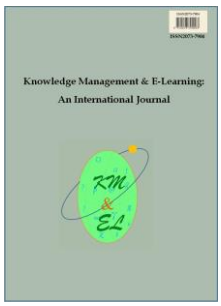
A review of two decades of research on the application of multicriteria decision making techniques to evaluate e-learning's effectiveness

Puong Koh Hii
UCSI University, Malaysia
Chin Fei Goh
Universiti Teknologi Malaysia, Malaysia
Amran Rasli
Inti International University, Malaysia
Owee Kowang Tan
Universiti Teknologi Malaysia, Malaysia



Knowledge Management & E-Learning: An International Journal (KM&EL)
ISSN 2073-7904

Recommended citation:
Hii, P. K., Goh, C. F., Rasli, A., & Tan, O. K. (2022). A review of two decades of research on the application of multicriteria decision making techniques to evaluate e-learning's effectiveness. *Knowledge Management & E-Learning, 14*(4), 466–488. https://doi.org/10.34105/j.kmel.2022.14.024

Knowledge Management & E-Learning, 14(4), 466–488

A review of two decades of research on the application of multicriteria decision making techniques to evaluate e-learning's effectiveness

Puong Koh Hii*

Faculty of Business and Management
UCSI University, Malaysia
E-mail: HiiPK@ucsiuniversity.edu.my

Chin Fei Goh

Faculty of Management
Universiti Teknologi Malaysia, Malaysia
E-mail: gcfei@utm.my

Amran Rasli

Faculty of Business, Communication and Law
Inti International University, Malaysia
E-mail: amran.rasli@newinti.edu.my

Owee Kowang Tan

Faculty of Management
Universiti Teknologi Malaysia, Malaysia
E-mail: oktan@utm.my

*Corresponding author

Abstract: Multicriteria decision-making (MCDM) techniques have been widely adopted to evaluate the effectiveness of e-learning. However, the literature review has not kept pace with the rapid accumulation of knowledge in this field. This study systematically reviews the MCDM techniques applied in e-learning issues. In total, we reviewed 77 published studies selected from the Web of Science and Scopus databases. We classified the selected studies by the publication year, the authors' nationality, and the type of MCDM techniques examined. We further discovered that the majority of previous studies adopted Information System Success Model (D&M model) which was proposed by Delone and McLean in 1992. Due to limited features that were provided by the e-learning system back in the mid-2000, the original D&M model might not consider some significant factors such as students' characteristics, instructors' characteristics, user interface and learning community. The goals of this systematic literature review are to understand if the original D&M model is addressed in modern e-learning and to determine if new factors have emerged to evaluate e-learning's effectiveness but not captured by the original D&M model. This review contributes three new theoretical perspectives. First, reclassification of the D&M model is conducted to include learners' characteristics, instructors' characteristics, user interface, and learning

community. Second, this study discovers that there is a need to perform reclassification of overlapping subfactors. Third, this review also identifies that the dependencies among the factors in the D&M model are inadequately examined in previous studies. Researchers can utilize the findings of this study as a foundation to formulate their research frameworks, and practitioners can integrate the significant factors identified in this study into their decision-making processes when developing e-learning at their institutions.

Keywords: e-Learning; Multicriteria decision-making; Systematic review; Analytic hierarchy process

Biographical notes: Puong Koh Hii is a lecturer in the Faculty of Business and Management, UCSI University, Malaysia. His research interests include E-learning and Multicriteria Decision Making.

Chin Fei Goh is a Senior Lecturer at the Universiti Teknologi Malaysia. His research interests focus on Information Systems and E-learning.

Amran Rasli is a professor at the Faculty of Business and Communication at INTI International University, Malaysia. His area of interest includes Institutional Service Quality, Human Resource Management, Institutional Administration and Psychological Studies.

Owee Kowang Tan is an Associate Professor in the Faculty of Management, Universiti Teknologi Malaysia (UTM). He has gained 21 years of industrial experience in the areas of Product and Tooling Design, Operation, Quality, Engineering and Projects management.

1. Introduction

In 2020, the widespread COVID-19 pandemic has significantly impacted the education sector all over the world (Azlan et al., 2020; Leong et al., 2020). The education mode was transformed from the traditional classroom towards an online learning method due to the shutdown of schools and universities (Chung et al., 2020; Humayun, 2020; Lan et al., 2020). In other words, e-learning became the best alternative and played a more significant role in teaching and learning process. e-Learning is viewed as the delivery of course content by using electronic media, such as the internet, intranet, extranets, audio/videotape, CD-ROM, interactive TV, and satellite broadcast (Ahmed, 2010; Farid et al., 2018; Selim, 2007).

e-Learning has many salient advantages over traditional learning (Sun et al., 2008). e-Learning can promote interactions among learners as well as interactions between learners and instructors. Furthermore, e-learning offers flexibility in both time and location to enable learners to take online courses anytime and anywhere through the Internet (Ahmed, 2010; Cheawjindakarn et al., 2012; Lee et al., 2009). e-Learning also decreases the cost of education, including the costs of printed materials, training, traveling, and labour (Bhuasiri et al., 2012; Lee et al., 2009). Finally, e-learning cultivates self-paced and self-directed learning by enabling learner-centred activities (Ahmed, 2010; Bhuasiri et al., 2012; Cheawjindakarn et al., 2012).

e-Learning has become a fast-growing trend in higher education industry after the post-Covid era (Bayrak, 2022). Even though e-learning has existed for several years in

the education field, the evaluation of e-learning's effectiveness is still a vital task for institutions. The essential purpose of evaluating e-learning's effectiveness is to understand the appropriateness, effectiveness, and efficiency of a course of action (Tzeng et al., 2007). By evaluating e-learning, academic managers and decision makers can identify good or bad actions, detect errors, correct mistakes, perceive risks, and make excellent investments, thus allowing learners to study effectively (Roffe, 2002). Over the past decades, a considerable number of articles using different evaluation approaches have been published to evaluate e-learning by examining its influencing factors (Al-Samarraie et al., 2018; Hu, 2016; Mohammed et al., 2017; Yigit et al., 2014).

During the evaluation of e-learning, there are multiple complex factors and subfactors to be evaluated. In addition, collecting data from e-learning experts and managers improves the accuracy and quality of factor evaluation that can help uncover the most significant factor for improvement (Lukhayu Pritalia et al., 2018; Yang et al., 2017). An alternative to that type of evaluation is multicriteria decision making (MCDM), which is an efficient and organized method of evaluating multiple complex factors. MCDM refers to a group of methodologies to rank, compare, and select multiple factors or alternatives (Zare et al., 2016). In other words, the MCDM approach is capable of modelling complex issues into several factors and subfactors. Additionally, the MCDM technique can evaluate the weighting of the factors and subfactors. Therefore, MCDM has recently been considered a suitable and sufficient approach for evaluating e-learning.

In recent decades, a significant number of MCDM approaches and techniques have been introduced, such as Elimination and Choice Expressing Reality (ELECTRE) in 1960s, the analytic hierarchy process (AHP) in 1970s, Decision-Making Trial and Evaluation Laboratory (DEMATEL) in 1972, Technique for the Order of Prioritization by Similarity to Ideal Solution (TOPSIS) in 1981 and the analytic network process (ANP) in 1996. Nevertheless, literature reviews have not kept pace with the rapid accumulation of knowledge in this field. Also, due to limited features that were provided by the e-learning system back in the mid-2000s, the original D&M model might not consider some significant factors. Thus, this study aims to conduct a new systematic study to consolidate the extant studies and to provide an up-to-date review of the literature. This study attempts to answer the following question:

RQ: Does the original Information System Success Model sufficient to evaluate the effectiveness of modern e-learning systems?

2. Literature review

MCDM is a collection of methodologies that evaluates real-world issues according to different types of qualitative or quantitative factors to generate a suitable course of action, policy, choice, or strategy among several available options (Zare et al., 2016; Zavadskas et al., 2014). In the 1950s, the foundations of MCDM were established and developed to assist decision makers in dealing with multicriteria decisions (Mardani et al., 2019; Mardani et al., 2015; Zavadskas et al., 2014). Then, the development of MCDM studies surged rapidly in the 1980s and early 1990s, and they grew exponentially (Mardani et al., 2015; Zavadskas et al., 2014). A variety of MCDM techniques have been developed, including the Analytic Hierarchy Process (AHP), the Analytic Network Process (ANP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Elimination and Choice Translating Reality (ELECTRE), VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR), Multi-Objective. Optimization Method by Ratio Analysis (MOORA), Decision making trial and evaluation laboratory (DEMATEL),

Simple Additive Weighting (SAW), and Complex Proportional Assessment (COPRAS), among others (Mardani et al., 2015).

The main goal of MCDM Is to find the best compromise by examining all the qualitative and quantitative factors that influence multicomplex issues (Mardani et al., 2019). Different types of decision problems, including sorting, classification, and ranking, can be solved by using MCDM techniques (Zare et al., 2016). Additionally, MCDM has been extensively adopted in many research areas, including management, economics, energy fuels, computer science, geography, and engineering (Zare et al., 2016; Zavadskas et al., 2014).

MCDM can be broadly divided into two categories: multiattribute decision making (MADM) and multiobjective decision making (MODM) (Kabir et al., 2014; Mardani et al., 2019; Mardani et al., 2015; Singh & Malik, 2014; Zavadskas et al., 2014). MADM involves the selection of the most appropriate alternative among prespecified alternatives by evaluating the multiple factors and subfactors (Singh & Malik, 2014). Unlike MADM, MODM involves the design of alternatives that optimize the prespecified multiple objectives of the decision-maker (Singh & Malik, 2014).

Generally, the MCDM process is divided into four phases: the intelligence phase, design phase, choice phase, and implementation phase (Zare et al., 2016). At the intelligence phase, the goal of the problem is identified. Then, a group of factors and alternatives is identified based on the goal, and the MCDM model is formulated at the design phase. In the choice phase, factors are evaluated by using the chosen MCDM technique, and a suitable solution is recommended for the decision problem. Last, a suitable solution is applied in the implementation phase (Zare et al., 2016).

3. Research method

This paper provides a systematic review of the MCDM approach in e-learning evaluation issues. Three main steps were conducted: literature search, selection of eligible articles, and data extraction and summarizing.

3.1. Literature search

In this study, the Web of Science and Scopus databases were the key information sources. Recent studies posited that these two databases satisfied all relevant performance criteria, making them ideal for evidence synthesis in the form of systematic reviews (Birkle et al., 2020; Gusenbauer & Haddaway, 2020). The systematic literature review was performed onto databases for articles published between 2001 and 2019 to identify substantial contributions that have been published in the field of e-learning. The year 2001 is used as the reference point of this study as per the seminal work by Murakoshi et al. (2001) that examined the postadoption of online learning by using the AHP technique. The search keywords were a combination of MCDM, MCDA, AHP, ANP, DEMATEL, TOPSIS, ELECTRE, e-learning, online learning, web-based learning, virtual learning distance learning, and network learning. Two hundred and seventy-four papers were retrieved from the two databases of which 86 were removed due to duplication (see Fig. 1).

3.2. Selection of eligible articles

In this stage, the titles and abstracts of the papers were screened. One hundred thirty-seven articles were found to be relevant. Then, the full texts of the relevant studies were read. Only papers that applied MCDM approaches in e-learning were chosen. As a result, 72 articles were identified. An additional five articles were identified in the references of those 72 articles. Therefore, 77 articles were reviewed herein (Fig. 2).

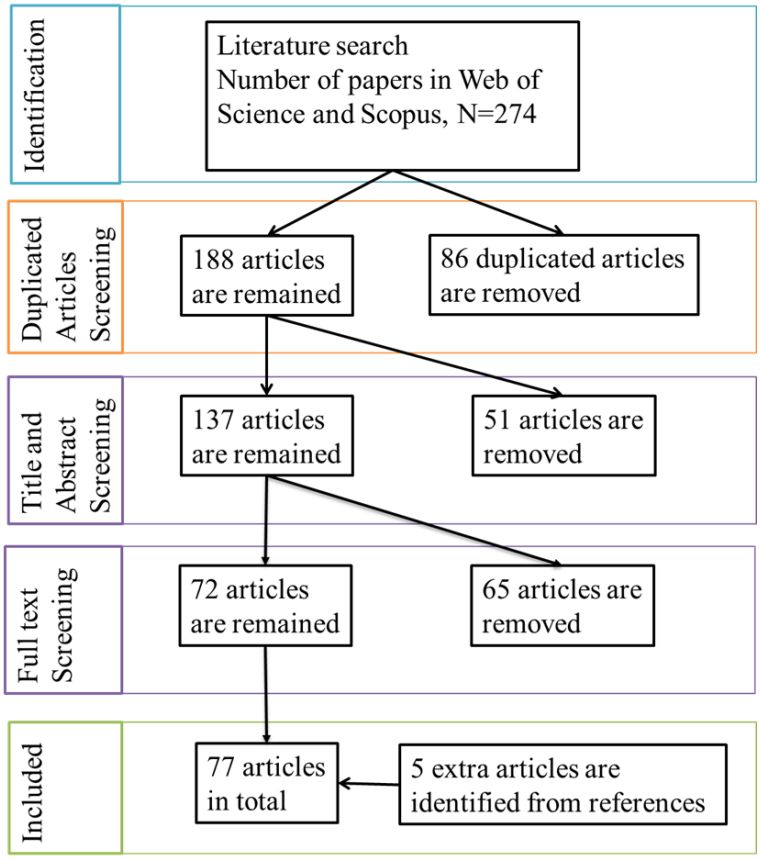


Fig. 1. Flow diagram of the systematic search

3.3. Data extraction and summary

In the final stage, the data from these 77 articles were extracted and summarized in an Excel file. Next, these articles were grouped into different categories based on the publication year, the author' nationality, and the MCDM techniques examined. This categorization helped to generate several critical and important insights. Consequently, several potential recommendations and future works were suggested.

4. Findings

The findings are mainly divided into two parts. The first part discusses the classification of academic papers based on publication year, MCDM method, and nationality of authors.

The second part further examines the D&M model which is the most popular theory used in previous studies. Three theoretical gaps are discussed in the second part, which are reclassification of the D&M model to include learners' characteristics, instructors' characteristics, user interface, and learning community and reclassification of overlapping subfactors. In addition, this review also identifies that the dependencies among the factors in the D&M model are inadequately examined in previous studies.

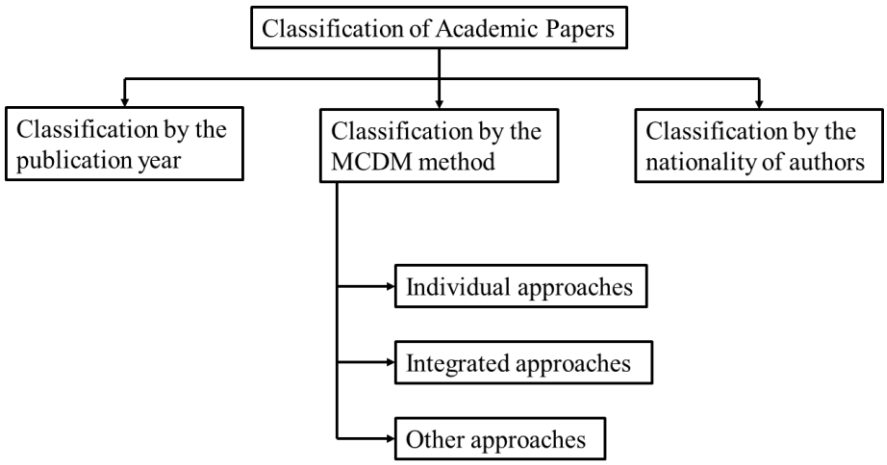


Fig. 2. Classification of academic papers

4.1. Classification of academic papers

This section presents an overview of the paper classification based on different factors, as shown in Fig. 2. As shown in the figure, the academic papers were categorized based on the publication year, the MCDM approach examined, and the nationality of the authors.

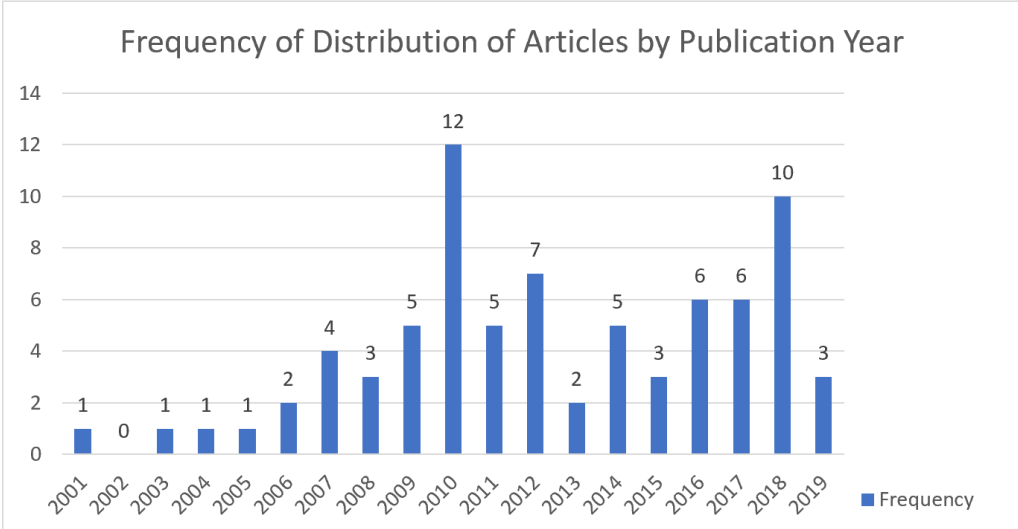


Fig. 3. Distribution of articles by the publication year

4.2. Distribution of academic papers by the publication year

Fig. 3 presents information related to the distribution of extant papers according to their publication year. The finding shows that there was an increase in the use of MCDM approaches between 2001 and 2019. The frequency of article publication remained almost constant throughout the first five years, followed by a gradual increase between 2006 and 2009. In 2010 the frequency of article publication experienced a dramatic surge, reaching a peak of 12 papers. Over the next nine years, the number of publications fluctuated between 2 and 7 papers, except for 2018, in which the number of publications rose to 10 papers. In conclusion, over the years, previous researchers have started to adopt MCDM techniques to evaluate the effectiveness of e-learning.

4.3. Distribution of academic papers by the nationality of authors

Table 1 shows the nationality of authors who have employed MCDM approaches in their studies. In total, 19 countries were identified. As shown in Table 1, most of the published papers were from China (44%), followed by Indonesia (8%) and India (6%). In conclusion, it can be concluded that researchers from China have more exposure to MCDM techniques, and they utilized MCDM techniques to study the effectiveness of e-learning.

Table 1
Distribution of articles by the nationality of authors

No.	Country	Frequency	Percentage (%)
1	China	34	44%
2	Indonesia	6	8%
3	India	5	6%
4	Malaysia	5	6%
5	Turkey	5	6%
6	Greece	3	4%
7	Iran	3	4%
8	Korea	3	4%
9	Croatia	2	3%
10	Spain	2	3%
11	Egypt	1	1%
12	Italy	1	1%
13	Japan	1	1%
14	Lithuania	1	1%
15	Mongolia	1	1%
16	Morocco	1	1%
17	Poland	1	1%
18	Thailand	1	1%
19	United Kingdom	1	1%
	Total	77	100%

4.4. Distribution of academic papers by the MCDM method

Fig. 4 shows the distribution of academic papers according to the application of MCDM methods. In general, MCDM techniques are classified into three groups: individual MCDM approaches, integrated MCDM approaches, and other MCDM approaches.

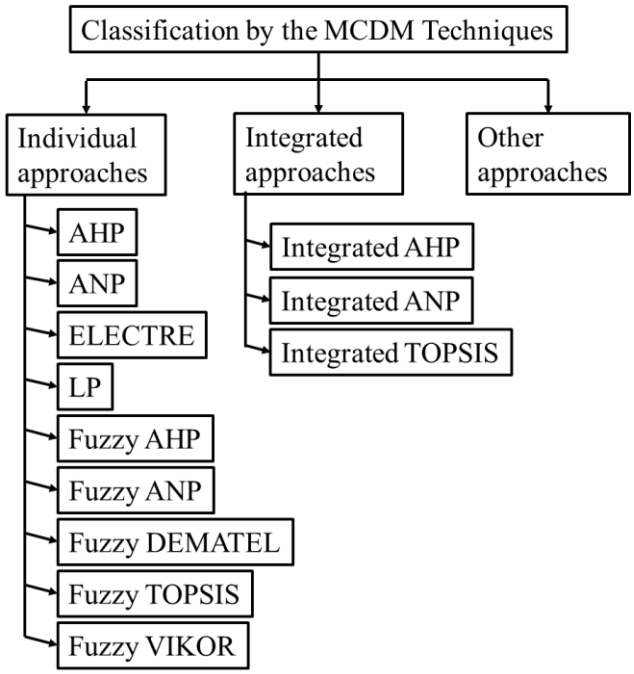


Fig. 4. Distribution of articles by the MCDM techniques

The individual MCDM approach implies that only one type of MCDM approach is applied in each academic paper. For example, the analytic hierarchy process (AHP), the analytic network process (ANP), fuzzy Technique for the Order of Prioritization by Similarity to Ideal Solution (TOPSIS), Elimination and Choice Expressing Reality (ELECTRE), linear programming (LP), fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL), fuzzy AHP, fuzzy ANP, and fuzzy VIKOR are all the individual MCDM techniques used in prior studies (Anggrainingsih et al., 2016; Chen & Qiao, 2015; Choi & Jeong, 2019; Hunjak & Begičević, 2006; Osman et al., 2018).

On the other hand, the integrated MCDM approach indicates that the MCDM approach is integrated with other theories to examine e-learning's effectiveness. For instance, the theories examined in these studied included the Association Rule, Quality Function Deployment, Balance Score Card, Complex Proportional Assessment, Multichoice Goal Programming, Data Mining, Adaptive Interval Vale, and others (Bhuasiri et al., 2012; Cobo et al., 2014; Ho et al., 2009; Kustiyahningsih et al., 2018; Wang & Lin, 2012).

Finally, some articles fall under other MCDM approaches. This group did not employ the abovementioned MCDM techniques. However, they have used the multicriteria analysis approach to assess the e-learning system. For example, Yuen (2012) suggested the Primitive Cognitive Process to appraise the multiple factors that will influence the effectiveness of the e-learning system. Jain et al. (2016) used weighted distance-based approximation to select and evaluate e-learning websites. Iryanati and Pandiya (2016) employed Consistent Fuzzy Preference Relations together with the DeLone and McLean Information System Success Model (D&M Model) to evaluate the factors influencing the postadoption of the e-learning system).

Table 2 displays the frequency of each MCDM technique applied in prior studies. The AHP method is the most popular MCDM method employed in the evaluation of e-learning systems (see Table 2). Approximately 78% of studies in our review apply individual AHP (31%), integrated AHP (30%), or fuzzy AHP (17%). Approximately 22% of studies used other MCDM techniques, including the ANP (4%), other MCDM approaches (4%), LP (3%), fuzzy ANP (3%), integrated ANP (2%), ELECTRE (1%), fuzzy DEMATEL (1%), fuzzy TOPSIS (1%), fuzzy VIKOR (1%), and integrated TOPSIS (1%).

Table 2
Percentage of distribution of articles by the MCDM techniques

No.	MCDM techniques	Frequency	Percentage
1	AHP	24	31%
2	Integrated AHP	23	30%
3	Fuzzy AHP	13	17%
4	ANP	3	4%
5	Other MCDM approach	3	4%
6	LP	2	3%
7	Fuzzy ANP	2	3%
8	Integrated ANP	2	3%
9	ELECTRE	1	1%
10	Fuzzy DEMATEL	1	1%
11	Fuzzy TOPSIS	1	1%
12	Fuzzy VIKOR	1	1%
13	Integrated TOPSIS	1	1%
	Total	77	100%

4.5. Theories used in prior studies

In the e-learning literature, most of the research frameworks were formulated upon literature review (Bakhouyi et al., 2016; İnce et al., 2019; Jeong & Yeo, 2014; Mohammed et al., 2017). It is noteworthy to mention that most studies overlook the application of theories. Only a limited number of studies constructed their research frameworks based on specific theories (see Table 3).

There are several theories applied in e-learning studies. First, Zhang et al. (2010) adopted the innovation adoption theory to investigate e-learning adoption. Second, the Learning Scenario Quality Model was used by Kurilovas and Zilinskiene (2013) to evaluate e-learning's effectiveness. Third, Tzeng et al. (2007) formulated the research framework based on the ADDIE Model, Kirkpatrick Theory, and CIRO Model. Intriguingly, the hexagonal e-learning assessment model, which was developed by Ozkan and Koseler (2009), was adopted in Lukhayu Pritalia et al. (2018)'s study. Yang et al. (2017) applied motivation theory, and Jami Pour et al. (2017) adopted the balance score card in their studies. The next popular theory used is the Technology Acceptance Model and Technology Readiness (Osman et al., 2018). Finally, meaningful learning theory was adopted by Huang and Chiu (2015). Among the above theories, Delone and McLean (2003)'s Information System Success Model (D&M Model) is the most popular theory used in e-learning literature (Bhuasiri et al., 2012; Choi & Jeong, 2019; Fitriastuti et al., 2019; Iryanti & Pandiya, 2016; Lin, 2010; Lo et al., 2011; Su et al., 2016; Bhuasiri et al., 2012).

Table 3
Adoption of theories in prior studies

No.	Adoption of theories in the articles	Authors
1	Innovation Adoption Theory	(Zhang et al., 2010)
2	Social Cognitive Theory	(Bhuasiri et al., 2012)
3	Learning Scenario Quality Model	(Kurilovas & Zilinskienė, 2013)
4	ADDIE Model, Kirkpatrick Theories, CIRO Model	(Tzeng et al., 2007)
5	Hexagonal e-Learning Assessment Model	(Lukhayu Pritalia et al., 2018)
6	Technology Readiness	(Osman et al., 2018)
7	Balance Score Card	(Jami Pour et al., 2017)
8	Meaningful Learning Theory	(Huang & Chiu, 2015)
9	Service Quality Model	(Büyüközkan et al., 2007)
10	Technology Acceptance Model	(Bhuasiri et al., 2012), (Osman et al., 2018)
11	Motivation Model	(Bhuasiri et al., 2012), (Bhuasiri et al., 2012), (Yang et al., 2017)
12	Information System Success Model	(Lin, 2010), (Lo et al., 2011), (Bhuasiri et al., 2012), (Bhuasiri et al., 2012), (Iryanti & Pandiya, 2016), (Su et al., 2016), (Choi & Jeong, 2019), (Fitriastuti et al., 2019)

4.6. Reclassification of the D&M model

In 1992, the Information System Success Model (D&M model) was proposed by DeLone and McLean (1992) to examine the effectiveness of an information system. The D&M model consists of six dimensions: system quality, content quality, use, user satisfaction, personal influence, and organizational influence. The D&M model was later advanced by Delone and McLean (2003) (see Fig. 5).

Delone and McLean (2003) included service quality in the D&M model because the theoretical evidence shows that service quality is a success factor that influences the use and user satisfaction of e-learning (Delone & McLean, 2003) (see Fig. 5). Another new factor, i.e., net benefits, was added into the D&M model as a result of merging personal influence and organizational influence. According to Delone and McLean (2003), system quality is viewed as the usability, performance, and technical characteristics of the system itself. Content quality relates to the quality of course contents in terms of accuracy, completeness, ease of understanding, consistency, relevance, and being up to date. Service quality corresponds to the support provided by the institutions to ensure the sustainability of the e-learning system. Use, user satisfaction, and net benefits evaluate the website's effectiveness. For instance, use is viewed as the effective use of a system, user satisfaction is the perceived level of agreeableness towards the entire system in terms of effectiveness and appropriateness, and net benefits are the perceived organizational and individual influence on task performance and efficiency (Delone & McLean, 2003).

Prior MCDM studies began to adopt the D&M model in evaluating e-learning's postadoption in 2007 (see Fig. 5). Since then, MCDM studies on online learning using the D&M model have flourished. Overall, our review shows that three main research strands are focusing on different factors influencing e-learning's postadoption (see Fig. 5). It is noteworthy to understand that three variables of the D&M model are excluded in prior MCDM studies, including use, user satisfaction, and net benefits.

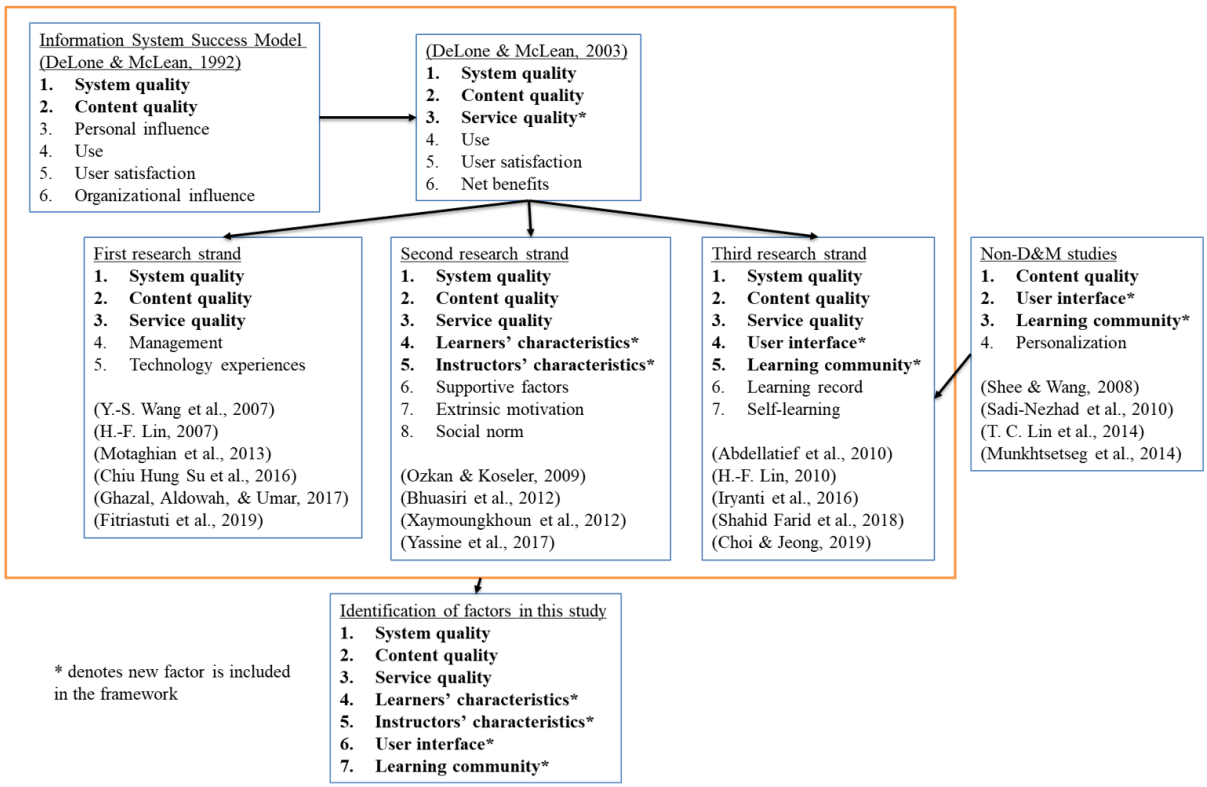


Fig. 5. The extension of the information system success model

Based on Fig. 5, the first line of research focuses on the three fundamental factors of the D&M model: system quality, content quality, and service quality. For instance, prior studies use these three factors as the main factors to evaluate e-learning's postadoption (Fitriastuti et al., 2019; Lin, 2007; Motaghian et al., 2013; Wang et al., 2007). Additionally, Su et al. (2016) evaluated e-learning's postadoption by using three factors, including content quality, service quality, and management. Ghazal et al. (2018) also examine e-learning's postadoption by using system quality, content quality, service quality, and technology experiences as the main factors of the research framework. Overall, these studies conclude that system quality, content quality, and service quality have vital influences on e-learning's postadoption.

The second line of research focuses on two new factors: learners' characteristics and instructors' characteristics. One explanation is that learners and instructors are the primary users who determine the postadoption of an e-learning system. For instance, Ozkan and Koseler (2009) extended the D&M model by including learners' characteristics, instructors' characteristics, and supportive factors in their study. Moreover, prior studies also integrate learners' characteristics, instructors' characteristics, and extrinsic motivation in their research frameworks (Bhuasiri et al., 2012; Bhuasiri et al., 2012). Yassine et al. (2017) propose that the system dimension, learner dimension, instructor dimension, and social norm are the main factors of the studies based on the D&M model, Expectation Confirmation Model and Technology Acceptance Model. Among these studies, supportive factors and extrinsic motivation are not considered in this study because the mentioned factors are the least important in their studies (Bhuasiri

et al., 2012; Ozkan & Koseler, 2009; Bhuasiri et al., 2012). Nevertheless, the second research strand recognizes the significance of learners' characteristics and instructors' characteristics in studying the postadoption of an e-learning system.

The last research strand focuses on two new factors: user interface and learning community. For instance, prior studies have extended the D&M model by including user interfaces in their studies (Abdellatief et al., 2010; Choi & Jeong, 2019; Farid et al., 2018; Lin, 2010). Furthermore, Iryanti and Pandiya (2016) propose the content quality, user interface, learning community, learning record, and self-learning as the main factors in evaluating e-learning's postadoption. Prior studies recognize the significance of the user interface and learning community in evaluating the postadoption of e-learning. This is because the learning community promotes active interactions among e-learning users, which leads to a high participation rate in the e-learning system (Lin et al., 2014). Additionally, e-learning users tend to adopt e-learning with a more friendly, easy to use, and comfortable user interface.

A theoretical gap is identified when there are none, or fewer studies focus on both the second and third research strands at the same time. The result may be dissimilar to prior studies if a study includes learners' characteristics, instructor' characteristics, user interface, and learning community in the D&M model. One explanation is that these seven factors examine e-learning's postadoption from different dimensions. For instance, system quality evaluates the stability and reliability of the system behind e-learning, whereas the user interface examines the appearance of e-learning portrayed to the users. Service quality assesses the support given by the institution that ensures the sustainability of e-learning. Instructor' characteristics and learners' characteristics are significant because they are the primary users of e-learning, whereas the learning community examines the interactions among them in the e-learning system.

In conclusion, to bridge this theoretical gap, this study proposes seven factors influencing the postadoption of e-learning: system quality, content quality, service quality, learners' characteristics, instructor' characteristics, user interface, and learning community. Several non-D&M studies are reviewed in this study to provide a better understanding of the user interface and learning community (Lin et al., 2014; Munkhtsetseg et al., 2014; Sadi-Nezhad et al., 2010; Shee & Wang, 2008) (refer to Fig. 5).

Among these seven factors, the most adopted and discussed factor in e-learning evaluation is content quality because 25.9% of previous studies included this factor (see Table 4), followed by the user interface (16.9%), system quality (15.6%), institution service quality (11.7%), instructor characteristics (9.1%), learning community (7.8%), and learner characteristics (6.5%).

Different wordings of factors are used in prior studies. For instance, system quality is also named "quality of the system", "infrastructure and system quality", "system support", "functionality" and "IT quality". The user interface is named the "learner interface", "portal interface design", "design of student interface", and "learner attractiveness". The factor instructor's characteristics are named "instructor attitudes" in some studies. Furthermore, institutional service quality is named "service quality" and "university". Last, content quality is named "course and information quality", "information quality", "system content", "quality of instructional contents", "quality of instructional contents", "quality design and courses", "e-learning material", "content quality" and "classes and class contents".

Table 4
Significant factors in e-learning evaluation

Authors	Factors						
	System quality	User interface	Instructors ' characteristics	Institution service quality	Learners ' characteristics	Content quality	Learning community
(Matsatsinis et al., 2003)	*	*				*	
(Hwang et al., 2004)		*				*	
(Hunjak & Begičević, 2006)						*	
(Büyüközkan et al., 2007)		*					
(Shee & Wang, 2008)		*				*	*
(Büyüközkan et al., 2010)		*					
(Jie, 2010)	*					*	
(Lin, 2010)	*	*		*		*	
(Sadi-Nezhad et al., 2010)		*				*	*
(Mehregan et al., 2011)	*		*		*	*	*
(Tseng et al., 2011)	*	*	*	*			
(Bhuasiri et al., 2012)	*		*	*	*	*	
(Bhuasiri et al., 2012)	*		*	*	*	*	
(Lin et al., 2014)		*				*	*
(Munkhtsetseg et al., 2014)		*				*	*
(Anggrainingsih et al., 2016)			*				
(Jain et al., 2016)		*					
(Iryanti & Pandiya, 2016)						*	
(Su et al., 2016)				*		*	
(Garg & Jain, 2017)	*					*	*
(Anggrainingsih et al., 2018)	*		*	*	*	*	
(Kabassi, 2018)						*	
(Lukhayu Pritalia et al., 2018)	*		*	*	*	*	
(Zhicheng & Feng, 2018)		*					
(Choi & Jeong, 2019)	*	*		*		*	
(Fitriastuti et al., 2019)	*			*		*	
Frequency	12	13	7	9	5	20	6
Percentage (%)	15.6	16.9	9.1	11.7	6.5	25.9	7.8

Table 5
Overlapping of the subfactors in the system quality and user interface factors

Authors	Subfactors System quality							Subfactors User interface						
	system response	learnability	ease of use	stability/system stability	user friendly	navigability	network security	response time of the user interface	learnability/easy to understand	ease of use/usability	operation stability	user-friendliness	navigation	quality of security mechanism
(Matsatsinis et al., 2003)	*						*					*		
(Hwang et al., 2004)								*		*				*
(Büyüközkan et al., 2007)						*	*							
(Tzeng et al., 2007)	*													
(Shee & Wang, 2008)									*	*	*	*		
(Chao & Chen, 2009)												*		
(Büyüközkan et al., 2010)						*	*							
(Jie, 2010)	*						*							
(Lin, 2010)	*	*				*								
(Mehregan et al., 2011)	*						*							
(Tseng et al., 2011)	*	*												
(Bhuasiri et al., 2012)	*		*											
(Wang & Lin, 2012)				*									*	
(Bhuasiri et al., 2012)	*		*											
(Yuen, 2012)												*		
(Jeong & Yeo, 2014)									*			*		
(Lin et al., 2014)									*		*	*		
(Munkhtsetseg et al., 2014)									*	*	*	*		
(Chen & Qiao, 2015)	*													
(Anggrainingsih et al., 2016)							*							
(Jain et al., 2016)						*	*							
(Garg & Jain, 2017)							*							
(Kabassi, 2018)												*		
(Lukhayu Pritalia et al., 2018)	*		*											
(Choi & Jeong, 2019)	*		*	*	*				*					
(Fitriastuti et al., 2019)	*													

4.7. Reclassification of overlapping subfactors

There are some overlapping subfactors under different factors proposed in prior studies (see Table 5). The overlap is seen in the system quality and learner interface. System quality measures the perceived ability of an e-learning system to deliver suitable

functions to learner control. In contrast, the learner interface means that the course website is subjectively attractive and fun to operate. Our review shows that prior studies categorized the same subfactors under both the system quality and learner interface factors (Choi & Jeong, 2019; Jain et al., 2016; Lukhayu Pritalia et al., 2018; Tseng et al., 2011). For instance, the subfactors learnability, ease of use, user-friendliness, navigability, operation stability, response time, and quality of security mechanism are presented in both the system quality and learner interface factors (Choi & Jeong, 2019; Jain et al., 2016; Lukhayu Pritalia et al., 2018; Tseng et al., 2011). Therefore, this overlap represents an important issue in the current literature, and there is a need to categorize factors distinctly in the future research.

4.8. Inadequate studies on dependencies among the factors in D&M model

This review indicates that there are a limited number of e-learning evaluation studies that consider the dependencies in their frameworks. There are only two studies that focus on the dependencies among their modified D&M model. Su et al. (2016) proposed that service quality influences content quality, whereas both service quality and information quality influence management. Furthermore, Choi and Jeong (2019) suggested that content quality influences service quality, whereas both service quality and content quality influence the user interface. Additionally, Choi and Jeong (2019) noted that there is a feedback relationship between system quality and service quality. There are too few studies that examine the dependencies among the modified D&M model. Therefore, there is a need to study the dependencies among the factors and subfactors that influence e-learning's postadoption.

5. Discussion

This study reviewed 77 academic papers that were published between 2001 and 2019 and examined the use of MCDM approaches for evaluating e-learning systems. The main aim of this review is to understand the significance of using MCDM to evaluate e-learning. Additionally, this study can provide researchers and practitioners with insight and guidance for adopting MCDM techniques in e-learning studies. Several significant implications are presented below.

First, this review shows that there has been slow growth in the usage of MCDM techniques in e-learning studies over the years (see Fig. 4). In the first five years after 2001, approximately one related article was published each year. After 2015, MCDM methods attracted researchers' attention, which has resulted in the gradual increase of papers published. Hence, it is forecasted that the number will keep growing in the coming years because of the increased exposure to different kinds of MCDM techniques and the significance of e-learning in this industry 4.0 era.

Second, according to the findings, China is the country that contributes the most to e-learning evaluation using MCDM techniques (see Table 2). Overall, 44% of 77 articles reviewed herein were published in China, which is high compared to other countries, such as Indonesia (8%), India (6%), and Malaysia (6%). The reason for this difference could be the great emphasis on online education in China or the high exposure to MCDM techniques among Chinese researchers. For instance, Tencent developed VooV Meeting platform to compete against established online collaborative learning platforms such as Blackboard, Google classroom and Microsoft Teams. Further research can be done to elucidate this phenomenon.

Third, the AHP is the most used MCDM technique among researchers, as it was used in 78% of the total articles reviewed. The AHP provides a solution to decision makers that addresses complex problems with several aspects. Simplicity and managerial transparency are deemed to be the main reasons for using the AHP method among practitioners and researchers. It can be observed that the AHP method was common among studies related to the effectiveness of e-learning.

Fourth, the AHP consists of some weaknesses regarding the evaluation of e-learning's effectiveness. Zare et al. (2016) argues that the popularity of the AHP is mainly attributed to convenience and simplification viewpoints, but the AHP does not reflect powerful modelling. The AHP assumes that the upper levels of the model are independent of all lower levels and that the elements in each level are also independent of each other (Mikhailov & Singh, 2003). Such an assumption represents a problem in many decision-making processes because there are some dependencies and feedback among the elements. In 1996, Saaty proposed the ANP, which is a MCDM method to address this issue (Saaty, 2005). The ANP is a generalization of the AHP but allows complex interrelationships among decision levels and factors (Tseng et al., 2011). However, our review shows that there are a limited number of e-learning evaluation studies utilizing the ANP technique. Thus, it is recommended to apply the ANP to evaluate e-learning's effectiveness to consider the potential dependencies among factors.

Fifth, there is a theoretical gap due to an insufficient number of studies on modified Delone and McLean (2003)'s Information System Success Model (D&M Model). Based on the review, three research lines focus on different factors influencing e-learning's postadoption (see Fig. 5). The first line of research focuses on the three fundamental factors of the D&M model: system quality, content quality, and service quality. Two new factors are the focus of the second line of research: learners' characteristics and instructors' characteristics. The last line of research focuses on two new factors: user interface and learning community.

Nonetheless, few studies, if any, converge on both the factors in the second and third lines of research strands. The result may be dissimilar to prior studies if a study incorporates learners' characteristics, instructors' characteristics, user interface, and learning community in the D&M model. One explanation is that these seven factors can be used to examine e-learning's postadoption from different dimensions. For instance, system quality assesses the stability and reliability of the system behind e-learning, whereas the user interface examines the appearance of e-learning portrayed to the users. Service quality assesses the support given by the institution that ensures the sustainability of e-learning (Tomczyk et al., 2022). Instructors' characteristics and learners' characteristics are significant because they are the primary users of e-learning (Ocak & Karakuş, 2022), whereas the learning community examines the interactions among them in the e-learning system (Pham & Tran, 2020).

Sixth, based on the D&M model, this study recommends seven factors that influence e-learning's postadoption (see Table 4). Researchers can adapt these seven factors as a foundation to formulate their research framework, while practitioners can integrate these seven factors into their decision-making process when developing e-learning in their institutions.

Last, the overlapping of subfactors under different factors was identified in prior studies. This phenomenon occurs in two factors: the system quality and learner interface factors. It is understood that these two factors overlap with each other in terms of an operational definition. Therefore, future research is needed to examine the subfactors mentioned above and to appropriately categorize them under relevant factors.

6. Conclusion and recommendations

This systematic review consolidates the extant studies and provides an up-to-date review of the literature, and attempt to answer the research question as mentioned earlier.

RQ: Does the original Information System Success Model sufficient to evaluate the effectiveness of modern e-learning systems?

Several new insights were found in this review paper. First, the original D&M model can be further extended by integrating learners' characteristics, instructors' characteristics, user interface, and learning community. Second, reclassification of some overlapping subfactors under system quality and user interface. Finally, inadequate studies on dependencies among factors in D&M model.

This study provides contributions to both researchers and practitioners. For instance, researchers can use the findings of this study and assess its applicability from the post COVID-19 perspective where blended learning involving hybridisation of online and face-to-face learning occurs. On the other hand, practitioners can identify success factors from diverse points of view such as system, support from the institution, managers, instructor, and student critically analyzed to make the e-learning system more dependable, effective, and successful. Subsequent cost-benefit and risk analyses of potential solutions MCDM should also be conducted accordingly.

There are some limitations to this study. First, due to the limitations of the finance and time, this study only covers articles from two electronic databases: the Web of Science and Scopus databases. Therefore, further research can be conducted to search other electronic databases such as Science Direct, Wiley Online Library, Emerald, Taylor and Francis, IEEE, and Springer to produce a more comprehensive literature search. The review shows that there are a limited number of e-learning evaluation studies utilizing the ANP technique. Thus, the researchers strongly recommend other researchers to explore the application of the ANP to evaluate e-learning's effectiveness and to consider the potential dependencies among factors. The researchers believe that further research that evaluates the dependencies among the factors and subfactors is highly recommended to provide results that are more accurate and acceptable.

Author Statement

The authors declare that there is no conflict of interest.

ORCID

Puong Koh Hii https://orcid.org/0000-0003-1022-4625

Chin Fei Goh https://orcid.org/0000-0003-3193-7122

Amran Rasli https://orcid.org/0000-0003-1101-1752

Owee Kowang Tan https://orcid.org/0000-0002-4222-7006

References

Abdellatief, M., Sultan, A. M., Jabar, M. A., & Abdullah, R. (2010). Developing general view of quality models for e-learning from developers perspective. In *Proceedings of*

the Knowledge Management 5th International Conference. Retrieved from https://repo.uum.edu.my/id/eprint/11112

Ahmed, H. M. S. (2010). Hybrid e-learning acceptance model: Learner perceptions: hybrid e-learning acceptance model. *Decision Sciences Journal of Innovative Education, 8*(2), 313–346. https://doi.org/10.1111/j.1540-4609.2010.00259.x

Al-Samarraie, H., Teng, B. K., Alzahrani, A. I., & Alalwan, N. (2018). E-learning continuance satisfaction in higher education: A unified perspective from instructors and students. *Studies in Higher Education, 43*(11), 2003–2019. https://doi.org/10.1080/03075079.2017.1298088

Anggrainingsih, R., Nugroho, A. A., Suryani, E., & Wahyuningsih, D. (2016). Determining elearning critical success factor at sebelas maret university using analytical hierarchy process (AHP). In *Proceedings of the 2016 International Seminar on Application for Technology of Information and Communication (ISemantic)*. https://doi.org/10.1109/ISEMANTIC.2016.7873836

Anggrainingsih, R., Umam, M. Z., & Setiadi, H. (2018). Determining e-learning success factor in higher education based on user perspective using Fuzzy AHP. In *Proceedings of the 1st International Conference on Industrial, Electrical and Electronics (ICIEE 2018)*. https://doi.org/10.1051/matecconf/201815403011

Azlan, C. A., Wong, J. H. D., Tan, L. K., A.D. Huri, M. S. N., Ung, N. M., Pallath, V., Tan, C. P. L., Yeong, C. H., & Ng, K. H. (2020). Teaching and learning of postgraduate medical physics using internet-based e-learning during the COVID-19 pandemic – A case study from malaysia. *Physica Medica, 80*, 10–16. https://doi.org/10.1016/j.ejmp.2020.10.002

Bakhouyi, A., Dehbi, R., & Talea, M. (2016). Multiple criteria comparative evaluation on the interoperability of LMS by applying COPRAS method. In *Proceedings of the 2016 Future Technologies Conference (FTC)*. https://doi.org/10.1109/FTC.2016.7821635

Bayrak, F. (2022). Associations between university students' online learning preferences, readiness, and satisfaction. *Knowledge Management & E-Learning, 14*(2), 186–201. https://doi.org/10.34105/j.kmel.2022.14.011

Bhuasiri, W., Xaymoungkhoun, O., Zo, H., Rho, J. J., & Ciganek, A. P. (2012). Critical success factors for e-learning in developing countries: A comparative analysis between ICT experts and faculty. *Computers & Education, 58*(2), 843–855. https://doi.org/10.1016/j.compedu.2011.10.010

Birkle, C., Pendlebury, D. A., Schnell, J., & Adams, J. (2020). Web of science as a data source for research on scientific and scholarly activity. *Quantitative Science Studies, 1*(1), 363–376. https://doi.org/10.1162/qss_a_00018

Büyüközkan, G., Arsenyan, J., & Ertek, G. (2010). Evaluation of e-learning web sites using fuzzy axiomatic design based approach. *International Journal of Computational Intelligence Systems, 3*(1), 28-42. https://doi.org/10.2991/ijcis.2010.3.1.4

Büyüközkan, G., Ruan, D., & Feyzioğlu, O. (2007). Evaluating e-learning web site quality in a fuzzy environment. *International Journal of Intelligent Systems, 22*(5), 567–586. https://doi.org/10.1002/int.20214

Chao, R.-J., & Chen, Y.-H. (2009). Evaluation of the criteria and effectiveness of distance e-learning with consistent fuzzy preference relations. *Expert Systems with Applications, 36*(7), 10657–10662. https://doi.org/10.1016/j.eswa.2009.02.047

Cheawjindakarn, B., Suwannatthachote, P., & Theeraroungchaisri, A. (2012). Critical success factors for online distance learning in higher education: A review of the literature. *Creative Education, 3*(8), 61–66. https://doi.org/10.4236/ce.2012.38B014

Chen, X., & Qiao, L. (2015). The application of ANP models in the web-based course development quality evaluation of landscape design course. *International Journal of*

Multimedia and Ubiquitous Engineering, *10*(9), 291–298. https://doi.org/10.14257/ijmue.2015.10.9.30

Choi, C.-R., & Jeong, H.-Y. (2019). Quality evaluation for multimedia contents of e-learning systems using the ANP approach on high speed network. *Multimedia Tools and Applications*, *78*(20), 28853–28875. https://doi.org/10.1007/s11042-019-7351-8

Chung, E., Subramaniam, G., & Christ Dass, L. (2020). Online learning readiness among university students in malaysia amidst covid-19. *Asian Journal of University Education*, *16*(2), 45-58. https://doi.org/10.24191/ajue.v16i2.10294

Cobo, A., Rocha, R., & Rodríguez-Hoyos, C. (2014). Evaluation of the interactivity of students in virtual learning environments using a multicriteria approach and data mining. *Behaviour & Information Technology*, *33*(10), 1000–1012. https://doi.org/10.1080/0144929X.2013.853838

DeLone, W. H., & McLean, E. R. (1992). Information systems success: The quest for the dependent variable. *Information Systems Research*, *3*(1), 60–95. https://doi.org/10.1287/isre.3.1.60

Delone, W. H., & McLean, E. R. (2003). The DeLone and McLean model of information systems success: A ten-year update. *Journal of Management Information Systems*, *19*(4), 9–30. https://doi.org/10.1080/07421222.2003.11045748

Farid, S., Ahmad, R., Alam, M., Akbar, A., & Chang, V. (2018). A sustainable quality assessment model for the information delivery in E-learning systems. *Information Discovery and Delivery*, *46*(1), 1–25. https://doi.org/10.1108/IDD-11-2016-0047

Fitriastuti, F., Rahmalisa, U., & Suganda Girsang, A. (2019). Multi-criteria decision making on succesfull of online learning using AHP and regression. *Journal of Physics: Conference Series*, *1175*: 012071. https://doi.org/10.1088/1742-6596/1175/1/012071

Garg, R., & Jain, D. (2017). Prioritizing e-learning websites evaluation and selection criteria using fuzzy set theory. *Management Science Letters*, *7*, 177–184. https://doi.org/10.5267/j.msl.2017.1.002

Ghazal, S., Aldowah, H., & Umar, I. (2018). Critical factors to learning management system acceptance and satisfaction in a blended learning environment. In F. Saeed, N. Gazem, S. Patnaik, A. S. Saed Balaid, & F. Mohammed (Eds.), *Recent Trends in Information and Communication Technology* (Vol. 5, pp. 688–698). Springer International Publishing. https://doi.org/10.1007/978-3-319-59427-9_71

Gusenbauer, M., & Haddaway, N. R. (2020). Which academic search systems are suitable for systematic reviews or meta-analyses? Evaluating retrieval qualities of google scholar, PubMed, and 26 other resources. *Research Synthesis Methods*, *11*(2), 181–217. https://doi.org/10.1002/jrsm.1378

Ho, W., Higson, H. E., Dey, P. K., Xu, X., & Bahsoon, R. (2009). Measuring performance of virtual learning environment system in higher education. *Quality Assurance in Education*, *17*(1), 6–29. https://doi.org/10.1108/09684880910929908

Hu, C. (2016). Application of e-learning assessment based on AHP-BP algorithm in the cloud computing teaching platform. *International Journal of Emerging Technologies in Learning (IJET)*, *11*(08), 27-32. https://doi.org/10.3991/ijet.v11i08.6039

Huang, Y.-M., & Chiu, P.-S. (2015). The effectiveness of a meaningful learning-based evaluation model for context-aware mobile learning: Context-aware mobile learning evaluation model. *British Journal of Educational Technology*, *46*(2), 437–447. https://doi.org/10.1111/bjet.12147

Humayun, M. (2020). Blockchain-Based secure framework for e-learning during COVID-19. *Indian Journal of Science and Technology*, *13*(12), 1328–1341. https://doi.org/10.17485/IJST/v13i12.152

Hunjak, T., & Begičević, N. (2006). Prioritisation of e-learning forms based on pair-wise comparisons. *Journal of Information and Organizational Sciences*, *30*(1), 47–61.

Hwang, G.-J., Huang, T. C. K., & Tseng, J. C. R. (2004). A group-decision approach for

evaluating educational web sites. *Computers & Education, 42*(1), 65–86. https://doi.org/10.1016/S0360-1315(03)00065-4

İnce, M., Yiğit, T., & Işık, A. H. (2019). A hybrid AHP-GA method for metadata-based learning object evaluation. *Neural Computing and Applications, 31*(S1), 671–681. https://doi.org/10.1007/s00521-017-3023-7

Iryanti, E., & Pandiya, R. (2016). Evaluating the quality of e-learning using consistent fuzzy preference relations method. In *Proceedings of the 6th International Conference on System Engineering and Technology (ICSET)*. https://doi.org/10.1109/ICSEngT.2016.7849624

Jain, D., Garg, R., Bansal, A., & Saini, K. K. (2016). Selection and ranking of e-learning websites using weighted distance-based approximation. *Journal of Computers in Education, 3*(2), 193–207. https://doi.org/10.1007/s40692-016-0061-6

Jami Pour, M., Hosseinzadeh, M., Bagherzadeh Azar, M., & Taheri, F. (2017). Developing a new framework for evaluating e-learning systems: Integrating BSC and FAHP. *Kybernetes, 46*(8), 1303–1324. https://doi.org/10.1108/K-02-2017-0060

Jeong, H.-Y., & Yeo, S.-S. (2014). The quality model for e-learning system with multimedia contents: A pairwise comparison approach. *Multimedia Tools and Applications, 73*(2), 887–900. https://doi.org/10.1007/s11042-013-1445-5

Jie, C. (2010). Evaluation and modeling of online course using fuzzy AHP. In *Proceedings of the 2010 International Conference on Computer and Information Application (ICCIA)*. https://doi.org/10.1109/ICCIA.2010.6141579

Kabassi, K. (2018). Analytic hierarchy process for website evaluation. *Intelligent Decision Technologies, 12*(2), 137–148. https://doi.org/10.3233/IDT-170316

Kabir, G., Sadiq, R., & Tesfamariam, S. (2014). A review of multi-criteria decision-making methods for infrastructure management. *Structure and Infrastructure Engineering, 10*(9), 1176–1210. https://doi.org/10.1080/15732479.2013.795978

Kurilovas, E., & Zilinskienė, I. (2013). New MCEQLS AHP method for evaluation quality of learning scenarios. *Technological and Economic Development of Economy, 19*(1), 78–92. https://doi.org/10.3846/20294913.2012.762952

Kustiyahningsih, Y., Fatmawati, F., & Suprijanto, H. (2018). MCGDM with AHP based on adaptive interval value fuzzy. *TELKOMNIKA (Telecommunication Computing Electronics and Control), 16*(1), 314-322. https://doi.org/10.12928/telkomnika.v16i1.7000

Lan, H. T. Q., Long, N. T., & Hanh, N. V. (2020). Validation of depression, anxiety and stress scales (DASS-21): Immediate psychological responses of students in the e-learning environment. *International Journal of Higher Education, 9*(5), 125-133. https://doi.org/10.5430/ijhe.v9n5p125

Lee, B.-C., Yoon, J.-O., & Lee, I. (2009). Learners' acceptance of e-learning in south korea: Theories and results. *Computers & Education, 53*(4), 1320–1329. https://doi.org/10.1016/j.compedu.2009.06.014

Leong, C.-M., Goh, C. F., Kho, I., Chieng, R., Then, S.-Y., & Hii, P. K. (2020). E-learning of continuance intention in Malaysia: What determines? PalArch's Journal of Archaeology of Egypt/Egyptology, 17(10), 523–535.

Lin, H.-F. (2007). Measuring online learning systems success: Applying the updated DeLone and McLean model. *CyberPsychology & Behavior, 10*(6), 817–820. https://doi.org/10.1089/cpb.2007.9948

Lin, H.-F. (2010). An application of fuzzy AHP for evaluating course website quality. *Computers & Education, 54*(4), 877–888. https://doi.org/10.1016/j.compedu.2009.09.017

Lin, T.-C., Ho, H.-P., & Chang, C.-T. (2014). Evaluation model for applying an e-learning system in a course: An analytic hierarchy process—multi-choice goal

programming approach. *Journal of Educational Computing Research, 50*(1), 135–157. https://doi.org/10.2190/EC.50.1.g

Lo, T.-S., Chang, T.-H., Shieh, L.-F., & Chung, Y.-C. (2011). Key factors for efficiently implementing customized e-learning system in the service industry. *Journal of Systems Science and Systems Engineering, 20*(3), 346–364. https://doi.org/10.1007/s11518-011-5173-y

Lukhayu Pritalia, G., Djoko Budiyanto, S., Triani Dewi, L., & Kusrohmaniah, S. (2018). Critical factor of E-learning component using HELAM and AHP. In *Proceedings of the 1st International Conference on Industrial, Electrical and Electronics (ICIEE 2018)*. https://doi.org/10.1051/matecconf/201821803020

Mardani, A., Hooker, R. E., Ozkul, S., Yifan, S., Nilashi, M., Sabzi, H. Z., & Fei, G. C. (2019). Application of decision making and fuzzy sets theory to evaluate the healthcare and medical problems: A review of three decades of research with recent developments. *Expert Systems with Applications, 137*, 202–231. https://doi.org/10.1016/j.eswa.2019.07.002

Mardani, A., Jusoh, A., Nor, K. M., Khalifah, Z., Zakwan, N., & Valipour, A. (2015). Multiple criteria decision-making techniques and their applications – A review of the literature from 2000 to 2014. *Economic Research-Ekonomska Istraživanja, 28*(1), 516–571. https://doi.org/10.1080/1331677X.2015.1075139

Matsatsinis, N. F., Grigoroudis, E., & Delias, P. (2003). User satisfaction and e-learning systems: Towards a multi-criteria evaluation methodology. *Operational Research, 3*(3), 249–259. https://doi.org/10.1007/BF02936404

Mehregan, M. R., Jamporazmey, M., Hosseinzadeh, M., & Mehrafrouz, M. (2011). Proposing an approach for evaluating e-learning by integrating critical success factor and fuzzy AHP. In *Proceedings of the International Conference on Innovation, Management and Service*. Retrieved from http://www.ipedr.com/vol14/23-ICIMS2011S00038.pdf

Mikhailov, L., & Singh, M. G. (2003). Fuzzy analytic network process and its application to the development of decision support systems. *IEEE Transactions on Systems, Man and Cybernetics, Part C (Applications and Reviews), 33*(1), 33–41. https://doi.org/10.1109/TSMCC.2003.809354

Mohammed, H. J., Kasim, M. M., & Shaharanee, I. N. M. (2017). Selection of suitable e-learning approach using TOPSIS technique with best ranked criteria weights. In *Proceedings of the 13th IMT-GT International Conference on Mathematics, Statistics and Their Applications (ICMSA)*. https://doi.org/10.1063/1.5012207

Motaghian, H., Hassanzadeh, A., & Moghadam, D. K. (2013). Factors affecting university instructors' adoption of web-based learning systems: Case study of Iran. *Computers & Education, 61*, 158–167. https://doi.org/10.1016/j.compedu.2012.09.016

Munkhtsetseg, N., Garmaa, D., & Uyanga, S. (2014). Multi-criteria comparative evaluation of the E-learning systems: A case study. In *Proceedings of the 2014 7th International Conference on Ubi-Media Computing and Workshops (UMEDIA)*. https://doi.org/10.1109/U-MEDIA.2014.47

Murakoshi, H., Kawarasaki, T., & Ochimizu, K. (2001). Comparison using AHP web-based learning with classroom learning. In *Proceedings of the 2001 Symposium on Applications and the Internet Workshops*. https://doi.org/10.1109/SAINTW.2001.998212

Ocak, G., & Karakuş, G. (2022). Investigating K-12 teachers' views on online education. *Knowledge Management & E-Learning, 14*(2), 202–222. https://doi.org/10.34105/j.kmel.2022.14.012

Osman, H. M., Mahinderjit, M., Serafin, M., Rahman, A., & Abu, A. (2018). Enhanced analytical hierarchy process for U-learning with near field communication (NFC)

technology. *International Journal of Advanced Computer Science and Applications, 9*(12). https://doi.org/10.14569/IJACSA.2018.091241

Ozkan, S., & Koseler, R. (2009). Multi-dimensional students' evaluation of e-learning systems in the higher education context: An empirical investigation. *Computers & Education, 53*(4), 1285–1296. https://doi.org/10.1016/j.compedu.2009.06.011

Pham, Q. T., & Tran, T. P. (2020). The acceptance of e-learning systems and the learning outcome of students at universities in Vietnam. *Knowledge Management & E-Learning, 12*(1), 63–84. https://doi.org/10.34105/j.kmel.2020.12.004

Roffe, I. (2002). E-learning: Engagement, enhancement and execution. *Quality Assurance in Education, 10*(1), 40–50. https://doi.org/10.1108/09684880210416102

Saaty, T. L. (2005). *Theory and applications of the analytic network process: Decision making with benefits, opportunities, costs, and risks*. Retrieved from http://sutlib2.sut.ac.th/sut_contents/H111204.pdf

Sadi-Nezhad, S., Etaati, L., & Makui, A. (2010). A fuzzy ANP model for evaluating e-learning platform. In N. García-Pedrajas, F. Herrera, C. Fyfe, J. M. Benítez, & M. Ali (Eds.), *Trends in Applied Intelligent Systems* (Vol. 6096, pp. 254–263). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-13022-9_26

Selim, H. M. (2007). Critical success factors for e-learning acceptance: Confirmatory factor models. *Computers & Education, 49*(2), 396–413. https://doi.org/10.1016/j.compedu.2005.09.004

Shee, D. Y., & Wang, Y.-S. (2008). Multi-criteria evaluation of the web-based e-learning system: A methodology based on learner satisfaction and its applications. *Computers & Education, 50*(3), 894–905. https://doi.org/10.1016/j.compedu.2006.09.005

Singh, A., & Malik, S. K. (2014). Major MCDM techniques and their application-A review. *IOSR Journal of Engineering, 4*(5), 15–25.

Su, C. H., Tzeng, G.-H., & Hu, S.-K. (2016). Cloud e-learning service strategies for improving e-learning innovation performance in a fuzzy environment by using a new hybrid fuzzy multiple attribute decision-making model. *Interactive Learning Environments, 24*(8), 1812–1835. https://doi.org/10.1080/10494820.2015.1057742

Sun, P.-C., Tsai, R. J., Finger, G., Chen, Y.-Y., & Yeh, D. (2008). What drives a successful e-learning? An empirical investigation of the critical factors influencing learner satisfaction. *Computers & Education, 50*(4), 1183–1202. https://doi.org/10.1016/j.compedu.2006.11.007

Tomczyk, Ł., Demeshkant, N., Potyrała, K., Czerwiec, K., & Oyelere, S. S. (2022). Elements of crisis e-learning: Perspectives of polish teachers. *Knowledge Management & E-Learning, 14*(3), 245–268. https://doi.org/10.34105/j.kmel.2022.14.014

Tseng, M., Lin, R., & Chen, H. (2011). Evaluating the effectiveness of e-learning system in uncertainty. *Industrial Management & Data Systems, 111*(6), 869–889. https://doi.org/10.1108/02635571111144955

Tzeng, G., Chiang, C., & Li, C. (2007). Evaluating intertwined effects in e-learning programs: A novel hybrid MCDM model based on factor analysis and DEMATEL. *Expert Systems with Applications, 32*(4), 1028–1044. https://doi.org/10.1016/j.eswa.2006.02.004

Wang, C.-S., & Lin, S.-L. (2012). Combining fuzzy AHP and association rule to evaluate the activity processes of e-learning system. In *Proceedings of the 2012 Sixth International Conference on Genetic and Evolutionary Computing (ICGEC)*. https://doi.org/10.1109/ICGEC.2012.72

Wang, Y.-S., Wang, H.-Y., & Shee, D. Y. (2007). Measuring e-learning systems success in an organizational context: Scale development and validation. *Computers in Human Behavior, 23*(4), 1792–1808. https://doi.org/10.1016/j.chb.2005.10.006

Yang, M.-H., Su, C.-H., & Wang, W.-C. (2017). The use of a DANP with VIKOR approach for establishing the model of e-learning service quality. *EURASIA Journal of Mathematics, Science and Technology Education*, *13*(8), 5927–5937. https://doi.org/10.12973/eurasia.2017.01041a

Yassine, S., Khalifa, M., & Franck, P. (2017). Towards a multidimensional model to study a critical success factors affecting continuity and success in E-learning systems. In *Proceedings of the 2017 10th International Conference on Developments in ESystems Engineering (DeSE)*. https://doi.org/10.1109/DeSE.2017.26

Yigit, T., Isik, A. H., & Ince, M. (2014). Web-based learning object selection software using analytical hierarchy process. *IET Software*, *8*(4), 174–183. https://doi.org/10.1049/iet-sen.2013.0116

Yuen, K. K. F. (2012). A multiple criteria decision making approach for E-learning platform selection: The primitive cognitive network process. In *Proceedings of the 2012 Computing, Communications and Applications Conference (ComComAp)*. https://doi.org/10.1109/ComComAp.2012.6154860

Zare, M., Pahl, C., Rahnama, H., Nilashi, M., Mardani, A., Ibrahim, O., & Ahmadi, H. (2016). Multi-criteria decision making approach in E-learning: A systematic review and classification. *Applied Soft Computing*, *45*, 108–128. https://doi.org/10.1016/j.asoc.2016.04.020

Zavadskas, E. K., Turskis, Z., & Kildienė, S. (2014). State of art surveys of overviews on MCDM/MADM methods. *Technological and Economic Development of Economy*, *20*(1), 165–179. https://doi.org/10.3846/20294913.2014.892037

Zhang, L., Wen, H., Li, D., Fu, Z., & Cui, S. (2010). E-learning adoption intention and its key influence factors based on innovation adoption theory. *Mathematical and Computer Modelling*, *51*(11/12), 1428–1432. https://doi.org/10.1016/j.mcm.2009.11.013

Zhicheng, D., & Feng, L. (2018). Evaluation of the smart campus information portal. In *Proceedings of the ICEEL 2018: 2018 2nd International Conference on Education and E-Learning*. https://doi.org/10.1145/3291078.3291083