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Procedia Computer Science 120 (2017) 742–749

Procedia Computer Science

www.elsevier.com/locate/procedia

9th International Conference on Theory and Application of Soft Computing, Computing with Words and Perception, ICSCCW 2017, 24-25 August 2017, Budapest, Hungary

Fuzzy DEMATEL method for identifying LMS evaluation criteria

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Abstract

Today, many common activities have been transformed to electronic and online based environments because of the increased usage of technology and the Internet. Education is one of the sectors that is using computer technologies for training and delivering learning information to learners. Learning management systems (LMS) applications are some of the frequently used applications. There are different LMSs with different feature specifications available on the Internet, which can be accessed at anytime, anywhere and by anyone who wants to use them. Making an appropriate evaluation of the LMS and identifying the most important features should be considered before the evaluation of the LMS can be a complex process because the increasing number of features that are now available. The Multi-Criteria Decision Making (MCDM) method is now widely used by researchers to solve various problems that involve different criteria. This study suggests a fuzzy DEMATEL model to determine the interrelations between LMS evaluation criteria, their effects on each other as well as which criteria are the most important. Twelve criteria selected as the most important by experts will be considered in the study. Ten LMS experts made decisions based on the pairwise comparison of the criteria to be used in the DEMATEL method. Based on the case study, the result demonstrates that the three most important criteria are user satisfaction, learnability and usability among the 12 criteria considered. The research proposes a combination of this method and other MCDM techniques in the future to evaluate and select an alternative based on selected criteria, the research also suggested developing an application to substitute the manual evolution process.

Peer-review under responsibility of the scientific committee of the 9th International Conference on Theory and application of Soft Computing, Computing with Words and Perception.

Keywords: Fuzzy set; DEMATEL; MCDM; learning management system; evaluation criteria.

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1877-0509
Peer-review under responsibility of the scientific committee of the 9th International Conference on Theory and application of Soft Computing, Computing with Words and Perception.
10.1016/j.procs.2017.11.304

1. Introduction

In the modern world, as a result of the development in information technology, educational organizations, research centers, and many other institutions have adopted the use of the Internet (Natarajan, 2015). The persistent and rapid improvements and developments of the Internet have prompted significant changes in learning methodologies as well as the creation of new learning environments (Albarrak, 2010). More progressive and moderate technologies have motivated numerous institutions and universities to seek various alternatives to conventional classroom teaching. The Internet lays the foundation for electronic learning (e-learning) instruction systems, in which information and learning material can be conveyed to learners by the means of the Internet and other technologies, particularly through a software product called a learning management system (LMS). An LMS is defined as a software product application that has a set of tools which help educational instructors in conveying learning material to students using the Internet, as well as to manage and monitor their learning progress during the entire learning exercise (Ramesh and Ramanathan, 2013).

LMSs have become one of the key pillars in educational development, and advancements in computer and web technologies have increased the number of LMSs available on the Internet, both commercial and open source (Cavus, 2013). For many years, universities and schools have been investing considerable amounts of time and money in implementing learning management systems (Edrees, 2013). In recent years, most users have preferred to use open source because (Caminero et al., 2013) it is does not incur costs, and almost all the features available commercially are also available in the open source LMSs. However, problems have been experienced by users when determining the features to be considered in selecting the most suitable LMS for their institutions or organisations due to the high number of LMSs available with different specifications. This has created a multi-criteria problem, which can be solved using a multi-criteria decision making approach (MCDM). A systematic method or a technique is required to identify and determine the relationships between the evaluation criteria. This is because LMSs predominantly have a large number of features, and some features are considered more important than others. However, a review of the literature shows that there is not sufficient research on the use of fuzzy logic in LMS evaluation methods with integrated MCDM techniques. It is anticipated that this study will fill the gap in the literature. Furthermore, fuzzy logic and DEMATEL methods will be combined together to evaluate LMS criteria, which have been identified by ten experts on LMS. The evaluation criteria used in this study are: accessibility, compatibility, evaluation tools, learnability, multilingual support, portability, reliability, security, support, sustainability, usability, and user satisfaction.

2. Related research

To identify the criteria for LMS evaluation, the related literature was reviewed in detail. The studies that are most relevant to the present study are presented below.

Radwan et al. (2016a) reviewed two multi valued logic models for managing uncertainty in expert systems in decision-making models, i.e. fuzzy sets and intuitionistic fuzzy sets. The study analyzed and compared their differences in terms of their problem solving application area. The results demonstrated that the reviewed models have some limitations, because they cannot represent paradoxes. The author then suggested a new method, which is called neutrosophic sets, as a more effective option for LMS evaluation due to its improved ability to stimulate human thinking over fuzzy and intuitionistic fuzzy sets; furthermore, it can also express a false membership and can handle indeterminacy of information. The study considered one main criteria of usability for the LMS evaluation, which is further divided into five attributes: efficiency, learnability, memorability, error tolerance and user satisfaction.

Mehta and Saroha (2016) suggested the use of a fuzzy inference system data mining technique as a method for evaluating and recommending learning management systems, by considering three principle criteria: learners' behavior, learners' style and teaching evaluation. On the other hand, Radwan et al. (2016b) used neutrosophic logic, which is an extension of the fuzzy logic for the evaluation of learning management systems based on three system quality attributes, which are usability, reliability, and accessibility, along with eleven sub-criteria, which are; efficiency, learnability, memorability, error tolerance, user satisfaction, fault tolerance, maturity, recoverability, navigability, robustness and understandability. The author then compared the results found form the neutrosophic logic and the fuzzy logic to determine the final results. The final results show that the fuzzy system has some deficiencies in the representation of paradoxes as a feature of human thinking. Neurosophic logic deals with vagueness, imprecision, ambiguity and inconsistency when information is naturally graded, unspecified, unclear, and contradictory to real world information. Additionally, Işık et al. (2015) used the Fuzzy Analytic Hierarchy Process

(FAHP) for the evaluation of the most appropriate LMS according to nine selected criteria: Multilingual support, cost, evaluation tools, compatibility, support, sustainability, reliability, source code, management. Ten alternatives were also considered for the LMS evaluation, which are Joomla LMS, Sum Total Systems, Moodle, Dokeous, OLIAS, Enocta, Sakai Project, Hotchalk, Blackboard, and Atutor. Based on the criteria considered, Joomla LMS is the most fitting LMS that meets the requirements. Moreover, Fardinpour (2014), in his research, proposed a fuzzy ANP method to evaluate an intelligent learning management system (ILMS) based on thirteen criteria that were identified as the most significant: Intelligent pedagogical agents, adaptive intelligent teaching support agents, personal learning assistant services, recommendation services, tracking student activities, (Semi) automated reasoning and argumentation, reporting, personalized learning paths, adaptive hypermedia, adaptability, plagiarism detection, scaffolding, and interoperability.

3. Research methodology

3.1. LMS evaluation criteria

In addition to the literature, interviews were conducted with voluntary learning management system (LMS) experts to collect their opinions on LMS evaluation criteria, which will be used in the DEMATEL method. Based on these interviews, the 12 most important criteria were determined, which are shown in Table 1 along with their definitions and representations.

Table 1. LMS Criteria, Descriptions and Representations

S/N	Criteria	Description	Representation
1	Accessibility	Accessible for everyone including people with disabilities	C1
2	Compatibility	Compatible with different OS platforms	C2
3	Evaluation Tools	Tests learners' performance	C3
4	Learnability	Enables effective learning of the course material	C4
5	Multilingual	Available in different languages	C5
6	Portability	Ability to be carried (mobile)	C6
7	Reliability	Performs consistently based on its specifications	C7
8	Security	Data integrity and user authorization access	C8
9	Support	Offline usage and online assistance available	C9
10	Sustainability	Maintainable and long lasting	C10
11	Usability	Intuitive and easy to use the system	C11
12	User satisfaction	Meets user's expectations	C12

In this study, fuzzy logic was integrated with the DEMATEL method in order to determine the most significant criteria and establish the ranking of the most valuable criteria in the LMS evaluation problem.

3.2. Fuzzy sets

In the real world, decision goals and constraints are not always known precisely, which makes decision-making problems also imprecise (Zadeh, 1965). For this reason, fuzzy logic was introduced in 1965 as a decision-making tool to validate ambiguous and unclear issues, along with unreliable human decisions. Fuzzy logic is different from Boolean logic in that it decides whether an element is in the set (1 or 0) or not; a fuzzy set determines the level of possession by a membership function. Thus, using fuzzy numbers during decision making has become very important. For this situation, Akyuz and Celik (2015) identified that a triangular fuzzy number is preferable in the evaluation, which is the most generally used fuzzy representation and can be defined as a triplet called a triangular fuzzy number (TFN) A=(l,m,u), where l, m and u denote lower, medium and upper numbers of the fuzzy sets ($x \leq y \leq z$), respectively. The membership function can be defined as follows:

$$\mu_A = \begin{cases} 0 & x - l \\ (x-l)/(m-l) & l \leq x \leq m \\ (u-x)/(u-m) & m \leq x \leq u \\ 0 & x \geq u \end{cases}$$

The Best Non-fuzzy Performance (BNP) defuzzification method is one of the techniques used in defuzzifying the fuzzy values into crisp values. The BNP of a triangular fuzzy number a = (l, m, u) can be expressed as:

$$BNP = l + \frac{(u-l)+(m-l)}{3} \quad (1)$$

3.3. Fuzzy DEMATEL

The DEMATEL (Decision Making Trial and Evaluation Laboratory) technique was introduced in 1973 by Geneva to solve complicated and unclear issues (Shieh et al., 2010). The method is used to transform the relationship between the causes and effects of the criteria from an unpredictable to a justifiable model of the chosen system (Dalalah et al., 2011). In particular, the final result of the DEMATEL procedure is a visual representation of digraphs, which separates components into cause and effect groups. Furthermore, Akyuz and Celik (2015) emphasized that DEMATEL is generally identified as one of the best functional techniques for finding the cause and effect relationship between assessed criteria in the evaluation process of any system or product. Another advantage determined by Tzeng et al. (2007) is that when the DEMATEL method is used, the number of chosen criteria for the evaluation will decrease, which will be beneficial for organizations in enhancing the efficiency of particular factors in view of the effect digraph map. In reality, crisp values are not effective because human judgments are largely indistinct and difficult to assess by exact crisp values, due to the imperfection of some assessment criteria and even uncertain factors (Nazeri and Naderikia, 2017). This is why fuzzy theory is used in the DEMATEL method to overcome this type of MCDM problem. The Fuzzy DEMATEL method is applied in different areas of research to solve different MCDM problems (Chang et al., 2011; Mohammadi et al., 2013; Akyuz and Celik, 2015).

In this study, the fuzzy DEMATEL method was chosen by the author to find the relationships between the identified LMS evaluation criteria. The technique is useful in discovering the connections among elements and requesting the criteria in view of the kind of connections and seriousness of their consequences for the other criteria (Dalalah et al., 2011). The basics principle of the DEMATEL technique assumes that a framework has an arrangement of different criteria (C), with the formula C = {C1, C2,...Cn}. In this study, twelve criteria are considered based on ten experts' opinions on LMS. The criteria and their representations can be seen in Table 1. The formula then becomes C = {C1, C2,...C12}. The main steps for the chosen method in this study are shown in Fig. 1.

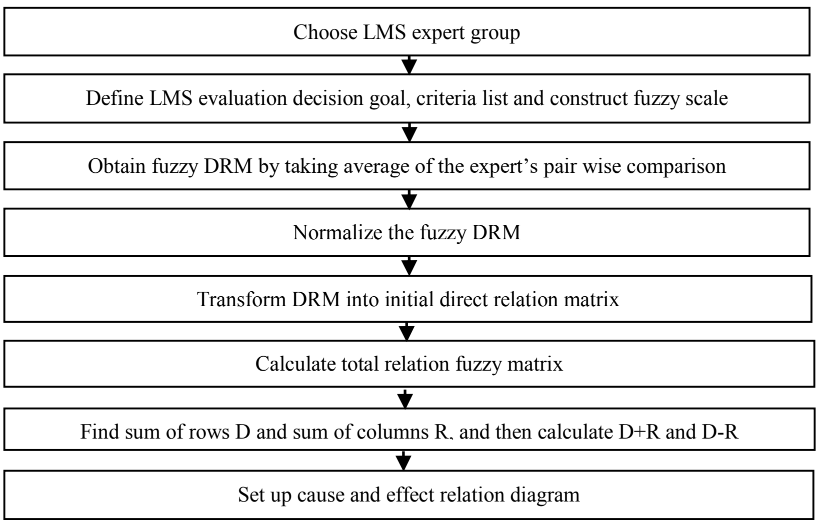

Fig. 1. Fuzzy DEMATEL method

To identify the best criteria for the LMS evaluation process, the flowchart of the fuzzy DEMATEL method, which can be seen in Fig. 1, demonstrates the order in which the steps are processed:
Step 1: Defining a decision goal, constructing a fuzzy scale and a list of criteria.
Step 2: The direct relational matrix is obtained by the LMS experts' pairwise comparison of the criteria using a five point fuzzy linguistic scale of 0-4, which was the most commonly used method found in the literature, where scores of 0 represent "no influence", 1 represents "low influence", 2 represents "normal influence", 3 represents "high influence", and 4 represents "very high influence", as shown in Table 2. The fuzzy direct-relation matrix D is calculated by taking the experts' opinion average, which is then converted into a triangular fuzzy number, as shown in Table 3.

Table 2: Fuzzy linguistic scale (Deng et al., 2015)

Linguistic terms	Influence score	Triangular fuzzy number
No influence	0	(0,0,0.25)
Very low influence	1	(0,0.25,0.50)
Low influence	2	(0.25,0.50,0.75)
High influence	3	(0.50,0.75,1)
Very high influence	4	(0.75,1,1)

Table 3. Fuzzy Direct Relation Matrix of the study

	C1	C2	C3	…	C10	C11	C12
C1	(0,0,0.25)	(0.25,0.38,0.63)	(0.13,0.29,0.54)	…	(0.13,0.38,0.63)	(0.13,0.38,0.63)	(0.50.75,1)
C2	(0.25,0.63,0.75)	(0,0,0.13)	(0.13,0.33,0.58)	…	(0.21,0.46,0.71)	(0.42,0.67,0.92)	(0.54,0.79,1)
C3	(0,0.13,0.38)	(0,0.13,0.38)	(0,0,0.21)	…	(0.13,0.33,0.58)	(0.38,0.63,0.88)	(0.42,0.67,0.92)
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
C10	(0.33,0.42,0.67)	(0,0.25,0.5)	(0,0.25,0.5)	…	(0,0,0.25)	(0.33,0.42,0.67)	(0.42,0.67,0.92)
C11	(0,0.25,0.5)	(0,0.25,0.5)	(0.25,0.5,0.75)	…	(0,0.25,0.5)	(0.13,0.33,0.42)	(0.25,0.38,0.63)
C12	(0,0.25,0.5)	(0,0.25,0.5)	(0.25,0.5,0.75)	…	(0,0.25,0.5)	(0.25,0.5,0.75)	(0,0,0.25)

Step 3. The normalized direct-relation matrix N can be seen in Table 4. This was obtained through the formula below:

$$N = K \text{ x } A \tag{2}$$

$$K = \frac{1}{\max\limits_{1 \le i \le n} \sum_{j=1}^{n} a_{ij}}, i, j = 1,2...n \tag{3}$$

Table 4. Normalized fuzzy direct relation matrix of the study

	C1	C2	C3	…	C10	C11	C12
C1	(0,0,0.03)	(0.03,0.05,0.08)	(0.02,0.05,0.08)	…	(0.02,0.05,0.08)	(0.02,0.05,0.08)	(0.06,0.09,0.12)
C2	(0.03,0.08,0.09)	(0,0,0.02)	(0.02,0.03,0.06)	…	(0.02,0.05,0.08)	(0.06,0.09,0.12)	(0.08,0.11,0.12)
C3	(0,0.02,0.05)	(0,0.02,0.05)	(0,0,0.02)	…	(0,0.03,0.06)	(0.05,0.08,0.11)	(0.06,0.09,0.12)
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
C10	(0.03,0.06,0.09)	(0,0.03,0.06)	(0,0.03,0.06)	…	(0,0,0.03)	(0.03,0.06,0.09)	(0.06,0.09,0.12)
C11	(0,0.03,0.06)	(0,0.03,0.06)	(0.03,0.06,0.09)	…	(0,0.03,0.06)	(0,0,0.03)	(0.03,0.05,0.08)
C12	(0,0.03,0.06)	(0,0.03,0.06)	(0.03,0.06,0.09)	…	(0,0.03,0.06)	(0.0.03,0.06,0.09)	(0,0,0.03)

Step 4: The BNP method was used in this study for the process of defuzzification. The initial direct-relation matrix F was computed using logistic formula, as seen in Table 5 according to Equation (1).

Table 5. Transformed fuzzy direct relational matrix of the study

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
C1	0.01	0.05	0.05	0.08	0.02	0.08	0.08	0.05	0.03	0.05	0.05	0.09
C2	0.07	0.01	0.05	0.08	0.05	0.08	0.06	0.05	0.03	0.05	0.09	0.11
C3	0.02	0.02	0.01	0.06	0.01	0.08	0.08	0.03	0.08	0.03	0.08	0.09
C4	0.01	0.01	0.03	0.03	0.01	0.01	0.08	0.02	0.08	0.03	0.09	0.09
C5	0.05	0.03	0.08	0.05	0.01	0.03	0.02	0.05	0.05	0.03	0.08	0.11
C6	0.08	0.03	0.03	0.08	0.01	0.01	0.05	0.03	0.03	0.03	0.06	0.09
C7	0.05	0.03	0.05	0.08	0.06	0.05	0.01	0.03	0.03	0.08	0.06	0.11
C8	0.05	0.05	0.03	0.05	0.01	0.05	0.09	0.01	0.03	0.05	0.02	0.05
C9	0.03	0.03	0.06	0.06	0.03	0.03	0.06	0.01	0.01	0.06	0.09	0.09
C10	0.06	0.03	0.03	0.06	0.03	0.03	0.06	0.01	0.03	0.01	0.06	0.09
C11	0.03	0.03	0.06	0.09	0.03	0.03	0.06	0.02	0.03	0.03	0.01	0.05
C12	0.03	0.03	0.06	0.09	0.03	0.03	0.06	0.01	0.03	0.03	0.06	0.01

Step 5: The Total-relation matrix T is acquired from the normalized direct-relation matrix, which can be seen in Table 6 using the formula below:

$$T = N(I - N)^{-1} \quad (4)$$

Table 6. Total relational matrix of the study

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
C1	0.06	0.09	0.1	0.16	0.05	0.12	0.15	0.08	0.08	0.1	0.13	0.19
C2	0.12	0.05	0.11	0.18	0.08	0.13	0.15	0.08	0.09	0.1	0.15	0.22
C3	0.07	0.05	0.07	0.15	0.04	0.12	0.15	0.06	0.12	0.08	0.15	0.18
C4	0.05	0.04	0.08	0.1	0.04	0.05	0.13	0.04	0.11	0.07	0.15	0.17
C5	0.09	0.06	0.13	0.13	0.04	0.08	0.09	0.07	0.09	0.08	0.15	0.2
C6	0.11	0.06	0.08	0.15	0.04	0.05	0.11	0.06	0.07	0.07	0.13	0.17
C7	0.09	0.07	0.1	0.16	0.09	0.09	0.09	0.06	0.08	0.12	0.14	0.21
C8	0.08	0.07	0.07	0.12	0.04	0.09	0.15	0.04	0.07	0.09	0.08	0.13
C9	0.07	0.06	0.11	0.14	0.06	0.08	0.13	0.04	0.06	0.11	0.16	0.18
C10	0.1	0.06	0.08	0.14	0.06	0.07	0.12	0.04	0.07	0.05	0.13	0.17
C11	0.07	0.06	0.1	0.16	0.06	0.07	0.12	0.05	0.07	0.07	0.08	0.13
C12	0.07	0.06	0.1	0.16	0.06	0.07	0.12	0.04	0.07	0.07	0.13	0.09

Step 6: The sum of rows and the sum of columns are separately represented by D and R in the total-relation matrix M. as shown in Table 7 using the formulae below:

$$D = \left[\sum_{i=1}^{n} t_{ij}\right]_{n\times 1} = \left[t_i\right]_{n\times 1} \quad (5)$$

$$R = \left[\sum_{i=1}^{n} t_{ij}\right]_{n\times 1} = \left[t_j\right]_{n\times 1} \quad (6)$$

Table 7. Criteria influence received and given in the study

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
D	1.31	1.46	1.24	1.03	1.21	1.1	1.3	1.03	1.2	1.09	1.04	1.04
R	0.98	0.73	1.13	1.75	0.66	1.02	1.51	0.66	0.98	1.01	1.58	2.04
D+R	2.29	2.19	2.37	2.78	1.87	2.12	2.81	1.69	2.18	2.1	2.62	3.08
D-R	0.33	0.73	0.11	-0.72	0.55	0.08	-0.21	0.37	0.22	0.08	-0.54	-1

Step 7: In Fig. 2, the causal diagram is formed by (D+R) on the horizontal axis and (D-R) the vertical axis. The value (D+R) represents how important the criterion is in the LMS evaluation process. If the value is high, then that criteria is very important and should be included in the LMS evaluation process. In this study, the most important three criteria are user satisfaction (C12), learnability (C4) and usability (C11). The value (D-R) divides the LMS criteria into a cause group and an effect group. When the value of D-R is positive, it means that the criterion is in the cause group, and if the D-R is negative, it means that the criterion is in the effect group. The user should analyze the values of D+R to determine the criteria that should be given highest priority for the evaluation process, and D-R to understand which criteria have an effect on each other. In addition, in the causal diagram shown in Fig. 2, the criteria are separated into the cause group, which includes accessibility (C1), compatibility (C2), evaluation tool (C3), multilingual (C5), portability (C6), security (C8), support (C9), sustainability (C10) and the effect group, which includes learnability (C4), reliability (C7), usability (C11), and user satisfaction (C12).

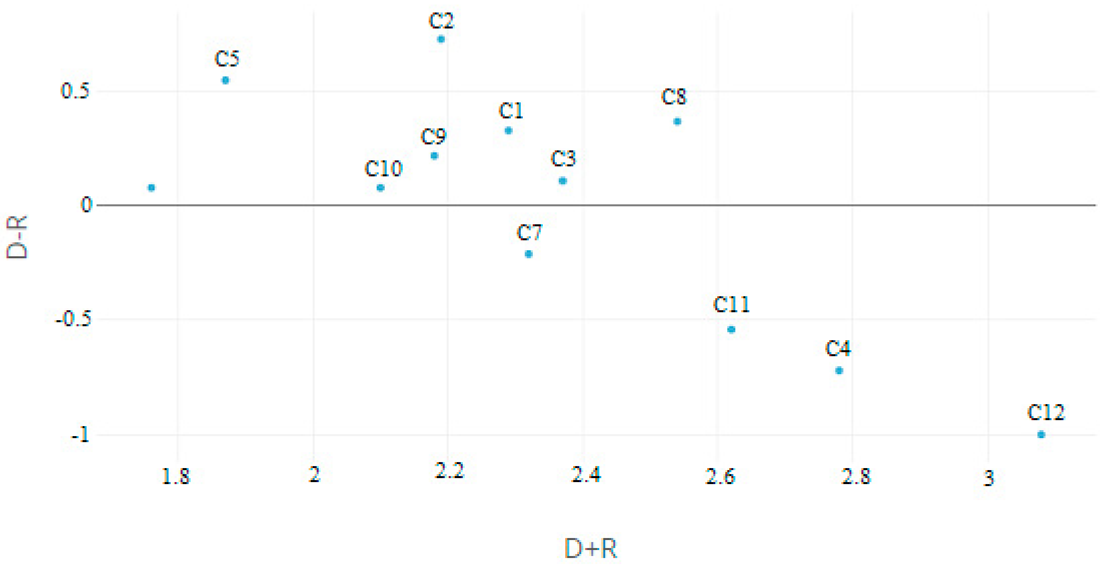

Fig. 2. Causal diagram of the study

4. Conclusion and further research

This study uses the DEMATEL method in combination with fuzzy logic to analyze and identify the most important LMS evaluation criteria. The results of the study demonstrate that accessibility, compatibility, evaluation tools, learnability, multilingual support, portability, reliability, security, support, sustainability, usability and user satisfaction should be considered for effective LMS evaluation that will satisfy users' (students, instructors, or educational institutions) needs. Among these features, learnability, reliability, usability, and user satisfaction should be given the highest priority for an effective LMS evaluation. The remaining criteria of accessibility, compatibility, tools, multilingual support, portability, security, support and sustainability should also be considered to achieve more efficient results, because they are the cause group of the first group of the LMS criteria.

The authors anticipate that the results of the study can be beneficial for educational institutions when identifying the most important features to be considered when evaluating LMSs. This research recommends using more criteria in the future, and further integration of the method with other MCDM techniques to select and rank the best alternatives based on the identified criteria. Software should also be developed in the future that will help users to evaluate LMS with minimal time and effort, which will replace the manual evaluation method.

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