A Systematic Review on the Use of Educational Technologies for Medical Education

Dalmaris Lima[1], Victor Sotero[1], Diego Dermeval[1,2][a], Jorge Artur[1,2] and Francisco Passos[2]
[1]*Center of Excellence for Social Technologies (NEES), Computing Institute, Federal University of Alagoas (UFAL), Av. Lourival Melo Mota, S/N, Tabuleiro do Martins, Maceió-AL, Brazil*
[2]*Faculty of Medicine, Federal University of Alagoas (UFAL), Av. Lourival Melo Mota, S/N,*

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Abstract: Educational technologies have been increasingly used in medical education to promote innovative pedagogical strategies in classroom. However, the medical scientific community still lacks a comprehensive understanding on how educational technologies are used in medical education. The objective of this work is to explore what types of technologies are employed in medical education, aiming to identify in which domains they have been applied and the reported evidence of using educational technologies in medical education. We conducted a Systematic Literature Review (SLR) to identify the primary studies on the use of educational technologies in medical education, following a pre-defined review protocol. One hundred sixty-eight papers were selected, covering nine types of education technologies, which were applied in more than 40 medical domains. Moreover, our SLR results also show that most of the papers included in this SLR reported positive evidence about the benefits of using these technologies in medical domain.

1 INTRODUCTION

The evolution of medical education has been taking place rapidly. Students enter in the medical school with a high level of technological skills and high expectation regarding innovative ways of learning. As such, many researchers and medical schools have been investigating how to apply new educational technologies in medical education. These technologies may be, for instance, adaptive platforms, educational games, gamification, mobile learning applications, simulated virtual patients, and so on (Jabbar et al., 2016; Ellaway and Masters, 2008) . Despite the existence of many works which rely on the use of educational technologies in medical education, it is not known to what extent there is evidence to state that the use of educational technologies, indeed, benefits medical education. Moreover, it is also important to understand: i) what are the main types of educational technologies that have been used in medical education; and ii) on which medical domains these technologies have been applied.

There are some works that investigated the application of educational technologies in health education (Kalaian and Kasim, 2017) and, specifically, its usage in medical education (Ellaway and Masters, 2008; Taveira-Gomes et al., 2016). However, these studies did not capture all the aspects and evidences that we are interested. We are interested in finding how promising educational technologies (e.g., ITS, CSCL, mobile learning, gamification, and so on) have been used in medical education.

In this article, we used the Systematic Review of Literature (SLR) method (Kitchenham and Charters, 2007) to identify, evaluate, interpret, and synthesize available studies to address specific research questions on the use and effectiveness of educational technologies in medical education settings and to establish evidence status with in-depth analysis. Thus, the objective of this systematic review is to better understand how these educational technologies are being developed, applied and evaluated, as well as to identify in what way these technologies have been applied to medical education. This paper presents the results of a SLR on studies published from 1986 to September 2017 and was conducted following a pre-defined review protocol, as will be further explained. The remainder of this paper is organized as follows. Section

[a] https://orcid.org/0000-0002-8415-6955

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2 describes the SLR method used in this review. Section 3 presents the results of the quality assessment and an overview the papers. Then, it reports the findings of the review along with an analysis and discussion for each research question. Finally, Section V presents conclusions, limitations and future works.

2 METHOD

A Systematic Literature Review (SLR) is a means of identifying, evaluating and interpreting the available research findings related to a research question, topic area, or phenomenon. The main purpose of conducting a systematic review is to gather evidence on which to base conclusion (Kitchenham and Charters, 2007).

Our SLR was structured based on the guidelines for conducting systematic reviews proposed by (Kitchenham and Charters, 2007). The SLR was divided into three main processes: SLR planning, conducting the SLR, and reporting the SLR. Following the steps: i) identification of the need for a systematic review; ii) formulation of a focused review question; iii) a comprehensive and thorough search of primary studies; iv) evaluation of the quality of included studies; v) identification of the data needed to answer the research question; vi) extraction of data; vii) summary and summary of study results; viii) interpretation of results to determine their applicability; and ix) reporting.

2.1 Research Question

The main objective of this SLR is to identify and map the existing studies in the literature that use educational technologies to promote medical education. Based on this main objective, specific questions were raised to identify the existing works in the area. The questions along with their respective descriptions and motivations are described below.

RQ1: What types of educational technologies have been used in medical education? This question aims to identify the main types of educational technologies (e.g., intelligent tutoring systems, computer-supported collaborative learning, learning management systems, and so on) used to support medical education;

RQ2: Which medical education domains have been supported by educational technologies? This question aims to identify the main domains, in the medical field, that make use of the technologies for educational support. It is important support researchers in future developments of educational tools to aid medical education;

RQ3: Are there evidences to state that using educational technologies benefits medical education? This question intends to analyze if such studies provide some evidence that the use of educational technologies benefits medical education considering its domains. Evidence should consider positive and negative results including empirical and non-empirical evaluation. They are important since they form a knowledge base about the use of educational technologies for medical education.

2.2 Inclusion and Exclusion Criteria

The definition of the inclusion and exclusion criteria is directly linked to the research objective. We defined the following inclusion criteria based on our research questions: (i) primary studies; (ii) peer-reviewed studies, and (iii) studies evaluating or using educational technologies in medical education. The exclusion criteria of this review are: (i) duplicated papers; (ii) gray literature; (iii) non-English papers; (iv) non-peer-reviewed studies; (v) position papers; (vi) redundant article authored by the same researcher; (vii) secondary studies; and (viii) short papers. We also excluded (ix) papers that use educational technologies for other health areas (e.g.,nursing, physiotherapy) and papers that received a score less than 50% of quality after conducting the quality assessment step of the review, as further explained in Section 2.4. Note that a primary study is a paper that presents any new contribution to a field (Kitchenham and Charters, 2007) and secondary studies are review papers, such as systematic reviews, meta-analysis or surveys.

2.3 Source Selection and Search

The search was performed only in electronic databases, the following electronic databases were searched: ACM Digital, EI Compendex, IEEE Digital Library, ISI Web of Science, Lilacs, PubMed, Science @ Direct, Scopus and Springer Link. The systematic review process is described in Figure 1 as well as the number of studies analyzed per step.

In step 1, the studies were obtained from the electronic databases using the following string: ((”Medical education” OR ”medical teaching” OR ”medical school”) AND (”authoring tool” OR ”authoring system” OR ”intelligent authoring” OR ”learning management system” OR ”m-learning” OR ”mobile learning” OR ”collaborative learning” OR ”computer supported collaborative learning” OR ”intelligent tutoring system” OR ”intelligent educational systems” OR ”massive open on line courses” OR ”adaptive ed-

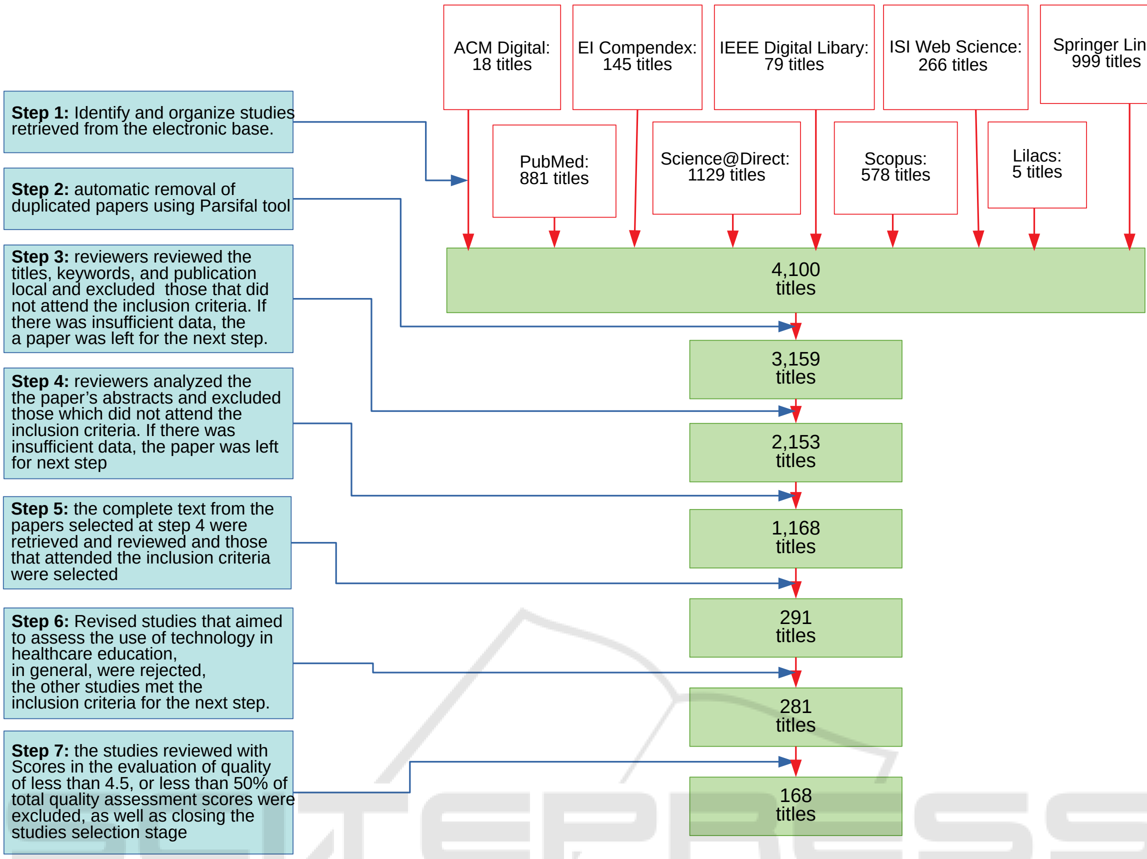

Figure 1: Research questions and motivations.

ucational systems" OR "adaptive learning systems" OR "artificial intelligence in education" OR "gamification")).

The results for the string search (4100 papers) were automatically downloaded and organized with the help of the *Parsifal* tool[1]. In Figure 1 we describe the selection stages, as well as the number of studies in each stage. In the end the selection process, 168 papers remained and were included in the review.

2.4 Quality Assessment

The quality assessment (QA) of the selected studies was based on a scoring technique to evaluate the credibility, integrity, and relevance of the selected papers. All the papers were submitted to a set of 9 quality criteria. Nine questions are adapted to quality assessments of studies in the literature. Table 1 presents the evaluation tool. All quality criteria were taken from the literature. The main basis for structuring the quality assessment questionnaire was the Systematic Review of the Literature conducted by (Dermeval et al., 2017).

We used a technique of score between 3 possible answers, Yes = 1,0, No = 0,0 and Maybe = 0,5. In questions Q6 and Q9, it would be possible only a direct answer (Yes / No), where Q6 was asked if the study was evaluated with some empirical method, already in Q9 is questioned if the study can be put in an industrial environment. In question Q5 brings the question of whether these tools would be available for download on the web, being scored with 1.0 if the tool is present and it is available for download on the web, 0.5 if only the tool is presented, but it's unavailable for download and has received score 0,0 those who did not present any type of tool. In the other questions, this line follows, taking into account the requirement of the question totally received 1.0, partially attending 0.5 and not meeting the requirements of question received 0.0.

Note that, in the selection steps, authors evaluated the studies separately to discuss disagreement regarding classification. Studies were organized in a spreadsheet, separated per retrieved papers over electronic databases. After this analysis, there was a cross-referencing of the data and a discussion of the diver-

[1] http://parsif.al

gences between the evaluations, reaching agreement on the issues.

2.5 Data Extraction and Synthesis

The data extraction was performed through the reading of the 168 articles selected in the previous steps. During this stage, the data was extracted by completing the extraction form (Table 2). All search, selection, and extraction were done with the aid of the *Parsifal* tool.

3 RESULTS AND ANALYSIS

A total of 168 papers met the inclusion criteria and their data were extracted. Prior to presenting the results and analysis for each research question, we review the quality assessment results and give a short overview of the general characteristics of the studies.

The quality assessment on the selected papers is useful to increase the accuracy of the data extraction results. This evaluation helped to determine the validity of the inferences conducted and in ascertaining the credibility and coherent of the synthesis of results. For the sake of space, the quality assessment results as well as the list of the 168 papers included in this review are available at *Google drive*[2]:

The scores of all papers are no less than 50% and the average score is 74,46%. We chose the minimum of 50% quality with the aim to establish an acceptable quality threshold for the articles. Taken together, these 9 criteria provided a measure of the extent to which we could be confident that a particular study's findings could make a valuable contribution to this review.

3.1 Overview of the Studies

In the following sections, we depict in detail publications years, local and type of paper, research methods, and application context information.

3.1.1 Publication Year

The reviewed papers were published between 1986 and 2017. From a temporal point of view (Figure 2), an increasing number of publications in the context of this review is observed since 2006. 2016 (24;14.12%) is the year with most publications, followed by 2014 and 2015 (each with 20 papers;11.76%), 2011 (12; 7.06%), 2013 (12; 7.06%), 2008 (10; 5.88%), 2006, 2010 and 2017 (each with 9 papers; 5.29%), 2012 (8; 4.71%), 2002 and 1990 (each with 4 papers; 2.35%), 2007, 2000, and 1992 (each with 3 papers; 1.76%), 2009, 2005, 2004, 2001, and 1991 (each with 2 papers; 1.18%). There is only one paper published in each of the following years: 1999, 1997, 1996, 1995, 1994, 1993, 1988, and 1986.

Note that there is an increasing interesting in the publications on the use of educational technologies in medical since 2006. It is also worth noting that, as the search process of this review was performed in September 2017, a slight decrease in the number of publications would be expected in 2017 because some papers might be in press.

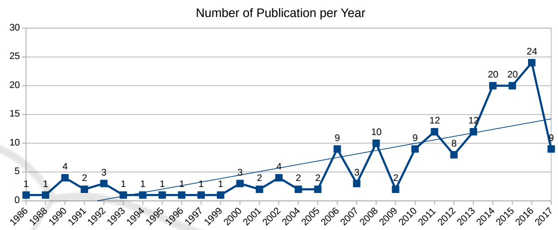

Figure 2: Number of publications per year.

3.1.2 Articles Types

The types of sources could be journal, conference, or book chapters. The majority of the articles are the journal papers (63.53%, 108 studies), followed by chapter books (20%, 34 studies), and conferences (15.29%, 26 studies).

The venues with more contributions are: BMC Medical Education (29 publications), Advances in Health Sciences Education (5 publications), Medical Science Educator and Lecture Notes in Computer Science (including subsections in Artificial Intelligence and Lecture Notes in Bioinformatics)(each one with 4 papers), and Medical Teacher (2 publications). However, one might note that several sources from educational technology, medicine and computer science have been considered as possible venues for publication, which may suggest that scientific communities are interested in this interdisciplinary field.

3.1.3 Research Method

The classification of the publications was based on the categories (i.e.,controlled experiment, quasi-experiment, case study, survey research, ethnography and action research) defined by (Easterbrook et al., 2008). However, we have defined two extra categories to classify papers that did not fit in those categories:

[2] https://drive.google.com/file/d/1MXBbYq97z-2euqCk_Fg5e6eJda9x43v7/view?usp=sharing

Table 1: *Study quality assessment criteria. These criteria are adapted from (Dermeval et al., 2017).* Y=Yes,N=No, and M=Maybe.

#	Questions	Possible answers
Q1	Is there a rationale for why the study was undertaken?	Y=1,0 ,N=0,0 ,M=0,5
Q2	Is there a clear statement of the goals of the research?	Y=1,0 ,N=0,0 ,M=0,5
Q3	Is the proposed technique properly described?	Y=1,0 ,N=0,0 ,M=0,5
Q4	Is there an adequate description of the context (industry, laboratory setting, products used and so on) in which the research was carried out?	Y=1,0 ,N=0,0 ,M=0,5
Q5	Does the study provide or use a tool? If so, is the tool available for download on the internet?	Y=1,0 ,N=0,0 ,M=0,5
Q6	Was the study empiricaly evaluated?	Y=1,0 ,N=0,0
Q7	Is there a discussion about the results of the study?	Y=1,0 ,N=0,0 ,M=0,5
Q8	Are the limitations of this study explicitly discussed?	Y=1,0 ,N=0,0 ,M=0,5
Q9	Does the study also evaluate the proposal in industrial settings?	Y=1,0 ,N=0,0

Table 2: *Extraction form.*

#	Study data	Description	RQ
1	Study Identifier	Unique id for the study	Overview
2	Author(s)		Overview
3	Type of article	Book chapter, Conference, Journal, Workshop	Overview
4	Article Source		Overview
5	Application context	Industrial, academic	Overview
6	Year		Overview
7	Title		Overview
8	Country		Overview
9	Researchers genders	Female, Male, Other	Overview
10	Research Method	Action research, Case study, Controlled experiment, Ethnography, Illustrative Scenario, Not applicable, Survey	Overview
11	Type of educational technologies	CSCL, Educational Game, Gamified, Environment, ITS, LMS, M-learning, MOOC, Simulation, T-learning	RQ1
12	Medical education domains supported		RQ2
13	Evidence	Negative argumentation, Negative with empirical evaluation,Positive argumentation, Positive with empirical evaluation	RQ3

illustrative scenario and not applicable. The first is appropriate for papers that just explain their contributions using small examples or argumentation. The latter refers to the papers that do not present any kind of research method or explanation of using the proposal.

Case Study (41.18%; 70 studies) constitute the majority of the studies, followed by Not applicable (20%; 34 studies), Survey (17.85%; 30 studies), Controlled experiment (10.59%; 18 studies), illustrative scenario (5.29%; 9 studies) and action research (3.53%; 6 studies). It is worth noting that 118 studies (70.23%) are concerned in conducting empirical studies (i.e., controlled experiment, case study, and survey) on evaluating or creating technologies for medical education. There were no ethnography and action research papers in our classification.

3.1.4 Application Context

The paper settings were categorized as industry and academic. The majority of them (93.45%; 157 papers) are in the academic category, whereas, 19 papers (11.30%) belong to the industry category

3.2 RQ1: Types of Educational Technologies

The purpose of this research question was to identify the main educational technologies used to support medical education.

3.2.1 Results

The technologies were categorized into nine different types, Computer-supported collaborative learning (CSCL), Gamified environment, Educational Game, learning management system (LMS), Simulation, mobile-learning, intelligent tutoring system (ITS), massive open online course (MOOC), tv-learning. As seen in Table 3, the predominant type of educational technology used in medical education is

Table 3: *Studies over Technologies used.*

Types of educational Technologies	Studies	Freq	%
LMS	S11, S46, S58, S59, S91, S167, S125, S154, S88, S140, S168, S1,S13, S16, S21, S32, S35, S36, 38, S48, S55, S56, S61, S62, S63, S65, S66, S68, S69, S70, S71, S72, S74, S75, S77, S81, 83, S90, S92, S94, S96, S97, S99, S102, S103, S104, S105, S108, S109, S110, S114, S121, S124, S130, S132, S138, S139, S141, S143, S144, S145, S148, S149, S150, S152, S157, S164, S14, S20, S127, S158, S159, S5, S34, S19	75	44.12%
M-Learning	S125, S8, S14, S20, S127, S158, S15, S22, S27, S28, S31, S67, S79, S82, S89, S106, S107, S112, S116, S117, S119, S120, S128, S129, S137, S142, S156, S163, S133, S165, S118	31	18.24%
Simulation	S50, S101, S53, S134, S169, S5, S34, S2, S3, S7, S17, S18, S23, S24, S39, S40, S42, S44, S54, S60, S76, S78, S87, S126, S136, S161, S162, S166, S95	31	18.24%
ITS	S10, S12, S25, S26, S29, S33, S37, S41, S47, S49, S64, S80, S93, S100, S115, S135, S147, S151, S153, S155, S170, S140, S168, S134, S169	25	14.71%
CSCL	S4, S43, S45, S52, S73, S131, S146, S160, S85, S11, S46, S58, S59, S91, S167, S125, S50	17	10%
Educational Game	S6, S8, S30, S53, S84, S101, S154	7	4.12%
Gamified Environment	S85, S84, S101, S86, S98, S88	6	3.53%
T-learning	S19, S118, S95, S57, S123	5	2.94%
MOOC	S159, S111, S122	3	1.76%

LMS (44.12%;75 studies), followed by Simulation (18.24%;31 studies), M-learning (18.24%;31 studies), ITS (14.71%;25 studies), CSCL (10%; 17 studies), educational games (4.11%;7 studies), gamified environment (3.52%;6 studies), t-learning (2.94%;5 studies) and MOOC (1.76%;3 studies). It is worth noting that a publication could have used more than one educational technology of the RE process. Thus, the sum of the percentage is greater than 100%

3.2.2 Analysis and Discussion

In summary, we could note that several distinct types of educational technologies have been used in medical education, showing the demand for different types of educational technologies to target different medical education needs. It is worth noting that most of the papers (44.12%) are using LMS, which could suggest that the studies are more focused on content repositories for medical education rather than on adaptive-intensive educational systems (e.g., ITS). An interesting result that we might mention is the frequent use of mobile technologies for medical education, this results could indicate that mobile devices may be well-accepted by medicine students. Moreover, educational technologies based on simulation are also frequently used, which is expected since medical school curricula uses lots of practical activities.

We also could note that some promising educational technologies might be underexplored in medical education. For example, educational games and gamification could be more used along with other types of educational games to target achieving more engagement of medicine students.

3.3 RQ2: Medical Education Domains

The purpose of this research question was to main medical domains where educational technologies have been used.

3.3.1 Results

The classification of the medical domains was performed after the data extraction step, that is, during the extraction of data to answer this research question. We identified 47 different medical domains where these technologies were applied. Educational technologies have been used in several domains, for example, for pediatric learning support (4.71 %, 8 studies), followed by anatomy study (4.12 %, 7 studies). These areas are followed by teaching and practice surgeries (3.53 %, 6 studies), diagnosis of diseases (1.18 %, 2 studies), cardiology (3 studies, 1.76 %). Note that a study could have targeted more than one domain, so the sum of the percentage may be greater than 100 %.

Table 4: *Medical education domains.*

Medical Education Domains	Studies	Freq	%
Anatomy	S11, S17,S28	7	4.12%
Anesthesia	S44	1	0.59%
Antimicrobia prescribing	S8	1	0.59%
Atheromatosis	S93	1	0.59%
Cardio-respiratory	S132	1	0.59%
Cardiology	S26, S47, S75	4	2.35%
Cardiopulmonary	S142	1	0.59%
Cardiovascular Physiology	S64	1	0.59%
Clinical education	S102	1	0.59%
Cryosurgery	S135	1	0.59%
Cytopathology	S57	1	0.59%
Dental	S150, S156	2	1.18%
Dermatology	S76	1	0.59%
Chiropractic	S151	1	0.59%
Diagnostic	S151	2	1.18%
Emergency	S50	1	0.59%
Endocrinology	S77, S161	2	1.18%
Forensic medicine	S24	1	0.59%
General practitioners	S32	1	0.59%
Gynecologic	S25	1	0.59%
Histology	S158, S83	3	1.76%
Human Anatomy	S35, S53, S165, S28	4	2.35%
Human Genetics	S2	1	0.59%
Laparoscopy	S54	1	0.59%
Microscopy	S71	1	0.59%
Neurology	S21	1	0.59%
Neuroradiology	S69	1	0.59%
Oncology	S13, S99, S134	3	1.76%
Operating	S101	1	0.59%
Orthopedy	S38, S90	2	1.18%
Pediatric	S109, S23, S143, S154, S96, S107, S133, S127	8	4.71%
Pathology	S83	5	2.94%
Pharmacology	S162, S28	2	1.18%
Physiology	S29	1	0.59%
Pneumology	S94	1	0.59%
Psychiatric	S97, S124	2	1.18%
Radiology	S19, S152	2	1.18%
Surgery	S88, S123, S136	3	1.76%
Thoracic Surgery	S87	1	0.59%
Traumatology	S90	1	0.59%
Urology	S30, S62, S159	3	1.76%
Venereology	S76	1	0.59%

3.3.2 Analysis and Discussion

In fact, the great majority of the papers are not targeting any particular medical domain. This results might suggest that researchers have been proposing generic educational technologies not tied to specific medical domains. However, it is worth noting that educational technologies have been applied in a plenty of medical domains, illustrating the need for research and development for solutions in several areas. Another interesting point that we can raise is that some technologies could be more amenable to be used in particular domains. For example, it is expected that simulation technologies might be more frequently use in surgery domain that in psychiatric. As such, it would be also interesting to investigate if there are some kind of correlation between medical domains and the types of educational technologies used.

3.4 RQ3: Supportive Evidence

The purpose of this research question was to gather and classify evidences to state that using educational technologies benefits or not medical education.

3.4.1 Results

The classification of the papers was defined according to the presence or absence of empirical evaluation in the paper and by the positive or negative indication that using educational technologies benefits medical education. The defined categories are: positive with empirical evaluation, positive without empirical evaluation, negative with empirical evaluation and negative without empirical evaluation (see Table 5). As shown in Table 5, 45.29% (77 studies) of the studies reported positive evidence after conducting empirical evaluation and 44.29% of studies (76 studies) only presented positive argumentation about the benefits of educational technologies. In addition, 4.71% (8 studies) presented negative evidence after running empirical evaluation and 3.53% (6 studies) argued about the negative implications of using educational technologies in medical education.

Table 5: *Supportive evidence.*

Types of evidence	Studies	Freq	%
Positive argumentation	S1, S2, S7, S8, S12, S16, S20, S21, S23, S24, S25, S26, S28, S33, S39, S40, S42, S43, S44, S45, S46, S47, S48, S49, S50, S53, S56, S57, S58, S59, S60, S61, S67, S69, S70, S77, S78, S80, S81, S83, S84, S85, S88, S91, S93, S98, S100, S101, S103, S105, S106, S107, S109, S110, S111, S112, S117, S120, S121, S125, S130, S131, S136, S145, S147, S148, S150, S152, S155, S159, S160, S162, S164, S165, S167, S170	77	45,29%
Positive with empirical evaluation	S3, S4, S5, S6, S9, S10, S11, S13, S14, S15, S18, S22, S27, S29, S30, S31, S34, S36, S37, S38, S41, S52, S54, S62, S63, S65, S66, S68, S74, S75, S76, S79, S82, S86, S87, S89, S90, S92, S94, S95, S99, S102, S104, S108, S115, S116, S118, S119, S122, S123, S124, S126, S127, S128, S129, S132 ,S133, S134, S137, S138, S139, S140, S142, S144, S146, S149, S151, S153, S154, S156, S157, S158, S161, S163, S166, S168,S169	78	45,88%
Negative argumentation	S17, S19, S32, S64, S72, S114, S143	8	4.71%
Negative with empirical evaluation	S35, S55, S71, S73, S135, S141	6	3.53%

3.4.2 Analysis and Discussion

Majority of the studies (91.07 %, 153 studies) presented positive evidence of the efficacy on using educational technologies in the context of medical education. Within these studies, 44.71% presented positive arguments and 45.29% reported positive evidence. These results indicate the potential of using educational technologies for medicine education. However, negative evidence is also reported in the studies. This result is interesting, since they are showing the criticism of the scientific community publishing a work that did not provide results as expected.

In summary, the evidence reported on studies suggests that different types of educational technologies benefit medical education in several distinct domains.

However, more research is needed to better explore promising educational technologies, for instance, educational games, gamification, ITS, CSCL – or the combination of them – considering different contexts.

4 CONCLUDING REMARKS

In this work, we aimed at understanding how educational technologies have been used in medical education through the conduction of a SLR. More specifically, the major objective of this SLR was to better understand how current educational technologies can give support to medical education and identify in what way this concept is being applied to this field.

One hundred and sixty eight papers on the review topic were included, in which nine types of technologies are applied in forty-two medical domains. Among the nine types of educational technologies, LMS is the highest technology used in medical education. Moreover, it is worth noting that the community is interested in using more "intelligent" educational systems or promising technologies to target medical education since technologies such as ITS, mobile learning applications, educational games and MOOCs have also been used (despite being quite underexplored so far).

As future work we intend to explore other research questions for this SLR, for instance, to understand which features have been incorporated in the educational technologies applied in medical education as well as to gather metrics for evaluating the effectiveness of the such technologies in learning improvement.

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