the impact of online teaching methods, largely due to the variety of methods used to evaluate them (Clunie et al., 2018; Nicoll et al., 2018). One of the strengths of the present study is its homogeneity, as previously discussed: so that the only thing that changed from one year to the next was the students. However, there were some unavoidable limitations. First, although we were able to control for the effect of academic level on the scores (all participants studied each topic using the same method), we were unable to contrast the differential effect of both types of learning on each topic. Second, in the case of in-person instruction, the teaching and educational atmosphere in face-to-face classes were unique. These environments are dynamic, with numerous variables that come into play (Choi-Lundberg et al., 2016). Third, there was the question of comparability with other studies, given the diversity of online media used and the peculiarities of exam scoring at each medical school (Abualadas and Xu, 2023).

5. Conclusions

This study was conducted with the largest and most homogeneous sample to date to analyze the academic impact on the human anatomy of the two learning modalities involved in b-learning. The results reveal that, overall, the students learn better in the topics taught face to face. This superiority occurs only in the half of the sample with the highest overall academic scores (first and second quartile). Conversely, it has been shown that the students with the lowest grades (the fourth quartile) learn better with e-learning. However, it should be considered that the two learning modes used in b-learning are effective since the difference between the academic grades of each modality was $\leq$0.54 points and 73.45 % of the examinees passed. It also shows that in the test exam students answer more questions on topics from the face-to-face modality than from the e-learning one. In the face-to-face learning modality, response attempts are strongly correlated with academic outcomes only in the first quartile. In e-learning, this degree of correlation is present in all four quartiles.

Ethical statement

The research did not require approval from the University Ethics Committee because it was a retrospective case report.

The anonymity of the students was maintained during the data collection and publication of this study. The gender of each student, the type of answer (correct, incorrect, or blank), and the score were obtained from the automated correction reports of the tests. The mean age of the students in each cohort was obtained from the university website

(UAB, 2024).

All students followed the two types of learning, the same for each topic, so they did not have to choose one or the other.

CRediT authorship contribution statement

Josep Nebot-Cegarra: Conceptualization, Data curation, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Carlos Nebot-Bergua:** Data curation, Investigation, Methodology, Resources, Validation, Visualization, Writing – original draft, Writing – review & editing. **Jordi Gascón-Bayarri:** Investigation, Resources, Writing – review & editing. **Enric Macarulla-Sanz:** Investigation, Resources, Writing – review & editing. **Sílvia Ricart:** Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors would like to thank the UAB for funding the open access publication fee of this article and Associate Professor Pere Jordi Fábregas-Batlle (Department of Morphological Sciences, Faculty of Medicine, UAB, Bellaterra, Spain) for taking part in teaching the module evaluated in this study.

Submission declaration

The authors declare that the work described has not been published previously, is not under consideration for publication elsewhere, and has been approved for publication by all the authors.

References

Abualadas, H.M., Xu, L., 2023. Achievement of learning outcomes in non-traditional (online) versus traditional (face-to-face) anatomy teaching in medical schools: a mixed method systematic review. Clin. Anat. 36, 50–76. https://doi.org/10.1002/ca.23942.

Aristovnik, A., Karampelas, K., Umek, L., Ravšelj, D., 2023. Impact of the COVID-19 pandemic on online learning in higher education: a bibliometric analysis. Front. Educ. 8, 1225834. https://doi.org/10.3389/feduc.2023.1225834.

Barteit, S., Guzek, D., Jahn, A., Bärnighausen, T., Jorge, M.M., Neuhann, F., 2020. Evaluation of e-learning for medical education in low- and middle-income countries: a systematic review. Comput. Educ. 145, 103726. https://doi.org/10.1016/j.compedu.2019.103726.

Bates, T., 2001. National strategies for e-learning in post-secondary education and training. In: Fundamentals in educational planning-70. UNESCO-IIEP, Paris, France.. URL: https://unesdoc.unesco.org/ark:/48223/pf0000126230 (Accessed: 15 July 2024).

Bell, B.S., Federman, J.E., 2013. E-Learning in postsecondary education. Future Child. Spring 23, 165–185. https://doi.org/10.1353/foc.2013.0007.

Biasutto, S.N., Caussa, L.I., Criado del Río, L.E., 2006. Teaching anatomy: cadavers vs. computers? Ann. Anat. 188, 187–190. https://doi.org/10.1016/j.aanat.2005.07.007.

Böckers, A., Claassen, H., Haastert-Talini, K., Westermann, J., 2021. Teaching anatomy under COVID-19 conditions at German universities: recommendations of the teaching commission of the anatomical society. Ann. Anat. 234, 151669. https://doi.org/10.1016/j.aanat.2020.151669.

Brassett, C., Cosker, T., Davies, D.C., Dockery, P., Gillingwater, T.H., Lee, T.C., Milz, S., Parson, S.H., Quondamatteo, F., Wilkinson, T., 2020. COVID-19 and anatomy: stimulus and initial response. J. Anat. 23, 393–403. https://doi.org/10.1111/joa.13274.

Cardoso, T., Pestana, F., Pina, J., 2019. Assessing a b-learning teaching approach and students' learning preferences in higher education. EDULEARN19 Proc 10007–10012. https://doi.org/10.21125/edulearn.2019.2502.

Cheung, C.C., Bridges, S.M., Tipoe, G.L., 2021. Why is anatomy difficult to learn? The implications for undergraduate medical curricula. Anat. Sci. Educ. 14, 752–763. https://doi.org/10.1002/ase.2071.

Chin, R.Y., Tjahjono, R., Rutledge, M.J.R., Lambert, T., Deboever, N., 2019. The evaluation of e-learning resources as an adjunct to otolaryngology teaching: a pilot study. BMC Med. Educ. 19, 181. https://doi.org/10.1186/s12909-019-1618-7.

Choi-Lundberg, D.L., Cuellar, W.A., Williams, A.M., 2016. Online dissection audio-visual resources for human anatomy: undergraduate medical students' usage and learning outcomes. Anat. Sci. Educ. 9, 545–554. https://doi.org/10.1002/ase.1607.

Clunie, L., Morris, N.P., Joynes, V.C.T., Pickering, J.D., 2018. How comprehensive are research studies investigating the efficacy of technology-enhanced learning resources in anatomy education? a systematic review. Anat. Sci. Educ. 11, 303–319. https://doi.org/10.1002/ase.1762.

Cook, D.A., Levinson, A.J., Garside, S., Dupras, D.M., Erwin, P.J., Montori, V.M., 2008. Internet-based learning in the health professions: a meta-analysis. JAMA 300, 1181–1196. https://doi.org/10.1001/jama.300.10.1181.

da Costa Vieira, R.A., Lopes, A.H., Sarri, A.J., Benedetti, Z.C., de Oliveira, C.Z., 2017. Oncology e-learning for undergraduate. A prospective randomized controlled trial. J. Cancer Educ. 32, 344–351. https://doi.org/10.1007/s13187-015-0979-9.

De Witte, K., François, M., 2023. Covid-19 learning deficits in Europe: analysis and practical recommendations. EENEE Analytical Report. https://doi.org/10.2766/881143 (Accessed: 8 May 2024).

Degerfält, J., Sjöstedt, S., Fransson, P., Kjellén, E., Werner, M.U., 2017. E-learning programs in oncology: a nationwide experience from 2005 to 2014. BMC Res. Notes 10, 39. https://doi.org/10.1186/s13104-017-2372-8.

Delafontaine, A., Saiydoun, G., Frogout, J., Fabeck, L., Degrenne, O., Sarhan, F.R., 2023. Pedagogical impact of integration of musculoskeletal anatomy blended learning on physiotherapy education. Front. Med. (Lausanne) 10, 1260416. https://doi.org/10.3389/fmed.2023.1260416.

Ellaway, R., Masters, K., 2008. AMEE Guide 32: e-Learning in medical education Part 1: learning, teaching and assessment. Med. Teach. 30, 455–473. https://doi.org/10.1080/01421590802108331.

Espinosa, M.P., Gardeazabal, J., 2010. Optimal correction for guessing in multiple-choice tests. J. Math. Psychol. 54, 415–425. https://doi.org/10.1016/j.jmp.2010.06.001.

Evans, D.J.R., Pawlina, W., 2022. The future of anatomy education: learning from Covid-19 disruption. Anat. Sci. Educ. 15, 643–649. https://doi.org/10.1002/ase.2203.

George, P.P., Papachristou, N., Belisario, J.M., Wang, W., Wark, P.A., Cotic, Z., Rasmussen, K., Sluiter, R., Riboli-Sasco, E., Tudor Car, L., Musulanov, E.M., Molina, J.A., Heng, B.H., Zhang, Y., Wheeler, E.L., Al Shorbaji, N., Majeed, A., Car, J., 2014. Online e-learning for undergraduates in health professions: a systematic review of the impact on knowledge, skills, attitudes and satisfaction. J. Glob. Health 4, 010406. https://doi.org/10.7189/jogh.04.010406.

Greenhow, C., Graham, C.R., Koehler, M.J., 2022. Foundations of online learning: challenges and opportunities. Educ. Psychol. 57, 131–147. https://doi.org/10.1080/00461520.2022.2090364.

Hachey, A.C., Conway, K.M., Wladis, C., Karim, S., 2022. Post-secondary online learning in the U.S.: an integrative review of the literature on undergraduate student characteristics. J. Comput. High. Educ. 34, 708–768. https://doi.org/10.1007/s12528-022-09319-0.

Jakwerth, P.R., Stancavage, F.B., Reed, E.D., 2003. NAEP validity studies: An investigation of why students do not respond to questions. Working Paper No. 2003-12. National Center for Education Statistics. URL: https://eric.ed.gov/?id=ED545953 (Accessed: 15 May 2024).

Jeffs, C., Scott, M., Fedorko-Bartos, K.M., 2024. Introduction to the seventh volume of papers on postsecondary learning and teaching. PPLT 7, i–iv. https://doi.org/10.55016/ojs/pplt.v7Y2024.79536.

Jesurasa, A., Mackenzie, K., Jordan, H., Goyder, E.C., 2017. What factors facilitate the engagement with flipped classrooms used in the preparation for postgraduate medical membership examinations? Adv. Med. Educ. Pract. 8, 419–426. https://doi.org/10.2147/AMEP.S132266.

Kadam, S.S., Bagle, T.R., Baviskar, P.A., 2018. Utilization of internet by undergraduate medical students. Natl. J. Physiol. Pharm. Pharmacol. 8, 1–6. https://doi.org/10.5455/njppp.2018.8.0515422072017.

Kemp, N., Grieve, R., 2014. Face-to-face or face-to-screen? Undergraduates' opinions and test performance in classroom vs. online learning. Front. Psychol. 5, 1278. https://doi.org/10.3389/fpsyg.2014.01278.

Khasawneh, R., Simonsen, K., Snowden, J., Higgins, J., Beck, G., 2016. The effectiveness of e-learning in pediatric medical student education. Med. Educ. Online 21, 29516. https://doi.org/10.3402/meo.v21.29516.

Kim, K., Bonk, C.J., Oh, E., 2008. The present and future state of blended learning in workplace learning settings in the United States. Perform. Improv. 47, 5-16. https://doi.org/10.1002/pfi.20018.

Koops, W., Van der Vleuten, C., De Leng, B., Oei, S.G., Snoeckx, L., 2011. Computer-supported collaborative learning in the medical workplace: students' experiences on formative peer feedback of a critical appraisal of a topic paper. Med. Teach. 33, e318–e323. https://doi.org/10.3109/0142159X.2011.575901.

Kumta, S.M., Tsang, P.L., Hung, L.K., Cheng, J.C., 2003. Fostering critical thinking skills through a web-based tutorial programme for final year medical students: a randomized controlled study. J. Educ. Multimed. Hypermed. 12, 267–273. https://www.learntechlib.org/primary/p/11927/.

Lam, J., 2014. The context of blended learning: The TIPS blended learning model. In: Cheung, S.K.S., Fong, J., Zhang, J., Kwan, R., Kwok, L.F. (Eds.), Hybrid learning. Theory and practice. ICHL 2014. Lecture notes in computer science, 8595. Springer, Cham. https://doi.org/10.1007/978-3-319-08961-4_9. ICHL 2014.

Law, G.C., Apfelbacher, C., Posadzki, P.P., Kemp, S., Tudor, Car, L., 2018. Choice of outcomes and measurement instruments in randomized trials on eLearning in medical education: a systematic mapping review protocol. Syst. Rev. 7, 75. https://link.springer.com/article/10.1186/s13643-018-0739-0.

Lehmann, R., Thiessen, C., Frick, B., Bosse, H.M., Nikendei, C., Hoffmann, G.F., Tönshoff, B., Huwendiek, S., 2015. Improving pediatric basic life support performance through blended learning with web-based virtual patients: randomized controlled trial. J. Med. Internet Res. 17, e162. https://doi.org/10.2196/jmir.4141.

Leung, S.F., Mok, E., Wong, D., 2008. The impact of assessment methods on the learning of nursing students. Nurse Educ. Today 28, 711–719. https://doi.org/10.1016/j.nedt.2007.11.004.

Lien, W.C., Lin, P., Chang, C.H., Wu, M.C., Wu, C.Y., 2023. The effect of e-learning on point-of-care ultrasound education in novices. Med. Educ. Online 28, 2152522. https://doi.org/10.1080/2F10872981.2022.2152522.

Liu, Q., Peng, W., Zhang, F., Hu, R., Li, Y., Yan, W., 2016. The effectiveness of blended learning in health professions: systematic review and meta-analysis. J. Med. Internet Res. 18, e2. https://doi.org/10.2196/jmir.4807.

McDonald, E.W., Boulton, J.L., Davis, J.L., 2018. E-learning and nursing assessment skills and knowledge - an integrative review. Nurse Educ. Today 66, 166–174. https://doi.org/10.1016/j.nedt.2018.03.011.

Means, B., Yukie, T., Murphy, R.F., Baki, M., 2013. The effectiveness of online and blended learning: a meta-analysis of the empirical literature. Teach. Coll. Rec. 115, 43. (Accessed: 16 July 2024). https://eric.ed.gov/?id=EJ1018090.

Messerer, D.A.C., Behr, J.L., Kraft, S.F., Schön, M., Horneffer, A., Kühl, S.J., Seifert, L.B., Huber-Lang, M., Böckers, T.M., Böckers, A., 2023. The gross anatomy course: SARS-CoV-2 pandemic-related effects on students' learning, interest in peer-teaching, and students' perception of its importance. Anat. Sci. Educ. 16, 629–643. https://doi.org/10.1002/ase.2245.

Nicoll, P., MacRury, S., van Woerden, H.C., Smyth, K., 2018. Evaluation of technology-enhanced learning programs for health care professionals: systematic review. J. Med. Internet Res. 20, e131. https://doi.org/10.2196/jmir.9085.

Nuuyoma, V., Lauliso, S.S., Chihururu, L., 2023. Perspectives of nursing students on challenges of e-learning during early stages of the COVID-19 pandemic. Curationis 46, 2358. https://doi.org/10.4102/2Fcurationis.v46i1.2358.

Ødegaard, N.B., Myrhaug, H.T., Dahl-Michelsen, T., Røe, Y., 2021. Digital learning designs in physiotherapy education: a systematic review and meta-analysis. BMC Med. Educ. 21 (48). https://doi.org/10.1186/s12909-020-02483-w.

Pickering, J.D., Swinnerton, B.J., 2019. Exploring the dimensions of medical student engagement with technology-enhanced learning resources and assessing the impact on assessment outcomes. Anat. Sci. Educ. 12, 117–128. https://doi.org/10.1002/ase.1810.

Rajab, M.H., Gazal, A.M., Alkattan, K., 2020. Challenges to online medical education during the COVID-19 pandemic. Cureus 12, e8966. https://doi.org/10.7759/cureus.8966.

Rangel-de Lazaro, J., Duart, J.M., 2023. Moving learning: a systematic review of mobile learning applications for online higher education. J. N. Approaches Educ. Res. 12, 198–224. https://doi.org/10.7821/naer.2023.7.1287.

Rouleau, G., Gagnon, M.P., Côté, J., Payne-Gagnon, J., Hudson, E., Dubois, C.A., Bouix-Picasso, J., 2019. Effects of e-learning in a continuing education context on nursing care: systematic review of systematic qualitative, quantitative, and mixed-studies reviews. J. Med. Internet Res. 21, e15118. https://doi.org/10.2196/15118.

Ruiz, J.G., Mintzer, M.J., Leipzig, R.M., 2006. The impact of e-learning in medical education. Acad. Med. 81, 207–212. https://doi.org/10.1097/00001888-200603000-00002.

Saiyad, S., Virk, A., Mahajan, R., Singh, T., 2020. Online teaching in medical training: establishing good online teaching practices from cumulative experience. Int. J. Appl. Basic Med. Res. 10, 149–155. https://doi.org/10.4103/ijabmr.IJABMR_358_20.

Sáiz-Manzanares, M.C., Casanova, J.R., Lencastre, J.A., Almeida, L., Martín-Antón, L.J., 2022. Student satisfaction with online teaching in times of COVID-19. Comunicar 70, 35–45. https://doi.org/10.3916/C70-2022-03.

Schulte, H., Schmiedl, A., Mühlfeld, C., Knudsen, L., 2022. Teaching gross anatomy during the Covid-19 pandemic: effects on medical students' gain of knowledge, confidence levels and pandemic-related concerns. Ann. Anat. 244, 151986. https://doi.org/10.1016/j.aanat.2022.151986.

Sheikhaboumasoudi, R., Bagheri, M., Hosseini, S.A., Ashouri, E., Elahi, N., 2018. Improving nursing students' learning outcomes in fundamentals of nursing course through combination of traditional and e-learning methods. Iran. J. Nurs. Midwifery Res. 23, 217–221. https://doi.org/10.4103/ijnmr.IJNMR_79_17.

Shikino, K., Rosu, C.A., Yokokawa, D., Suzuki, S., Hirota, Y., Nishiya, K., Ikusaka, M., 2021. Flexible e-learning video approach to improve fundus examination skills for medical students: a mixed-methods study. BMC Med. Educ. 21, 428. https://doi.org/10.1186/s12909-021-02857-8.

Sierra-Fernández, C.R., Alejandra, H.D., Trevethan-Cravioto, S.A., Azar-Manzur, F.J., Mauricio, L.M., Garnica-Geronimo, L.R., 2023. Flipped learning as an educational model in a cardiology residency program. BMC Med. Educ. 23, 510. https://doi.org/10.1186/s12909-023-04439-2.

Singh, T., Gupta, P., Singh, D., 2013. Principles of Medical Education, Fifth edition. Jaypee Brothers Medical Publishers, New Delhi, India.

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. Anat. Sci. Educ. 15, 993–1006. https://doi.org/10.1002/ase.2126.

Sonne, C., Persch, H., Rosner, S., Ott, I., Nagy, E., Nikendei, C., 2021. Significant differences in written assessments as a result of a blended learning approach used in a clinical examination course in internal medicine: a randomized controlled pilot study Doc42 GMS. J. Med. Educ. 38. https://doi.org/10.3205/zma001438.

Stevens, N.T., Holmes, K., Grainger, R.J., Connolly, R., Prior, A.R., Fitzpatrick, F., O'Neill, E., Boland, F., Pawlikowska, T., Humphreys, H., 2019. Can e-learning improve the performance of undergraduate medical students in clinical microbiology examinations? BMC Med. Educ. 19, 408. https://doi.org/10.1186/s12909-019-1843-0.

Turčić, M., Ćutić, D., Rudolf, M., Bogović, T., 2023. Comparison of distance, hybrid and face-to-face learning process using GitHub and GitHub classroom. EDULEARN23. Proc 742–750. https://doi.org/10.21125/edulearn.2023.0288.

UAB, 2024. Bachelor's degree in medicine (UAB): Quality (Degree in figures). Universitat Autònoma de Barcelona. URL: https://www.uab.cat/web/estudiar/ehea-degrees/quality/degree-in-figures/medicine-1345467897063.html?param1=1263281708763 (Accessed: 8 May 2024).

Ullah, M.S., Hoque, M.R., Aziz, M.A., Islam, M., 2023. Analyzing students' e-learning usage and post-usage outcomes in higher education. Comput. Educ. Open 5, 100146. https://doi.org/10.1016/j.caeo.2023.100146.

Vallée, A., Blacher, J., Cariou, A., Sorbets, E., 2020. Blended learning compared to traditional learning in medical education: systematic review and meta-analysis. J. Med. Internet Res. 22, e16504. https://doi.org/10.2196/16504.

Van Nuland, S.E., Rogers, K.A., 2016. E-learning, dual-task, and cognitive load: the anatomy of a failed experiment. Anat. Sci. Educ. 9, 186–196. https://doi.org/10.1002/ase.1576.

Vanderoost, J., Janssen, R., Eggermont, J., Callens, R., De Laet, T., 2018. Elimination testing with adapted scoring reduces guessing and anxiety in multiple-choice assessments but does not increase grade average in comparison with negative marking. PloS One 13, e0203931. https://doi.org/10.1371/journal.pone.0203931.

Vaona, A., Banzi, R., Kwag, K.H., Rigon, G., Cereda, D., Pecoraro, V., Tramacere, I., Moja, L., 2018. E-learning for health professionals. In: The Cochrane Database of Systematic Reviews. Wilei and Sons, Hoboken, NJ, USA. https://doi.org/10.1002/14651858.CD011736.pub2 (Accessed: 8 May 2024).

Voutilainen, A., Saaranen, T., Sormunen, M., 2017. Conventional vs. e-learning in nursing education: a systematic review and meta-analysis. Nurse Educ. Today 50, 97–103. https://doi.org/10.1016/j.nedt.2016.12.020.

Wu, D., 2015. Online learning in postsecondary education: A review of the empirical literature (2013-2014). Ithaka S+R. URL: https://doi.org/10.18665/sr.221027 (Accessed: 16 July 2024).

Zhang, X., Zhang, G., Chen, Y., Wang, F., Guo, Y., Li, X., Zhang, J., 2024. Exploration and evaluation of reporting quality of randomized controlled trials on blended learning in medical education. Br. J. Hosp. Med. 85. https://doi.org/10.12968/hmed.2024.0166.