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A Meta-Analysis of the Effectiveness of Educational Technologies in Medical Education

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Abstract

Objectives: Considering the contradictory evidence on the effectiveness of educational technologies, this meta-analysis was conducted to evaluate the impact of these technologies on medical education.
Data Sources: This meta-analysis was conducted based on secondary analysis methods. The analysis included experimental and semi-experimental studies on the effectiveness of educational technologies in the medical education of Iran. The census sampling method was applied in this study, and 54 studies were identified as relevant based on the inclusion and exclusion criteria. For data collection, a researcher-made checklist consisting of three sections, i.e., bibliographic information, methodological information, and findings, was completed. Finally, the Comprehensive Meta-Analysis (CMA) software was used for analysis of data.
Results: Among different educational technologies, multimedia education, E-learning, and computer-mediated learning using compact discs and software packages had significant effects on medical education; therefore, use of these technologies was effective in medical education. According to our findings, multimedia education (effect size, 1.793) was considered to be the most influential virtual technology in medical education. In general, all educational technologies were effective in the medical education of Iran; however, their effectiveness was insubstantial. Considering the area under the normal curve, the average effectiveness of educational technologies was 63% higher in the virtual education groups, compared to the controls without virtual education.
Conclusions: One of the most important issues in medical education and training is preparation of an engaging learning environment for students, which can be realized through a variety of educational technologies. However, for optimal effectiveness, complementary use of virtual technologies along with traditional methods or their integration in other educational approaches is suggested.

Keywords: Technology, Virtual Education, Medical Education

1. Context

Today, the importance of quality improvement in medical education is increasing rapidly. Although the prevailing instructional methods involve the teacher's presence in the classroom, some believe that with the advent of modern educational technologies, students can distance themselves from traditional approaches and move towards new learning methods. There are new communicative practices and opportunities, which can facilitate learning outside the classroom. In fact, students are encouraged towards self-learning through information technologies to improve their learning experience (1).

Currently, most educational studies and instructors are looking for effective ways to present educational content to students and maximize learning (2). Therefore, educational systems are carefully monitored to determine if adequate attention has been paid to the learning of students. Previous studies have emphasized on the idea that educational institutions should devise alternative teaching methods in order to guarantee high levels of knowledge and skills among students after graduation (3).

Recent developments in information technologies have led to the design of new teaching models and approaches. The majority of university instructors use face-to-face lectures traditionally, while technological advances can be utilized to provide a better learning environment for students (4). Over the past decade, changes in the learners' characteristics, economic development, and Internet technology have caused changes in the educational environment. As a result, many instructors are now examining new educational models to ensure the success of graduates (5).

New and accessible technologies are often incorporated to improve traditional education and foster educational processes (6). One of the most widely used technologies in recent years is "virtual education". Several definitions have been proposed for virtual education from different standpoints. In general, virtual education is a novel educational approach, which can be used to facilitate simple and inexpensive access to educational resources and services through communication technologies (e.g., electronic devices), regardless of time and place. In other words, virtual education implicates education and learning based on electronic tools (7, 8).

Application of virtual technologies can help medical students examine different scientific phenomena using proper tools, data collection techniques, and scientific models and theories in physical (interactions with the material world) or virtual (simulations) laboratories (9). On the other hand, healthcare education is faced with clinical constraints and increased demand for online education (10). Generally, the results of various studies have confirmed the effectiveness of these technologies in education.

Previous findings indicate that virtual education is as effective as traditional education in learning transfer (11). According to the literature, distance learning and information technologies promote vocational education for employment, improve the transfer of learning and learning techniques, and encourage entrepreneurial skills (12). In addition, online interactive engagement has a positive impact on student learning (13). Overall, capacity development for the improvement of learning outcomes (14), professional skills (15), and effectiveness of virtual educational system (16) is among the educational outcomes of these technologies.

Virtual learning and E-learning can help eradicate many of the current teaching-learning problems owing to their special characteristics: unlimited accessibility; time management; cost reduction; increased productivity; increased motivation; increased contact with the learner; group-work opportunities in multimedia environments and E-conferences; and sufficient spatial and temporal resources for interacting with a large number of applicants for education. In fact, use of virtual learning along with academic education can improve the process of education (17).

Today, knowledge and technology are closely integrated and almost inseparable. The virtual world provides its users with a wealth of resources for knowledge acquisition and offers many educational opportunities due to its interactivity and lack of spatial and temporal constraints (18). In other words, if the medical education system seeks to promote knowledge and technology, it should be prepared for a vital systematic change and take advantage of new technologies with respect to educational goals.

2. Objectives

Many studies have been conducted on the effectiveness of a variety of virtual technologies in Iran. Some studies have highlighted the effectiveness of this type of training in teaching-learning activities, while some have reported its ineffectiveness in medical education. Considering these contradictions in the findings, we need to determine if these virtual technologies are effective or ineffective in teaching-learning activities. Therefore, in the current review study, we applied a meta-analysis method to answer this question.

3. Data Sources

The meta-analysis method was applied in the current review study. Meta-analysis is a statistical technique for summarizing quantitative data from a series of studies. This technique can be used to combine the results of quantitative research and discover new relationships among social phenomena (19). Accordingly, the current study is an applied research in terms of goals and a quantitative study in terms of the applied method and nature of data. The unit of analysis was the quantitative data of previous studies, and the statistical samples consisted of studies on the effectiveness of various educational technologies in the medical education of Iran.

Multiple studies have been conducted on the effects of virtual learning, each incorporating different technologies, i.e., online education, multimedia education, E-learning, video-based education, virtual education, self-learning, computer-mediated instruction using educational software packages and compact discs, mobile learning, web-based education, blog-based learning, and wiki-based learning; nevertheless, each of these studies has reported inconsistent findings. The present review included all experimental and semi-experimental studies on the effectiveness of electronic and virtual technologies in medical education in 2005 - 2017; these studies were selected to evaluate the effects of educational technologies in practice.

On the other hand, educational studies outside the field of medical education were excluded, as medical education studies should not be combined with studies in other teaching realms considering the differences in the teaching domains. The census sampling method was applied according to the study unit. For implementing the meta-analysis, it was essential to develop a framework with respect to the study constraints. Therefore, three sampling frameworks were defined to select relevant studies:

- Full-text articles in IranDoc, SID, Magiran, Noormags, Iranian Human Sciences Portal, Elmnet search engine, Google and Google Scholar, and scientific journals on educational technology, besides checking the reference lists of available articles;

- Dissertations submitted to different universities of the country in line with our research purposes; and

- Government-funded research projects.

To select the primary studies based on these frameworks, proper keywords were determined for search purposes by reviewing the literature. The keywords were selected based on the theoretical framework of the study and expert viewpoints on a variety of virtual and E-learning methods, including "distance learning", "virtual education", "mobile learning", "mobile education", "E-learning", "virtual learning", "programmed instruction", "learning management system", "online education", "compact disc-mediated learning", "software-assisted learning", and "self-learning". In order to improve the search quality, two individuals, who were familiar with the search methods and information sources, conducted the search independently. In addition, an expert in meta-analysis monitored the entire process.

After identifying the keywords, studies were selected based on the inclusion and exclusion criteria. The inclusion criteria were as follows: Studies related to the research objectives; semi-experimental studies; medical education research; and implementation of an appropriate research methodology and a scientific approach. Finally, based on our manual search using the keywords and inclusion criteria, a total of 119 studies were retrieved. The titles of these studies were related to the purpose of our review. As some of these studies were not considered suitable for the final analysis, they were excluded.

The exclusion criteria were as follows: studies with poor methodology and quality; studies extracted from dissertations which were already included in the review; and similar articles or dissertations submitted to different institutions or universities with different titles. In a total of 119 studies, which were retrieved according to the inclusion and exclusion criteria and our keyword search, 14 articles were excluded considering their irrelevant titles (n, 105). Similarly, 32 out of 105 articles were excluded after reviewing the abstracts (n, 73). Also, 19 out of 73 full-text articles were eliminated after reviewing the full manuscripts (n, 54). Finally, a total of 54 national articles were reviewed.

To analyze the data, the effect size index and heterogeneity test were applied. Generally, the most common effect size indices include Cohen's d and r; the former is often used for group differences, while the latter is measured for correlation studies (19). In the present study, Cohen's d index was measured with respect to the semi-experimental analyses and group differences.

For data collection, a researcher-made worksheet was designed to record the primary research data. This tool, which was developed with respect to the required information from the primary research, consisted of three major sections: bibliographic information, methodological information, and findings. In the bibliographic section, information including the study title, type of study, author's name, place of study, and year of publication was extracted.

The methodological section included information, such as the study population characteristics, sampling methods, data collection tools, type of research, and number of groups, while the findings section recorded the reported data of retrieved studies. It should be noted that all studies in our review had inter- and intra-group designs; therefore, when measuring the effect size of studies with an inter-group design, the scores of the case groups were lower than the controls. Also, pretest-posttest differences were calculated to measure the effect size of studies with an intra-group design.

To ensure the accuracy of our review, two evaluators assessed the process. For this purpose, the researcher presented a Likert-scale checklist about the data collection process, including the identification process of articles, inclusion/exclusion criteria, data selection, and effect size indices, to two meta-analysis experts. After assessing the checklist, the evaluators examined the review accuracy and reported any ambiguities to the researcher. After correcting the ambiguities, the researcher presented the checklist again to the examiners. In addition, to confirm its reliability, Cohen's Kappa coefficient was measured in SPSS V. 20 (IBM Corporation, Armonk, NY). Inter-rater agreement was estimated at 0.73, which indicates 73% agreement between examiners in the accuracy assessment.

To investigate the primary research, mixed effect models including the fixed effect model and random effects model were applied. On the other hand, Orwin's Fail-safe N was calculated to evaluate publication bias, and Cochran's Q and I-square indices were measured to study heterogeneity. In addition, due to lack of sensitivity to the sample size, the Hedge's g coefficient was calculated to convert the effect size. All meta-analysis calculations were analyzed in Comprehensive Meta-Analysis (CMA) version 2.

In general, the basic principle in meta-analysis is to calculate the effect sizes for individual studies, convert them to a common metric, and then combine them to obtain an average effect size. Generally, the effect size indicates the magnitude or extent of the presence of a phenomenon in a population and tests a null hypothesis. The importance of effect size has been emphasized following statistical power analysis. A true null hypothesis represents an effect size of zero, while a rejected null hypothesis shows that the effect size is non-zero. Therefore, effect size is an indicator of the effectiveness and magnitude of experimental interventions, relationships, and differences, with larger effect sizes representing the greater presence of a phenomenon (19, 20).

As mentioned earlier, there are two common indices of effect size, i.e., Cohen's d and r, which are used as measures of difference and relationship, respectively. In the present study, the Cohen's d index was measured considering the nature of our analysis. Cohen proposed that effect sizes of 0.2, 0.5, and 0.8 represent small, moderate, and large effect sizes, respectively (20). In meta-analyses, similar to many other statistical methods, it is necessary to examine the assumptions before analyzing the data. One of the most important assumptions is the absence of anomalies such as outliers (studies with publication bias) and normal distribution of data.

Publication bias occurs in meta-analysis when all studies related to the subject have not been reviewed, and the analysis is not a proper representative of the available evidence. In fact, some studies may not have been formally published for multiple reasons or published in non-indexed journals. When publication bias is present, the final results of the meta-analysis are affected, and the final estimates are biased and inaccurate. Therefore, it is necessary to identify and correct publication bias in the initial steps of meta-analysis in order to improve the validity of findings (21).

Some large effect sizes may occur in the meta-analysis, which can distort the normal effect size distribution; accordingly, they need to be removed for a normal distribution. Sensitivity analysis was applied in our meta-analysis to eliminate the effects of outliers. Although no exact effect size has been specified for outliers in the meta-analysis literature, effect sizes above 2.5 - 3 are assumed to represent the outlier effect sizes (as effect size is a standard score) (20); the outliers were excluded accordingly in our meta-analysis. Generally, the outlier effect sizes are detected and removed in sensitivity analysis, and then, the analysis is repeated.

4. Results

In this study, publication bias was examined by measuring Orwin's Fail-safe N, as presented in Table 1. This measure does not have the limitations of Rosenthal's test, i.e., emphasis on statistical significance rather than clinical significance and assumption of null effect size for missing studies. Orwin's Fail-safe N considers the smallest effect size, which is indicative of clinical or practical insignificance. Also, rather than nullifying the effect sizes of missing studies, a value other than zero is described as the average effect size (20). According to our findings, the minimum effect size was considered to be 0.2, and the average effect size of missing studies was 0.1; the results are presented in Table 1.

Table 1. Orwin's Fail-Safe N Measurements

Variables	Values
Z score for observed studies	0.395
Minimum effect size	0.2
Average effect size of missing studies	0.1
Number of required missing studies	106

As indicated in Table 1, a total of 106 studies with an average effect size of 0.1 were required for a combined effect size of < 0.2. Given the high number of required studies, it can be said that the overall effect size is reliable, and there is no publication bias.

Since all the observed dispersions in the effect sizes are not real, but partly related to random errors, it is necessary to measure between-studies heterogeneity. The initial heterogeneity can be attributed to factors, such as differences among subjects, intervention methods, definition of variables, research design, study location, sampling method, and many other factors. The results of heterogeneity test based on Cochran's Q and I-square indices were 935.363 and 94.548, respectively ($P < 0.001$; $df = 51$).

Considering the significance of Cochran's Q index, studies were considered largely heterogeneous. In fact, this test suggests that the characteristics of studies on educational technologies in medical education vary greatly, and moderating variables should be taken into consideration to determine variances and differences. Also, since the Q index is sensitive to an increase in effect size (possibility of heterogeneity increases relative to an increase in effect size), I-square was measured. This index ranges from zero to 100 and represents heterogeneity in percentage. Overall, heterogeneity in the effect size of primary research increases as the I-square value approaches 100 (21). The I-square index indicated that 94% of dispersion in the distribution of educational technologies in medical education was related to moderating variables.

Since the main objective of meta-analysis is to combine the statistics of primary research into a common metric, the fixed effect and random effect models were applied in our analysis. In the fixed effect model, it is assumed that there is an effect size underlying all analyses, and all differences in the effect sizes of primary research are related to sampling errors. In contrast, in the random effect model, it is assumed that the effect size changes from one study to another. One of the main reasons for this change is the presence of mediating variables in the relationships between independent and dependent variables (20). Since the results of homogeneity test were significant, indicating the presence of mediating variables, the random effects model was applied to report the results in this study.

The effect sizes of all studies on the efficacy of virtual educational technologies in medical education were determined. The results are presented in Table 2.

According to Table 2, among educational technologies, multimedia education, E-learning, self-learning, and computer-mediated instruction using educational software packages and compact discs were significant; therefore, use of these technologies is effective in medical education. The analysis of self-learning also confirmed its effectiveness. However, given the negative value of the effect size, it can be claimed that effectiveness was in the reverse direction. In other words, traditional or in-person training was more effective than self-learning. On the other hand, multimedia education with an effect size of 1.793 was the most effective virtual technology in medical education. Finally, the results showed that other educational technologies described in the table were not effective enough.

The average combined effect size was 0.369 in the fixed effect model and 0.344 in the random effect model, which was significant at 0.001. According to Cohen's criterion (20) for interpretation of the practical significance of effect size, Cohen's d values were equal to 0.2 (small effect size), 0.5 (moderate effect size), and 0.8 (large effect size). Regarding the average effect size of variables in the fixed effect and random effect models (range, 0.2 - 0.5), the effect size was interpreted as small. Therefore, it can be concluded that all virtual education technologies were effective in Iran's medical education, although the level of efficacy was low.

On the other hand, since effect size is normally reported as a standard score (z score), we can refer to the normal distribution table for interpretations. According to this table, the area under the normal curve represents z scores of 0.34 (start point of the curve) to 0.63. These effect sizes indicate that the average use of educational technologies was 63% more effective in the technology groups, compared to the controls without educational technologies. Moreover, in order to investigate the effect of the quantitative variable of "publication year" in the results, the meta-regression method was applied, the results of which are presented in Figure 1.

The horizontal axis in Figure 1 represents the effect size, and the vertical axis indicates the year of study implementation. In this figure, the large circles represent studies which included a larger sample size and consequently had higher accuracy and weight in the analysis of research data. The slope of the regression line follows an ascending trend, which means that educational technologies in medical education gradually became more effective over time; the increase is significant in Figure 1 (slope = 0.1) ($P < 0.001$). Therefore, it can be claimed that with one unit of increase in the implementation of virtual methods, the effect size and effectiveness of these methods increase by 0.1. In other words, implementation of virtual education methods has become more effective year after year.

5. Discussion

The results of the present study showed that multimedia education, E-learning, and computer-mediated education using software packages and compact discs were the most effective educational technologies in medical education. According to the results, multimedia education was the most influential virtual technology in medical education. In this regard, Hashemi and colleagues concluded that use of multimedia software packages in medical education is associated with increased learning efficacy and long-term storage of information; in addition, this method is easily accessible and more cost-effective than other methods (23). Khoshsima et al. also confirmed the significant effectiveness of multimedia education in nursing training (63, 64).

Today, learning tools and practices have evolved, and students prefer learning methods involving electronic devices, such as cell phones, tablets, and laptops; this preference is attributed to the ease of use and appeal of these devices. In addition, the literature suggests that audiovisual tools can activate the individual's visual and auditory senses, and as a result, lead to deeper learning. In other words, students learn and understand the audiovisual subjects better than theoretical topics, whereas in textbook-based methods, there is more emphasis on the individual's auditory capacity.

Based on the present findings, it can be concluded that all virtual education technologies have been influential in the country's medical education; nevertheless, they have exhibited limited effectiveness, which is almost consistent with the results of several previous studies (37, 38). Overall, the medical education literature confirms the efficacy of virtual education methods as alternative approaches in Iran. Moreover, similar to traditional educational methods, they can be integrated in the educational curriculum (37).

Virtual and in-person teaching methods have almost similar effects on learning (38). Computer simulations facilitate training in a realistic virtual environment (47), and participation in a virtual educational program can improve the attitude of participating students in the course (40). In addition, use of E-learning promotes active and

Table 2. Effectiveness of Different Types of Educational Technologies in Medical Education

Type of Education	References	Frequency	Effect Size (g Index)	Standard Error	P Value
Online education	(17)	1	-0.265	0.736	0.719
Programmed instruction	(22)	1	0.692	0.741	0.350
Multimedia education	(23)	1	1.793	0.775	0.021[a]
Electronic education	(24-30)	7	0.691	0.272	0.011[a]
Movie-based education	(31, 32)	2	-0.771	0.550	0.160
Self-learning	(33)	1	-1.824	0.744	0.014[a]
Virtual teaching	(34-43)	10	0.040	0.206	0.845
Computer-mediated instruction with educational packages and compact discs	(44-54)	12	0.670	0.211	0.002[a]
Mobile learning	(55-57)	3	0.156	0.388	0.688
Web-based education	(23, 58-61)	5	0.500	0.315	0.112
Blog-based education	(62)	1	1.059	0.727	0.145
Wiki-based education	(63)	1	-0.224	0.798	0.779
Fixed effect	Total	52	0.369	0.030	< 0.001[a]
Random effect	Total	52	0.344	0.105	0.001[a]

[a] Significance level at 0.05.

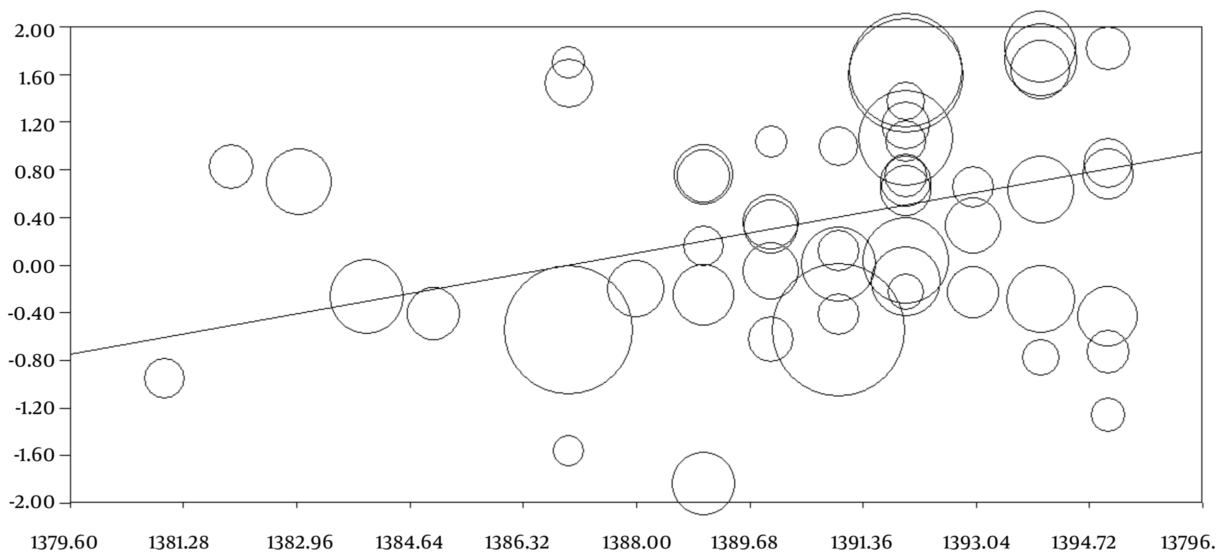

Figure 1. Meta-regression analysis of the effect of publication year

deep learning (48), and instructors can use web-based methods to improve the students' academic achievement and self-efficacy (59). In fact, use of educational software packages significantly influences the students' learning and improves their performance in practical courses (51).

According to the present findings, use of educational technologies can be effective in medical education. As our literature review indicated, incorporation of these technologies as a complementary approach to in-person and traditional methods (42, 50, 63) or their integration in other educational methods can increase the efficacy of education (24, 44). Figure 1 represents the gradually increasing efficacy of educational technologies in the country's medical education. Generally, implementation of educational technologies improves year after year and becomes more comprehensive over time. Therefore, if these methods are accurately and thoroughly implemented, their effectiveness in medical teaching-learning activities can be guaranteed.

In order to facilitate the development, expansion, and application of E-learning and virtual education technologies, it is necessary to increase the level of students' knowledge in this area and facilitate the implementation of such methods with respect to students' needs and demands (18). It is also recommended to employ virtual methods by providing interesting interactive environments for learners (28). However, despite the students' interest and enthusiasm about the application of these technologies, further analysis is recommended to improve this type of training, given the students' unfamiliarity with the Internet, poor telecommunication infrastructure, and poor quality of the presented content (58).

One limitation of the present study was our emphasis on previous medical education studies; therefore, caution should be taken in generalizing the results to other training methods. Moreover, only national databases were searched in our review, while international databases were discarded. Therefore, some national studies might have been published in international databases, such as PubMed and ISI, which were naturally excluded from our analysis.

6. Conclusions

Considering the recent developments and current status of medical education in our country, one of the most important learning-teaching activities is to create an engaging learning environment for students, using a variety of technologies. Overall, complementary application of educational technologies along with other traditional and in-person teaching methods or their integration in other educational approaches can increase the effectiveness of instruction.

Supplementary Material

Supplementary material(s) is available here [To read supplementary materials, please refer to the journal website and open PDF/HTML].

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