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Fuzzy Analytic Hierarchy Process (FAHP) in Analyzing Mathematical E-Learning Success Factors

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ABSTRACT

E-learning approaches have emerged as a prominent method in educational institutions in Malaysia since the Covid-19 outbreak. Moreover, rapid growth in educational technologies with new software and high-end hardware has provided better accessibility for e-learning. To ensure efficient and conducive e-learning environment, the factors and sub-factors that leads towards e-learning success must be recognized and identified. Therefore, this research aims to rank the important factors and sub-factors influencing the success of e-learning in Mathematics from lecturers' perspectives. Fuzzy Analytic Hierarchy Process (FAHP) is used in analyzing the data collected. The result of this study shows that among the four chosen success factors, Quality of Infrastructure and System is the most important factor (0.3876), followed by Characteristics of Students towards e-learning (0.2428), Quality of Design and Courses (0.1942) and lastly Characteristics of Lecturers Towards e-learning (0.1753). The top four out of 12 e-learning success sub-factors are Design and User Interface System (0.1447), Students' Attitude Towards e-learning (0.1232), Understanding the Use of Infrastructure (0.1218) and Level of Product Reliability (0.1211). This finding may help to improve the effectiveness of e-learning process to not only for schools and universities but also for corporate and business sectors especially in global training programs. For future studies, students' perspective towards e-learning success in Mathematics and other subjects should be further studied in order to have a complete view of success factors.

1. INTRODUCTION

E-learning is a way of delivering lessons solely online without having a physical interaction between educators and students. Nowadays, the learning and teaching approach used by students and teachers has changed significantly as accrued from newly advanced technologies in educational institutions (Hooshyar et al., 2020). Online platform's dominance creates a distinctive learning environment and the most exciting feature of e-learning is its capability to vary the time and location of educational engagement. Moreover, e-learning also allows students to get information from various sources in various formats to easily access their learning contents, which takes advantage of all media attributes (Anderson, 2000). According to

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Nguyen (2015), e-learning improves students learning process while utilising limited resources, particularly in higher education. E-learning allows students to enrol in a course without having to physically attend the subject. Students can also take courses from the convenience of their own home or somewhere else. Furthermore, e-learning has gained in popularity due to its ability to provide more flexible access to contents and teaching materials. It is able to gather and deliver learning content in an organised way, in addition to enhance student-instructor ratio while achieving the same degree of learning outcomes as face-to-face learning (Bakia et al., 2012).

The Novel Coronavirus started in 2019 (Covid-19) has dawned on new ways of teaching and learning. Educational institutions around the world started to use e-learning platforms to conduct the said process. The new educational paradigm is based on an altered educational model, with e-learning at its core. It is no longer uncommon for educators and students to rely on digital learning. Due to this new technology, many educational institutions had to adapt to an unorthodox way of teaching and learning. Hence, it is very important to analyse the many aspects affecting the implementation of e-learning (Anggrainingsih et al., 2018). Some educational institutions have already returned to normal face-to-face learning system by the middle of 2022, but some still use e-learning and blended e-learning method. Hence, it is very important to analyse the many aspects affecting the implementation of e-learning.

This study aims to analyse the success factors for Mathematics subject and to rank the relevant sub-factors from lectures' perspectives. It is well-known that these subjects require students to intensively understand and solve questions regularly. The subject's teaching and learning process is very challenging for both teachers and students to excel in Mathematics. Therefore, it is necessary to have a study on the factors contributing to success in Mathematics.

2. LITERATURE REVIEW

Many studies have been conducted to evaluate factors affecting e-learning success. A study by Mehregan (2011) evaluated the e-learning system by defining and ranking the initial e-learning key success factors (CSFs) which universities and educational institutions should focus on. The outcome of such performance appraisal then serves as an instructive resource for the development of an e-learning systems plan. It proposed a comprehensive strategy to evaluate e-learning programs using the CSF methodology and the Fuzzy AHP method. The AHP is made up of seven main CSFs which are characteristics of instructors, characteristics of students, quality of content, quality of information technology, interaction between participants, support from educational institutions and knowledge management. The result indicates that students' characteristics and IT quality are more important than instructors' characteristics, content quality, support from educational institutions, participants, interaction, and knowledge management. As for the sub-categories, the most important things to focus on are students' computer skills, motivation, and financial support from educational institutions.

Anggrainingsih et al. (2018) used Fuzzy AHP approach to determine the rank of aspects that influence the effectiveness of e-learning in a higher learning institution. Based on the lecturers' and students' point of views, they found that university involvement, quality of infrastructure and system, quality of design and courses, student's characteristics and lecturer's characteristics are the most critical success criteria for e-learning at that university. Furthermore, the university involvement is the most critical factor of e-learning success, and the most important sub-factor is university policy such as financial and regulatory policy.

The success of e-learning also depends on the website's level of quality. A study by Nilashi and Janahmadi (2012) shows that the quality of website, the content of website, as well as the design of the website contributed positively to the success of e-learning. It is also found that website quality has the most favourable effect on online learners' perception of an e-learning website. This result is parallel with the study by Cilekbilek and Adigüzel Tüylu (2022) in which they found that technology-based components

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such as perfect IT system, user interface, system security, and diversity of the instruments are most affected in e-learning system. However, despite the advance technology in educational system, the online learning will not be successful without considering the readiness of e-learning execution (Alqahtani & Rajkhan, 2020).

Students and lecturers involve directly in determining the successful of online learning. High participation in e-learning may enrich students' interest and knowledge (Mystakidis et al., 2019). The interaction between students and lecturers affects the participation and the performance of the student in online learning (Kedia & Mishra, 2023; Gümüşhan & Çakır, 2023). Besides, students' emotion and motivation can either facilitate or inhibit the learning process. A study by Zainuddin (2018) showed that intrinsic motivation is associated with deep learning, high performance and learning resilience. Progressive emotion is correlated with high achievement and self regulation (Xie et al., 2019).

3. METHODOLOGY

This section explains in detail on data collection method and essential steps used to apply FAHP in analysing the data.

3.1 Data Collection

Data was collected by distributing questionnaires to a senior Mathematics lecturer in UiTM Perlis Branch, Arau Campus. Based on literature review done, the study has determined four critical factors that influence the e-learning success which are quality of infrastructure and system, quality of design and courses, characteristics of students toward e-learning and characteristics of lecturers towards e-learning. Each factor was later defined by three sub-factors that correspond to it. The sub-factors for quality of infrastructure and system are level of product reliability, understanding the use of infrastructure and as well as design and user interface system. The sub-factors for quality of design and courses are quality, relevance, and completeness of the content. For the students' characteristics factor, the sub-factors include expertise in using computers and internet as well as their attitudes toward e-learning. Lastly, for lecturers' characteristics, the sub-factors are attitudes toward students and e-learning and their timely responses.

3.2 FAHP Model

Provided are the steps used to implement FAHP:

Step 1: Select an expert group for the decision-making process. The lecturers of Calculus subject at UiTM Perlis Branch Arau Campus are selected as the experts who have substantial knowledge and experience in organising e-learning programmes.

Step 2: Compute the fuzzy triangular number. A pairwise comparison between the factors and sub-factors is conducted by the experts to determine the relative score. Fuzzy AHP is a range of values that considers the decision-makers' uncertainty in place of a crisp value. The pairwise comparison matrix, denoted by C_{ij} is represented by the following matrix:

$$C_{ij} = \begin{matrix} C_1 \\ C_2 \\ \vdots \\ C_k \end{matrix} \begin{bmatrix} f_{11} & f_{12} & \cdots & f_{1k} \\ f_{21} & f_{22} & \cdots & f_{2k} \\ \vdots & \vdots & \cdots & \vdots \\ f_{k1} & f_{k2} & \cdots & f_{kk} \end{bmatrix} \tag{1}$$

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for i = 1, 2 …, k and j = 1, 2 …, k, where f_{11}, f_{12}, … f_{1k} is a triangular fuzzy number. Then, Table 1 will be used as a reference to compare the two factors for the decision maker to consider.

Table 1. Linguistic variable of pairwise comparison matrix for factors and sub-factors

Saaty Scale	Linguistic Variable	Fuzzy Triangular Scale
1	Equally Important (EI)	(1,1,1)
3	Weakly More Important (WI)	(2,3,4)
5	Strongly More Important (SI)	(4,5,6)
7	Very Strongly Important (VSI)	(6,7,8)
9	Absolutely More Important (AI)	(9,9,9)
2		(1,2,3)
4	Intermediate Values	(3,4,5)
6		(5,6,7)
8		(7,8,9)

Step 3 : Calculate the consistency ratio (CR) to assure the consistency judgement of expert(s) by using the formula:

$$CI = \frac{\lambda_{max} - N}{N - 1} \quad (2)$$

$$CR = \frac{CI}{SI} \quad (3)$$

where

λ_{max} : largest eigenvalue of the comparison matrix

N: dimension of matrix or number of criteria

CI: consistency index

RI: random inconsistency index

CR: consistency ratio

If CR is equal or less than 0.1, then the comparison is acceptable. When CR is greater 0.1, the value is indicative of inconsistent judgment.

Step 4: Calculate the geometry mean of fuzzy comparison value by using Eq. (4).

$$\tilde{r}_i = \left(\prod \tilde{d}_{ij}\right)^{\frac{1}{n}}, i=1,2,\ldots,n \quad (4)$$

Step 5: Calculate fuzzy weights. The vector sums of each geometric mean will be computed to determine the fuzzy weights, $\tilde{w}_i$. Following that, the summation vector's reciprocal is computed, and the fuzzy triangular number is sorted in ascending order. To obtain the fuzzy weight, geometric averages must be multiplied by this reverse vector.

$$\begin{aligned} \tilde{w}_i &= \tilde{r}_i \otimes (\tilde{r}_i \oplus \tilde{r}_i \oplus \cdots \oplus \tilde{r}_i)^{-1} \\ &= (lw_i\ , mw_i, uw_i) \end{aligned} \quad (5)$$

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Step 6: Perform Defuzzification. The fuzzy weights must be defuzzified using the centre of area method because they are still in a fuzzy triangular number. This method was proposed by Chou and Chang (2008) using the equation stated below:

$$M_i = \frac{lw_I + mw_i + uw_I}{3} \quad (6)$$

Step 7: The final step is to normalise the defuzzification result using the following equation:

$$N_i = \frac{M_i}{\sum_{i=1}^{n} M_i} \quad (7)$$

where n represents the total number of M_i.The criterion with the highest score will be considered as the most important factor and sub-factor based on the results.

4. RESULT AND DISCUSSION

The lecturers' evaluation (experts' evaluation) on the four criteria used in the study is summarized in Table 2.

Table 2. Pairwise comparison matrix for decision criteria of factors affecting e-learning success from lecturers' perspective

Criteria	Quality of Infrastructure and System	Quality of Design and Courses	Characteristics of Students toward E-Learning	Characteristics of Lecturers toward E-Learning
Quality of Infrastructure and System	1.00	2.00	2.00	2.00
Quality of Design and Courses	0.50	1.00	1.00	1.00
Characteristics of Students toward E-Learning	0.50	1.00	1.00	2.00
Characteristics of Lecturers toward E-Learning	0.50	1.00	0.50	1.00

In this study, $\lambda_{max} = 4.06065$, N = 4, SI = 0.9, resulting the consistency ratio of 0.02246 (<0.1) indicates that the evaluation of the expert is consistent.

Table 3 shows the triangular fuzzy matrix and normalised weights for each criterion of factors influencing e-learning success from lecturers' perspectives. Based on the table, with the highest score of 0.3876, the Quality of Infrastructure and System is the most significant factor, followed by Characteristics of Students toward E-learning (0.2428), Quality of Design and Course (0.1942) and Characteristics of Lecturers toward E-learning (0.1753).

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Table 3. Triangular Fuzzy Matrix and normalised weight of e-learning success factors from lecturers' perspectives

Factors	Quality of Infrastructure and System	Quality of Design and Courses	Characteristics of Students toward E-Learning	Characteristics of Lecturers toward E-Learning	Normalised Weight
Quality of Infrastructure and System	1,1,1	1,2,3	1,2,3	1,2,3	**0.3876**
Quality of Design and Courses	0.33,0.50,1	1,1,1	1,1,1	1,1,1	**0.1942**
Characteristics of Students toward E-Learning	0.33,0.50,1	1,1,1	1,1,1	1,2,3	**0.2428**
Characteristics of Lecturers toward E-Learning	0.33,0.50,1	1,1,1	0.33,0.50,1	1,1,1	**0.1753**

Table 4 displays the triangular fuzzy matrix and normalised weight for the sub-factors that affect e-learning success. The normalised weights were then used to compute the overall weightage based on the factors' weights.

Table 4. Triangular Fuzzy Matrix and normalised weight of e-learning success sub-factors from lecturers' perspectives

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Sub-Factors	Level of Product Reliability	Understanding The Use of Infrastructure	Design and User Interface System	Quality of Content	Relevance of Content	Completeness of Content	Expertise in Using Computer	Expertise in Using Internet	Students' Attitudes toward E-Learning	Lecturers' Attitudes toward E-Learning	Lecturers' Attitudes toward Students	Lecturers' Timely Response	Normalised Weight
Level of Product Reliability	1,1,1	0.33,0.50,1	1,1,1	0.33,0.50,1	0.25,0.33,0.50	0.25,0.33,0.50	0.25,0.33,0.50	0.25,0.33,0.50	0.20,0.25,0.33	0.20,0.25,0.33	0.33,0.50,1	0.33,0.50,1	**0.0350**
Understanding The Use of Infrastructure	1,2,3	1,1,1	0.25,0.33,0.50	0.25,0.33,0.50	0.25,0.33,0.50	0.25,0.33,0.50	0.25,0.33,0.50	0.25,0.33,0.50	0.20,0.25,0.33	0.33,0.50,1	0.33,0.50,1	0.25,0.33,0.50	**0.0352**
Design and User Interface System	1,1,1	2,3,4	1,1,1	0.25,0.33,0.50	0.25,0.33,0.50	0.20,0.25,0.33	0.33,0.50,1	0.33,0.50,1	0.20,0.25,0.33	0.33,0.50,1	0.33,0.50,1	0.25,0.33,0.50	**0.0418**
Quality of Content	1,2,3	2,3,4	2,3,4	1,1,1	1,1,1	1,1,1	0.25,0.33,0.50	2,3,4	0.25,0.33,0.50	1,2,3	1,2,3	1,1,1	**0.0944**
Relevance of Content	2,3,4	2,3,4	2,3,4	1,1,1	1,1,1	1,1,1	1,2,3	1,2,3	1,1,1	1,1,1	1,2,3	0.33,0.50,1	**0.1067**
Completeness of Content	2,3,4	2,3,4	3,4,5	1,1,1	1,1,1	1,1,1	1,2,3	2,3,4	1,2,3	1,2,3	1,2,3	1,1,1	**0.1331**
Expertise in Using Computer	2,3,4	2,3,4	1,2,3	2,3,4	0.33,0.50,1	0.33,0.50,1	1,1,1	1,1,1	0.33,0.50,1	0.25,0.33,0.50	0.33,0.50,1	0.25,0.33,0.50	**0.0728**
Expertise in Using Internet	2,3,4	2,3,4	1,2,3	0.25,0.33,0.50	0.33,0.50,1	0.25,0.33,0.50	1,1,1	1,1,1	0.20,0.25,0.33	0.33,0.50,1	0.33,0.50,1	0.25,0.33,0.50	**0.0566**
Students' Attitudes toward E-Learning	3,4,5	3,4,5	3,4,5	2,3,4	1,1,1	0.33,0.50,1	1,2,3	3,4,5	1,1,1	1,1,1	1,1,1	1,2,3	**0.1333**
Lecturers' Attitudes toward E-Learning	3,4,5	1,2,3	1,2,3	0.33,0.50,1	1,1,1	0.33,0.50,1	2,3,4	1,2,3	1,1,1	1,1,1	1,1,1	1,1,1	**0.0957**
Lecturers' Attitudes toward Students	1,2,3	1,2,3	1,2,3	0.33,0.50,1	0.33,0.50,1	0.33,0.50,1	1,2,3	1,2,3	1,1,1	1,1,1	1,1,1	1,1,1	**0.0850**
Lecturers' Timely Response	1,2,3	2,3,4	2,3,4	1,1,1	1,2,3	1,1,1	2,3,4	2,3,4	0.33,0.50,1	1,1,1	1,1,1	1,1,1	**0.1103**

The overall weightage of sub-factors for each criterion are shown in Table 5, Table 6, Table 7 and Table 8.

Table 5. Overall weightage of sub-factors under quality of infrastructure and system criteria

Factor	Weightage	Sub-factors	Weightage	Weightage per Criteria	Overall Weightage per Criteria
Quality of Infrastructure and System	0.3876	Design and User Interface System	0.0418	0.373214286	**0.1447**
		Understanding The Use of Infrastructure and System	0.0352	0.314285714	**0.1218**
		Level of Product Reliabiliy	0.0350	0.3125	**0.1211**
		TOTAL	**0.1120**	**1**	

Table 6. Overall weightage of sub-factors under characteristics of students

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Factor	Weightage	Sub-factors	Weightage	Weightage per Criteria	Overall Weightage per Criteria
Characteristics of Students toward E-Learning	0.2428	Students' Attitudes toward E-learning	0.1333	0.507422916	**0.1232**
		Expertise in Using Computer	0.0728	0.277122193	**0.0673**
		Expertise in Using Internet	0.0566	0.215454892	**0.0523**
		TOTAL	**0.2627**	**1**	

Table 7. Overall weightage of sub-factors under quality of design and courses criteria

Factor	Weightage	Sub-factors	Weightage	Weightage per Criteria	Overall Weightage per Criteria
Quality of Design and Courses	0.1942	Completeness of Content	0.1331	0.398264512	**0.0773**
		Relevance of Content	0.1067	0.319269898	**0.0620**
		Quality of Content	0.0944	0.282465589	**0.0549**
		TOTAL	**0.3342**	**1**	

Table 8. Overall weightage of sub-factors under characteristics of lecturers toward e-learning criteria

Factor	Weightage	Sub-factors	Weightage	Weightage per Criteria	Overall Weightage per Criteria
Characteristics of Lecturers toward E-Learning	0.1753	Lecturers' Timely Response	0.1103	0.379037801	**0.0664**
		Lecturers' Attitudes toward E-Learning	0.0957	0.328865979	**0.0577**
		Lecturers' Attitudes toward Students	0.0850	0.29209622	**0.0512**
		TOTAL	**0.2910**	**1**	

From the overall weightage for each criterion, the sub-factors affecting e-learning success were then ranked. The results indicates that Design and User Interface System is the most important sub-factor in determining the success of e-learning with a score of 0.1447 followed by Students' Attitudes toward E-learning(0.1232), Understanding the Use of Infrastructure and System (0.1218), Level of Product Reliability (0.1211), Completeness of Content (0.0773), Expertise in Using Computer (0.0673), Lecturers' Timely Response (0.0664), Relevance of Content (0.0620), Lecturer's Attitude toward E-learning (0.0577), Quality of Content (0.0549), Expertise in Using Internet (0.0523) and finally Lecturers' Attitudes toward Students (0.0512). Table 8 illustrates the ranking of e-learning success sub-factors from the lecturers' perspectives.

Table 9. Sub-factors' ranking

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Ranking	Sub-Factors	Score
1	Design and User Interface System	0.1447
2	Students' Attitudes toward E-learning	0.1232
3	Understanding The Use of Infrastructure and System	0.1218
4	Level of Product Reliabiliy	0.1211
5	Completeness of Content	0.0773
6	Expertise in Using Computer	0.0673
7	Lecturers' Timely Response	0.0664
8	Relevance of Content	0.0620
9	Lecturers' Attitudes toward E-learning	0.0577
10	Quality of Content	0.0549
11	Expertise in Using Internet	0.0523
12	Lecturer's Attitudes toward Students	0.0512

5. CONCLUSION

E-learning platforms are widely used by educational institutions around the world for teaching and learning activities. As a result, it is important to consider the factors that contribute to the success of e-learning. There is no reason to be apprehensive about deploying e-learning if all of the success factors and sub-factors can be implemented well. As a result of examining the factors and sub-factors affecting e-learning success, the e-learning process will be successful and yield such outstanding results. It can help students and instructors comprehend technology more deeply while also saving time and energy, in keeping with the current state of IT.

It is recommended to properly manage the important success aspects of e-learning by utilising relevant resources such as technology and software. Based on Table 3, it shows that quality of infrastructure and system become the most significant factors affecting e-learning success. Table 9 also shows that the top ranking of sub-factors (rank no 1, 3 and 4) come from this factor. This result is consistent with the findings from Nilashi and Janahmadi (2012) as well as Cilekbilek and Adigüzel Tüylu (2022). Furthermore, suitable e-learning system trainings should be offered to students and lecturers so that they can gain appropriate skills. A lack of training might impede proper utilisation of technology and limit the potential benefits that can be obtained. Professional training can help lecturers become more capable of utilising virtual classroom tools.

In addition, the e-learning process will be more interesting with the multimedia in e-learning settings. Lecturers will be able to manage a range of technical applications for effective course management including online quizzes and tests, discussion board and grading. Full benefits of the system can be realised by students with adequate instruction. Lecturers can also foster a favourable learning atmosphere by utilising instructional notes, films, and other types of multimedia.

For future research, it is recommended to study the success factors of e-learning for not only on Mathematics subjects but also for other subjects from the perspective of students because they are central to online learning.

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7. CONFLICT OF INTEREST STATMENT

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare the absence of conflicting interests with the funders.

8. AUTHORS' CONTRIBUTION

Nor Syahazlin Mohd Zaki: Conceptualisation, methodology, formal analysis, investigation and writing-original draft; **Jasmani Bidin**: Conceptualisation, supervision, methodology, formal analysis, writing – review and editing, and validation; **Noorzila Sharif**: Writing – review and editing, and validation; **Ku Azlina Ku Akil**: Writing- review and editing, and validation; **Surina Nayan**: Writing- review and editing, and proofreading.

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