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RESEARCH ARTICLE

A Fuzzy Analytic Hierarchy Process for Usability Requirements of Online Education Systems

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ABSTRACT Recent advances in information and communication technology have greatly increased the popularity of online education. The COVID-19 pandemic has further accelerated the adoption of online education due to the need for educational institutions to adopt online learning models. On the other hand, the online education system faces several challenges, such as lack of usability to overcome access barriers and scalability issues. These problems stand in the way of widespread adoption of the online education system. The usability of online education websites is one of the fundamental challenges because it directly affects students' learning experience. This study focuses on the challenges related to usability of online education websites. If an online education website has usability issues, students may have difficulty using the learning materials provided. This makes it difficult to achieve the required level of service, which can lead to a poor reputation for the website. Therefore, in order to develop a well-functioning online education website, it is necessary to ensure that all usability requirements (URs) are met efficiently. Considering the different backgrounds, knowledge, and skills of students, they may have different preferences regarding usability requirements. Therefore, prioritization of URs is necessary to focus on the most preferred requirements. In this study, we apply the fuzzy analytic hierarchy process (FAHP) to analyze the usability requirements in the requirements analysis phase. We consider the online education website of Virtual University of Pakistan, a leading online university in the country with more than 0.1 million active students. The result of this work is a flexible approach to identify precise usability requirements for developing a functionally sound website with an optimized and easy-to-use user interface that will ultimately improve the quality of education.

INDEX TERMS E-learning, virtual university, distance learning, human–computer interaction (HCI), usability requirements (URs)/usability factors (UFs), fuzzy analytic hierarchy process (FAHP).

I. INTRODUCTION

The Virtual University (VU) is a non-profit public university in Pakistan that offers distance education. Students can attend lectures through VU website without visiting the campus. In this type of learning, students are taught using computer technology. The desire for this type of learning has increased greatly, resulting in a large number of e-learning websites. Also, the growing number of students, the rapidly changing technological development and the drastic differences in

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learning tasks lead to significant challenges and make it more difficult than ever to define the perspective of using e-learning systems [1]. Researchers have presented that in e-learning environment, the learning schemes and the way lectures are delivered are not adequately adapted to accommodate the large number of learners with different perceptions. For this reason, learning in a virtual environment leads to problems that must be taken into account [2]. The main goal of an educational website is to provide a high quality educational platform, and the most important thing is that it should lead to valuable functions for academic purposes. In the last decade, much of the research effort has been focused on the actual delivery of high quality web-based education around the world [3], [4]. Various strategies have been employed to improve the performance of e-learning websites, many of which still need to be improved. This study addresses the question: how can the performance of an e-learning system be improved by considering usability requirements (UR) in the form of usability factors (UF) and sub-factors during the requirements engineering phase for a distance education website?

The importance of usability in interactive systems is widely recognised [5] and described by various definitions [6], [7], [8], [9] and is an important discipline of human-computer interaction [10]. Undoubtedly, a tremendous amount of research is being done that deals with usability in general. However, more research needs to be done on usability requirements to help website designers develop a collaborative environment that meets users' needs. The results of previous studies have shown that usability requirements (UR) have a great impact on the successful use of e-learning systems. Usually, students have no idea of the impact of usability features while visiting an ongoing hypothetical platform to understand academic objectives [11]. To explore this, it is necessary to consider their perspectives.

Therefore, it is necessary to establish their preferences regarding the importance of these attributes at the grassroots level and highlight them so that they are detailed, up-to-date, and contextually accurate. This will lead to operational and effective learning platforms that will essentially create a supportive atmosphere for knowledge acquisition, especially in a virtual environment.

Ensuring optimal usability of the final software system is directly related to the architectural design of a system [12]. For this reason, both the usability and architecture of a software system must be considered and studied in the early stages of software development [13]. However, it is a challenge to satisfy all the usability attributes mentioned by the stakeholders. This is because the requirements collected are usually vague and verbal. Due to this practice, verbal expressions in the requirements elicitation phase lead to ambiguities that result in poor software design because usability attributes are interrelated in complex ways [14]. Consequently, a highly efficient system will inevitably have a negative impact on performance of the software system users. It is imperative to analyze URs like other requirements earlier to save time. cost and effort.

A. MOTIVATION

In our earlier study [15], we worked on conflicts among URs and implemented the proposed model on an electronic healthcare system. The result showed that there were inconsistent UR, although all the staff are trained and the level of understanding is almost at the same level and the system is only used for entering, retrieving and sharing patient data. In another study [16] our focus was to study the impact of various situational factors on software development. The results of this study prompted us to look at the VU system (because one of our co-authors is serving in VU and facing usability issues in VU system) where the audience is larger and has different background situations. As the authors of [17] have stated that during use of traditional software, users learn the software repeatedly but using e-learning software, users do not usually use the environment for long-term.

Therefore, e-learning software must be understood immediately to further improve user requirements when developing an e-learning system. For example, if the modalities of delivery and interaction are not adapted to the users' requirements, it will lead to a degradation of learning in a virtual environment. VU in Pakistan [18], which is one of e-learning institutes and other such institutes around the world need to further understand the usability requirements in order to have an improved system with a better interface. Selecting the appropriate UR is a complex process. Several criteria need to be considered when deciding on the preferred UR. Since the online education system is accessible to audiences from different parts of the country with different backgrounds, ages, abilities, interests and intelligence. This makes it difficult to develop a system that takes into account the preferences of a large population. In general, beginners consider ease of use as the first criterion when choosing UR. However, among the beginners, there are some students who are computer literate and need a more efficient system, and others who are comfortable with the pleasant design of the system. Therefore, it is really difficult for the decision makers to select the best UR in the required order that meets the needs of students and teachers in every aspect.

B. SIGNIFICANCE OF THE STUDY

Numerous researchers, including Ahlstrom and Longo [19], Mobrand & Spyridakis [20], Nielsen [6], Hutchinson [21] and Nielsen & Levy [7] agree that the usability of websites can conflict when they are designed according to usability constraints. Users come from different geographic regions, have different age groups and expertise, etc. Therefore, in order to develop a well-functioning virtual education website, it is necessary to ensure that all usability requirements or user concerns are met, and this should be clear from the beginning. To get a grip on this problem, the importance of each usability factor for a given system must be measured.

The main objective of this study is therefore to prioritize usability requirements taking into account all relevant attributes, with a focus on the highest prioritized requirements. Ranking usability factors (UFs) depending on their importance according to user preference is actually a multi-criteria decision making (MCDM) problem [22]. The usability of a system is based on usability factors [7] and the preferences for these usability factors stated by the experts or the users are expressed in verbal form and can therefore be understood vaguely and ambiguously. To deal with this vagueness and ambiguity, a truly quantitative measurement method is needed to avoid the vagueness and ambiguity caused by verbal communication for ranking usability factors. Fuzzy set theory with multi-criteria decision making [22], is the most suitable technique to evaluate URs in the requirements analysis phase due to its intuitive nature. It will be a great effort to develop a more user-friendly virtual education system that can be fully utilized by learners, teachers and administrators.

C. CONTRIBUTION

Usability is an important part of any interactive system. If the portfolio of an educational website is not easy for users to understand, they will not stay on the site. Therefore, it is inevitable to keep the students and teachers engaged with the website to spread the knowledge and skills. To summarize, usability is crucial for any online business to survive and grow on the internet. Therefore, great attention must be paid to the usability of online education systems. In contrast, the conceptual usability evaluation models in the literature (Shackel's model, Nielsen's model, ISO 9241-11, QUIM model, discussed in Section II) have not simulated mathematically to calculate the UF weights individually, but have only followed the principles of human computer interaction. The proposed approach determines the UF weights by incorporating AHP and fuzzy theory so that the elicited URs are analyzed and prioritized to address the shortcomings and deficiencies in the literature. Moreover, it is not only a literature-based study, but also a study that involves student participation and expert evaluation in a fuzzy system environment, which makes it a highly reliable method of modeling. The work we propose contributes to the fulfillment of this goal in the following ways.

1) This study facilitates users of the system by determining comprehensive user preferences against each UR attribute individually.
2) Prioritization of UR attributes is done using Fuzzy Analytic Hierarchy Process (FAHP) in the requirement analysis phase.
3) It is quite difficult for the requirement analyst to determine the actual URs and how important a particular UR is? Our proposed approach (FAHP) will help the development team gain an unbiased understanding of UR with greater accuracy.
4) Our proposed method (FAHP) will help the development team to get an unbiased view of the UR with greater accuracy, making it easier for requirements analysts to understand the actual user requirements and their meaning.
5) Since all usability attributes are prioritized, this helps to resolve conflicts between URs, which helps developers to focus on the most important URs to develop a more effective, efficient and user-friendly online education system.

The rest of the article is structured as follows. Section II discusses the state of the literature on URs and the proposed approach. Section III explains the proposed fuzzy approach in terms of extraction, formation and final prioritization of UR factors for the VU's online education system. Section IV contains the results, discussion and analysis of the results. Finally, Section V concludes the study.

II. LITERATURE REVIEW

To gain deeper insight into existing virtual university systems and the methods and practices used to conduct research to improve the overall usability of these systems, an extensive literature review was conducted. A number of standards and researchers have comprehensively attempted to improve system performance by categorizing quality requirements by type [23]. On the other hand, many authors [6], [9], [24], and [25] have worked on usability. Many of them focused on categorizing usability (a quality requirement) into a set of attributes and developed guidelines and heuristics to improve and evaluate usability. Moreover, without considering usability factors, it is impossible to develop an online learning system that engages users in learning with greater interest [25].

According to [26] usability consists of Efficiency, Learnability, Error-proneness, Memorability, and Satisfaction. ISO 9241-11 has defined usability with associated factors, evaluation and testing. In addition, the field of human computer interaction has grown tremendously in the last decade and the use of interactive systems and the use of the Internet has increased greatly and is likely to increase in the future [27]. For this reason, a great deal of attention is being paid to the need to accurately determine the usability attributes that make an interactive system more successful and useful.

In [28] and [29] the authors found that usability influences learner motivation and satisfaction when using an e-learning system, with better learning performance expected when the system has high usability. Through an empirical analysis, they evaluated the usability (in terms of effectiveness and efficiency) of the e-learning system based on experiences with different levels of control and adaptability. According to Carlos [30], the usability of a website includes five factors: i) Easy understanding of a system and how it works. ii) Quick access to certain information. iii) Ensuring simplicity in early stages. iv) Good controllability. v) Easy navigation. In another study [31], the authors proposed a theoretical model was proposed and validated the impact of usability factors on the continued use of e-learning systems in the cloud by university students [31]. They found that five usability factors, namely computer self-efficacy, enjoyment, ease of use, perceived usefulness, and user perception, had a positive impact on intention to continue using.

Authors of the research articles [32] and [33] have shown that interface usability has a significant impact on user insight into ease of use and usefulness, which ultimately affects attitudes and intentions to use an information system. However, there is increasing confusion about "what appropriate level of usability" is required for the virtual university system to function successfully. There are numerous students from different backgrounds with different skills, abilities, and technological developments. The constant redesign of learning and teaching tasks is very problematic to achieve a clear context of use for such systems.

In the literature, there have been ongoing efforts to analyze the impact of usability in software development. The authors in [34] paid considerable attention to this quality criterion and emphasized the relevance of usability and software design. We followed their idea that, as with other requirements, it is important to address usability requirements at the latest in the design phase of system development to save cost, time, and effort. In order to keep users on the site and successfully accomplish the task of e-learning, the opportunity to study usability factors [35], [36], [37]. Another study [38] emphasized the high cost of e-learning systems, noting that the cost of e-learning systems is high and the systems are not easy to use. Although widespread influence has led to widespread acceptance of usability, there are many features to be worked on, i.e., there is no single point value for the usability index to be calculated. In addition, a validated quantitative method needs to be researched that includes a checklist. Overall, it can be said that usability factors should be analyzed using an appropriate technique and ranked according to user preferences to avoid the aforementioned problems.

More appropriate components and techniques are needed to develop an interface that is easy to use and control. Techniques such as fuzzy models can be used to solve various problems [39], [40], [41]. FAHP is deliberately proposed as an applicable reference model for the decision making process [42].

As a result of the new approaches in requirements engineering, there have been various discussions among professionals and requirements engineers about the requirements characteristics, factors, and user needs that affect an e-learning website. Our proposed study uses the FAHP technique, which combines the AHP with fuzzy. Analytic hierarchy process (AHP) was introduced by Saaty [43] and has been used in several methods to rank/prioritise user-specified requirements. Many researchers worked with AHP [44] and manually evaluated the required usability factors, which led to ambiguities that can be a potential reason for project failure. Therefore, Zadeh proposed the fuzzy logic [45] to eliminate the ambiguities in the evaluation. Van Laarhoven and Pedrycz [46] were the first to introduce the fuzzy pairwise comparison into the AHP to balance the element of ambiguity in the standard AHP.

Ramanayaka et. al., [47], and Ramanayaka et. al., [48], consider this fact and have developed a model based on fuzzy logic. They believe that combining software engineering processes and usability engineering in an object-oriented approach leads to improved system usability. They proposed an extended version of the ISO-9241 [49] Usability model with a fuzzy modeling approach. The model conjugates the fuzzy logic knowledge based on the usability attributes of a software system. However, in this study, no explanations of the important data of the real scenario were provided, and only the usability of the system was evaluated, but the level of the desired usability was not elaborated, moreover, the other important usability attributes are missing.

Gulzar et. al., [14] used MATLAB Fuzzy Logic Toolbox to apply fuzzy methodology to usability requirement conflicts by combining usability factors defined by ISO [49] and Neilson [50], and concluded that URs should be considered at early stages. The study by Nakamura et al. [51] showed that user experience (UX) and usability of learning management systems (LMSs) need to address the lack of research in LMS usability and the lack of studies on accurate responses to interface-related problems. All of the above literature identified the gap for solving the aforementioned problem using an intuitive technique.

A. RESEARCH GAPS

Mirjana Ivanovi et. al.,'s noted that ensuring the usability of e-learning systems is becoming an increasingly important issue in design, development, and maintenance [52]. The framework proposed by the authors is useful because it emphasizes classification based on categories and subcategories of design categories and explores their actual impact on student practice in using e-learning. Ultimately, the goal is to identify the features that deserve the attention of designers and usability experts for further improvement. In particular, careful consideration of usability factors in the design phase, including adaptation or evaluation of the e-learning system, is essential [53]. This study confirms the gap in the literature for researchers to consider user needs and concerns when developing a usable online educational website. The most common problems encountered in online education systems are interface problems, navigation, controllability and attitude. Based on these issues, instructional designers are advised to exercise to develop more usable and reliable e-learning systems. Added to this, [29] endorsed SCI, the necessity to highlight the lack of consideration of these factors in e-learning in the leading literature. Furthermore, it has been observed that numerous efforts were made but the influence was on usability evaluation approaches. Continuing ahead, the usability evaluation is done on the basis of guidelines and heuristics given in literature. In these methods, system functionality and usability were tested by comparing designs with provided criteria, guidelines and evaluators' comments [54].

Furthermore, none of the models cited in this study (Shakle's model, Nelson's model and ISO 9241-11, QUIM model) used mathematical simulations to ensure accurate measurements. Based on previous research, no clear cause-effect relationship can be established as these are non-experimental studies and no manipulative controls of the independent variables were performed. A recent study [53] emphasised over the need for an exploratory study to determine the effects of usability attributes. They claimed that it would be very helpful for the policy makers and developers to improve the online education system in terms of usability according to students' perception. Furthermore, throughout the literature reviewed, every effort was made to evaluate usability in the testing phase of the software. In contrast, emphasis needs to be placed on the requirements analysis phase, where a preferred and desirable set of URs is derived to avoid usability problems in later phases. We try to close this gap by analysing the URs in the requirements analysis phase as criteria for the MCDM technique. Since each UR has more than one attribute (sub-criterion), the appropriate meaning of each UR must be derived from multiple attributes. For this reason, MCDM is best suited to solve this problem. It is important to determine the correct priority weights for each criterion as they ultimately affect the final results (usability of the system).

Why we used FAHP to prioritize URs for VU system is explained in the following. Various techniques have been used in the past to calculate the criteria weights, such as the mathematical programming (MP), analytic network process (ANP), linear weighting (LW), analytic hierarchy process (AHP), and fuzzy analytic hierarchy process (FAHP) methods. URs selection is a type of multi-criteria decision problem that involves both qualitative and quantitative factors, some of which are in conflict with each other. Studies have shown that the FAHP is a truly operational solution for MCDM. Moreover, it helps decision makers to assign linguistic values to each criterion in the form of numerical values to avoid ambiguity as it can account for incomplete and inaccurate data [55]. A multi-criteria decision making technique helps decision makers (DMs) to evaluate a suitable set of URs with desired UFs for an educational website. In FMCD, a fuzzy comparison matrix is developed in which each sub-criterion of one criterion is compared with all sub-criteria of another criterion to check all possible comparisons. In this way, all criteria and sub-criteria are examined to see whether they influence each other, either positively or negatively. The purpose of introducing FAHP in the requirements analysis phase of the system design process is to analyze the UR first in order to resolve conflicts between the URs. Since the UR is weighted first, the conflict is resolved by focusing on the UR with the highest weight.

In the next section, the assessment of URs through the hierarchical structure (factor and sub-factors) is described and the fuzzy AHP approach for URs of VU system is explained in detail.

III. PROPOSED FUZZY AHP APPROACH

A. DATA COLLECTION

1) EXTRACTION OF USABILITY FACTORS

The research is aimed at improving the usability of interactive systems by analyzing the implementation of designed relics [56]. An overview of the proposed research is shown in Figure 1. Surveys and questionnaires are a widely used practise to get users' opinion about the acceptability of a product. It can be performed in two ways: either the important usability factors are rated on a scale based on user opinion, which are referred as stated importance, or the importance of elements derived using fuzzy rating scale for analysis. A survey of more than hundred users of information systems about the usability of the system was carried out. Fifty eight university students, seventeen university teachers and ten experts from industry (software houses, educational institutions), who frequently come into contact with university systems in their office work, and a few are ordinary users such as internet users, participated in it. Demographics of survey participants is given in Table 1. The questionnaire contains twenty two questions. The first part consists of five questions related to the demographic data of the users. The second part focused on the selected key factors and sub-factors that are suitable to define usability in a comprehensive way.

TABLE 1. Demographics of survey participants.

Users	Age	Number	Type of use
Students	16-35	58	Use website for learning
Teachers	27-50	17	Teach and advise
Experts	35- 50	10	Design and develop software

2) FORMATION OF USABILITY FACTOR SETS

The factors were examined using closed questions with corresponding multiple-choice options. From the literature review and survey analysis, 6 key UR or UF, shown in Table 2, were selected as key factors and 29 attributes of usability requirements, shown in Table 3, were selected as sub-factors. Memorability is considered as a component that can improve comprehension and usability, while effectiveness and error-proneness mainly influence reliability. Satisfaction refers to the information being relevant and meeting expectations. Efficiency refers to the speed of accessing information and other content such as page loading and active control. Learnability indicates how easy a website is to learn.

After obtaining users' opinions, a group of 10 experts was convened to reach consensus on the collected data set and to determine the degree of importance of factors and sub-factors through pairwise comparisons. The questionnaires for the experts were designed to assist in providing opinions in pairwise comparisons [57].

B. FUZZY AHP TO ESTIMATE THE WEIGHT SETS FOR UFS

Fuzzy-AHP, a systematic method, is an extension of Saaty's AHP, which is a combination of AHP and fuzzy set theory

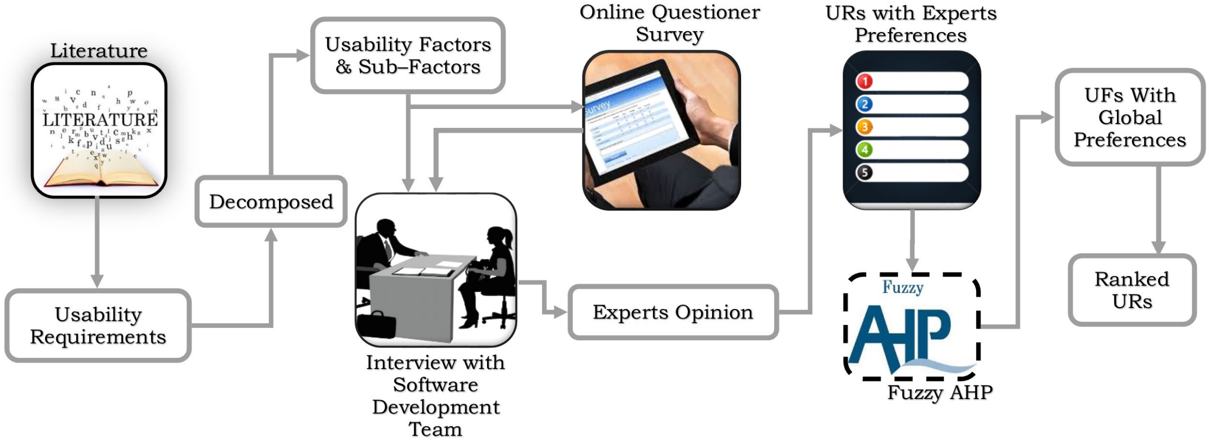

FIGURE 1. Proposed fuzzy analytic hierarchy process (FAHP) approach.

TABLE 2. Usability requirements (Sub-factors).

Usability factors	Description
Effectiveness	Completeness and accuracy with which a user achieves the user's objective
Efficiency	Resources expended by users to ensure accurate completion of objective
Learnability	Ease of learning; new users can easily start work on the system
Satisfaction	How pleasant the system is to use?
Error	There should me minimum errors, and if there is any user error then how system reacts to user errors, either to correct independently or let the user inform for easy correction
Memorability	When users return to the design after a period of not using it, how easily can they reestablish proficiency?

TABLE 3. Usability requirements (Sub-factors).

Usability factors	Sub Factors
Effectiveness	Quality of output, Functionality, usefulness, productive, task completion
Efficiency	Accessibility, Operability, Scalability, Time Efficiency, Availability, Resource Efficiency, Compatibility
Learnability	Wizard, help, Self-Descriptiveness, Simplicity, Workload
Satisfaction	User attitude, Interaction Experience, Empathy, Support, Assurance
Error	Error Observed, Error Recovery, Error Rate, Error tolerating, Error handling, Integrity
Memorability	Minimum Metal load, Memorable interaction, Clear Label Links

[46]. The FAHP method is a disciplined approach to solving MCDM problems and selecting the best alternative from the set of given alternatives by introducing fuzzy comparison into the simple pairwise comparison matrix of the AHP. The experts have the possibility to indicate the importance of UR key factors and sub-factors in nuclear or natural language form. These importance scores are combined with the collected data using FAHP. Preference levels for the usability factors are determined by the authors of [43] and described in Table 4.

TABLE 4. Relative significance of usability factors (UFs) on the basis of Saaty's scale.

Scale	Significance of usability factors
1	Assigned to represent that both elements are equally important
2	Assigned to represent an intermediate value
3	Assigned to represent that elements are moderately important
4	Assigned to represent an intermediate value
5	Assigned to represent that elements are strongly important
6	Assigned to represent an intermediate value
7	Assigned to represent that elements are very strongly important
8	Assigned to represent an intermediate value
9	Assigned to represent that elements are absolutely important

The step wise procedure of Fuzzy AHP is described in the following.

Step 1: The AHP method's first stage involves accessing usability elements through a hierarchical structure. Except for the fuzzy representation of the pairwise comparison, the processing stages in FAHP are identical to those in AHP. Due to the fact that AHP does not adequately take into consideration the linguistic assessment's imprecision and that the expert assessments were gathered in linguistic terms. This shortcoming is overcome by introducing the fuzzy set theory [45] into the pairwise comparison by using fuzzy numbers (FN) [59]. In pairwise comparison, three real numbers are expressed as triples (l, m, u) to represent a triangular fuzzy number (TFN), whereas the fuzzy AHP approach uses integers 1 to 9 to represent triangular fuzzy numbers notwithstanding their distinctness. In order to address the ambiguity and imprecision of the pairwise priority values of URs, Figure 2 illustrates the fuzzy set definition using 5 triangular fuzzy numbers. In fuzzy set theory, an entity can have an affiliation represented by 1 and not have an affiliation represented by 0. If u is the universe of discourse, then l(x) is a membership function that lies between [0, 1]. Mathematically, the triangular fuzzy membership function for a fuzzy number B = (l, m, u) is defined as follows in

TABLE 5. Pairwise comparison matrix for key UFs at level 1.

	Efficiency	Effectiveness	Error	Satisfaction	Memorability	Learnability
Efficiency	1.00	3.00	3.00	3.00	1.00	5.00
Effectiveness	0.33	1.00	1.00	1.00	0.33	3.00
Error	0.33	1.00	1.00	1.00	0.33	3.00
Memorability	0.33	1.00	1.00	1.00	0.33	3.00
Learnability	1.00	3.00	3.00	3.00	1.00	5.00

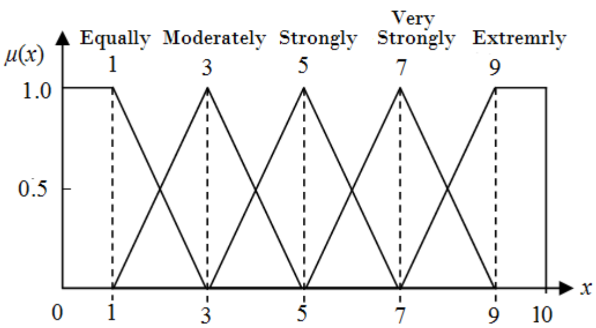

FIGURE 2. Fuzzy set definition with triangular membership function.

Equation 1.

$$\mu(x)=\begin{cases}0 & x<1\\ \dfrac{x-1}{m-1} & l\le x\le m\\ \dfrac{u-x}{u-m} & m\le x\le u\\ 0 & x>u\end{cases} \tag{1}$$

In Equation 1, u and l stand for the fuzzy number B's upper and lower bounds, respectively, and m is the modal value, which is B.

Step 2: After the hierarchical structure has been established, an initial pair-wise comparison is made to compare pairs of criteria or measures, at each level.

The pairwise comparison judgment matrix of expert's opinion at each level are formulated as shown in Equation 2.

$$\tilde{A}=\begin{bmatrix}1 & C_{12} & C_{13} & \cdots & C_{1n}\\ 1/C_{12} & 1 & \cdots & \cdots & C_{2n}\\ \vdots & \vdots & 1 & \ddots & \vdots\\ 1/C_{n1} & \cdots & \cdots & \cdots & 1\end{bmatrix} \tag{2}$$

for $i=1,2,\ldots,n,\ \ j=1,2,\ldots,\ \ if i=j\ \ then\ Cij=$ (1 1 1)

Step 3: The fuzzy synthetic extent with regard to the i^{th} object is currently calculated using Equation 3.

$$S_j^k=\sum\nolimits_{j=1}^{n}C_{ij}^k\bigotimes\left(\sum\nolimits_{i=1}^{nk}\sum\nolimits_{j=1}^{nk}C_{ij}^k\right)^{-1},\quad i=1,2,\wedge,n_k \tag{3}$$

Step 4: Then the degree of possibility of Si is computed by Equation 4 and Equation 5.

$$\begin{aligned}V(C_1\ge C_2)&=sup_{x\ge y}(min(\mu C_1(x),\mu C_2(y)))\\ V(C_1\ge C_2)&=1\qquad if\ m_1\ge m_2\\ V(C_1\ge C_2)&=hgt(C_1\cap C_2)=\mu C_1(d)\\ V(C_1\ge C_2)&=hgt(C_1\cap C_2)\end{aligned} \tag{4}$$

$$V(C_1\ge C_2)=\frac{l_1-u_2}{(m_2-u_2)-(m_1-l_1)} \tag{5}$$

where $Si=(l1,m2,u3)$ and $Sj=(l1,m2,u3)$. To compare Si and Sj, we have to compare both the values of $V(S_i\ge S_j)$ and $V(S_j\ge S_i)$.

Step 5: Determine the minimum degree of possibility as shown in Equations 6, 7 and 8.

$$\begin{aligned}V(C\ge C_1,C_2,\cdots,C_k)&=V(C\ge C_1)\ and\ (C\ge C_2)\\ and\cdots and(C\ge C_k)&=min\ V(C\ge C_i),\ i=1,2,\ldots,k\end{aligned} \tag{6}$$

if

$$d'(S_i)=minV(S_i\ge S_k) \tag{7}$$

then

$$W'=(d'(S_1),d'(S_2),\ K,\ d'(S_n))^T \tag{8}$$

Step 6: Using the formula provided in Equation 9, normalised weight vectors are created by dividing the elements in each column by the sum of that column, adding the elements in each subsequent row, and dividing this sum by the number of elements in that row.

$$W'=(d'(S_1),d'(S_2),\ K,\ d'(S_n))^T \tag{9}$$

The final weight of each element involved is determined by multiplying the criteria and the matrix obtained by calculating each alternative with respect to each element. In the next section, this model is applied to rank URs, with an explanation of each step based on a single expert opinion.

C. IMPLEMENTATION DETAILS AND SIMULATION RESULTS OF FUZZY AHP APPROACH

1) IMPLEMENTATION DETAILS

In this sub-section, we have described the step-by-step procedure of the fuzzy AHP model to compute the weights of the URs for the virtual university system.

Step 1: As for expert opinion, the respective influences are collected and a hierarchical model of URs is created and

TABLE 6. Fuzzy numbers.

Importance of linguistic scale	Triangular fuzzy scales	Triangular fuzzy reciprocal scales
EI: Equally important	(1, 1, 1)	(1, 1, 1)
IM1: Intermediate 1	(1, 2, 3)	(1/3, 1/2, 1)
MI: Moderately important	(2, 3, 4)	(1/4, 1/3, 1/2)
IM2: Intermediate 2	(3, 4, 5)	(1/5, 1/4, 1/3)
I: Important	(4, 5, 6)	(1/6, 1/5, 1/4)
IM3: Intermediate 3	(5, 6, 7)	(1/7, 1/6, 1/5)
VI: Very important	(6, 7, 8)	(1/8, 1/7, 1/6)
IM4: Intermediate 4	(7, 8, 9)	(1/9, 1/8, 1/7)
AI: Absolutely important	(9, 9, 9)	(1/9, 1/9, 1/9)

shown in Figure 3. A multilevel (three-level) hierarchy of an AHP model represents the structural relationship between URs. The first level indicates the key factors of the URs (Table 5), which can be achieved by estimating the effects of the second level sub-factors.

Step 2: A decision matrix is then created for all UF and sub-factors in a pairwise comparison based on the expert opinion. First, all sub-factors are evaluated and then the key factors are derived. After assigning weights to all criteria (factors & sub-factors), the consistency is checked [43]. The consistency test is used to measure the degree of consistency using the following equation:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{10}$$

Overall, a CI value of less than 0.1 is acceptable. Currently, the consistency ratio (CR) is calculated using the following relationship:

$$CR = CI/RI \tag{11}$$

CR = 0.1 can be regarded as sufficiently consistent. If the values determined for the two indices (CI and CR) are less than 0.10, this shows the consistency of the fuzzy matrix. If the value found is greater than 0.10, then the prioritization needs to be revised [58].

Step 3: The fuzzy comparison matrix for UR estimation was calculated using expert opinion. Conversion of fuzzy linguistic variables into fuzzy numbers is performed as per [60]. Three arguments of triangular fuzzy numbers are used to describe a scale of fuzzy numbers symbolizing a membership function, as shown in Table 6. Fuzzy comparison judgment matrices for key UFs are given in Tables 7 to 10.

Step 4: After creating the fuzzy judgment matrix of six UFs, the sum of the rows of all factors is calculated based on various criteria. Each UF and sub-factor is calculated separately using the same calculation method.

Step 5: Equation 3 is used to calculate the integrated fuzzy expansion to determine synthetic extend.

Step 6: By means of normalization, the preference weights of the key UFs are calculated by Equation 8.

2) SIMULATION RESULTS

The results of this study have shown that the usability of the Virtual University website is composed of certain factors and the six factors are truly descriptive. FAHP was then used to articulate all the important UFs in a model to evaluate which of the important UFs are the most significant. The results of FAHP and the selection of the most important UFs can then help evaluate the architecture and determine which UR is most important, and software architects decide how to allocate resources between the most desired and least needed requirements. In this work, we transfer the users' concerns that are the most difficult to handle. Users are not aware of the software architecture and evaluate the system based on usability requirements. Therefore, each high-ranked requirement must be fulfilled, and it is desirable to devote some resources to the medium-high ranked requirements and defer the low ranked requirements until additional resources are available and less effort is required to fulfil them. While the least important URs also contribute to increasing system acceptance, they do not exclusively cause the user to leave the system or website. However, if many of the least important URs are neglected, their combined effect can in some cases lead to a lower user experience.

Virtual University/distance learning institutes play an important role in education but have many challenges to overcome, such as conflicting usability requirements that may be different for different students taking the same course. One of the key features of the virtual university system is that both students and teachers are scattered across Pakistan and also use different procedural models of interactive systems. Therefore, great attention needs to be paid to prioritising usability attributes and coordinating trade-offs in such a cluttered environment. The proposed approach uses FAHP to rank the attributes according to their importance. In general, the better results of the proposed FAHP framework could be related to the claim that FAHP is suitable to deal with nonlinearities in the data. Its potential to account for the way variables interact along with imprecise, complicated features emphasises its value in predicting user preferences for a web system interface based on preferences regarding the attributes of a particular website. Furthermore, the results show that it is very important but difficult to achieve user satisfaction. Therefore, the old notion that these requirement attributes are only managed asymmetrically should be replaced by a newer strategy, such as the one we propose, that deals with this kind of complexity. It has been shown that the importance of some attributes and their influence on user acceptance is related to the performance of the application. More specifically, we can say that there are attributes that have a relative influence that is very different at high and low performance.

Regarding the specific usability attributes, it's found that the agreement of the group is indifferent in identifying users and experts during requirements elicitation and that it's worth reflecting on the importance of efficiency, reliability (no errors). Satisfaction, effectiveness and learnability are also of great importance and shouldn't be overlooked. Ease of use, speed of access, timeliness, accuracy and availability have a negative impact on satisfaction, while active control and detail have more or less the same impact on

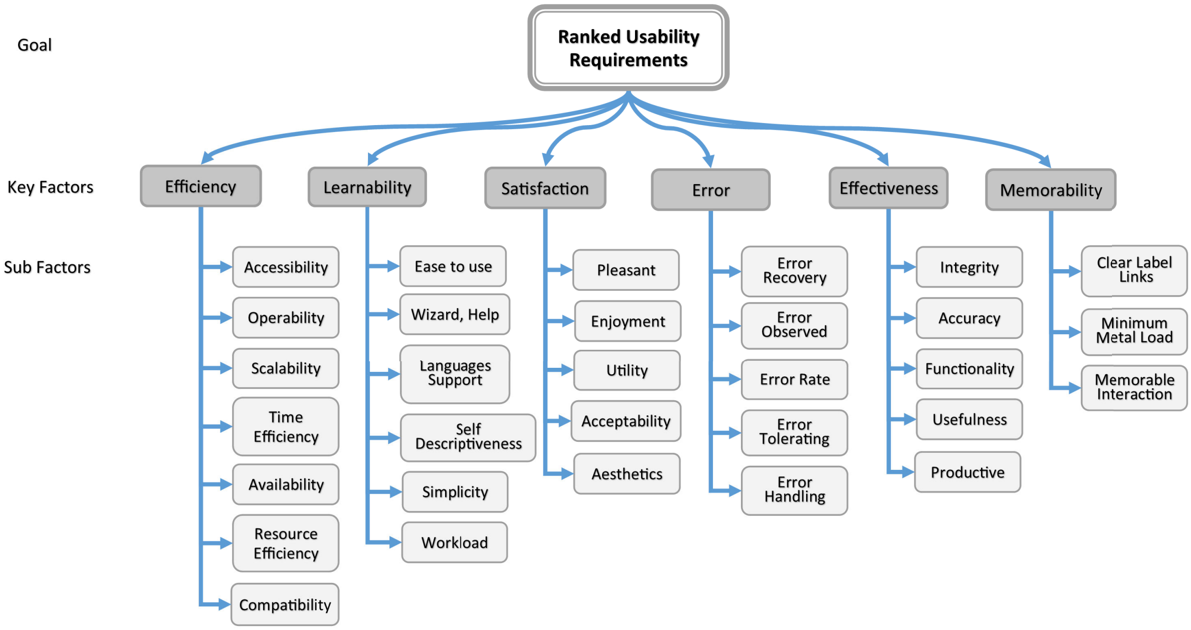

FIGURE 3. Analytical hierarchy structure for prioritization of URs for virtual university education system.

TABLE 7. Level 1 integrated fuzzy comparison matrix.

	Efficiency			Effectiveness			Error			Satisfaction			Memorability			Learnability		
Efficiency	1	1	1	0.7253	0.8748	1.0801	0.7490	0.9029	1.0718	1.5157	1.8228	2.0828	1.1644	1.4666	1.8294	0.7937	0.9368	1.1298
Effectiveness	0.6259	0.2431	0.3787	1	1	1	0.6330	0.5746	0.4727	0.5040	0.2457	0.5157	0.298	0.5640	0.4772	0.2360	0.4779	0.6413
Error	0.3330	0.0176	0.3351	0.2790	0.4513	0.0718	1	1	1	0.5337	0.0362	0.6703	0.7071	0.4737	0.1161	0.3343	0.4574	0.4294
Satisfaction	0.2801	0.286	0.2598	0.1598	0.0257	0.4500	0.1745	0.2911	0.2520	1	1	1	0.2515	0.3008	0.260	0.2359	0.3444	0.5123
Memorability	0.3466	0.3819	0.4588	0.4814	0.2394	0.5851	0.5960	o.4145	0.4142	0.1161	0.4269	0.5131	1	1	1	0.6520	0.7628	0.9066
Learnability	0.8851	1.0675	1.0599	0.8762	0.6226	0.7962	0.5466	0.6862	0.8816	1.2311	0.7518	0.8661	0.7031	06.3110	0.8337	1	1	1

TABLE 8. Composed fuzzy column matrix at level 1 for UFs.

	Sum of rows		
Efficiency	7.4136	8.9012	10.3885
Effectiveness	5.0672	5.9685	7.0828
Error	4.2440	4.9614	5.9220
Satisfaction	4.1951	4.8917	5.8518
Memorability	4.7774	5.6251	6.6416
Leranability	6.1619	7.3521	8.6588

TABLE 9. Composed fuzzy column matrix at level 1 for Key UFs.

	Sum of columns		
Efficiency	0.1664	0.2361	0.3261
Effectiveness	0.1138	0.1583	0.2223
Error	0.0953	0.1316	0.1859
Satisfaction	0.0942	0.1298	0.1837
Memorability	0.1072	0.1492	0.2085
Learnability	0.1383	0.1950	0.2718

TABLE 10. Normalization at level 1.

	Minimum Degree of Possibility	Normalization
Efficiency	1.000	0.3623
Effectiveness	0.418	0.1515
Error	0.157	0.0569
Satisfaction	0.140	0.0506
Memorability	0.0326	0.1181
Leranability	0.719	0.2607

performance, with increased interactivity reducing satisfaction. In summary, this study presents a model for evaluating the importance of usability features for the development of an e-learning system. It also provides a number of study hypotheses that could provide us with a deeper understanding of user satisfaction with online services. In the following section, the results obtained with our proposed approach are validated through a comparative analysis and a sensitivity analysis.

IV. DISCUSSION AND ANALYSIS

In this study, an attempt was made to facilitate the work of system users by identifying general user preferences based on usability characteristics. The degree of acceptance or rejection of a factor by the users was taken into account. The rated value of each factor encompasses usability as a whole and is relative to the perceived metrics. In this study, we looked at the key factors for achieving the desired level of usability and determined the importance of these factors through a series of questionnaires relevant

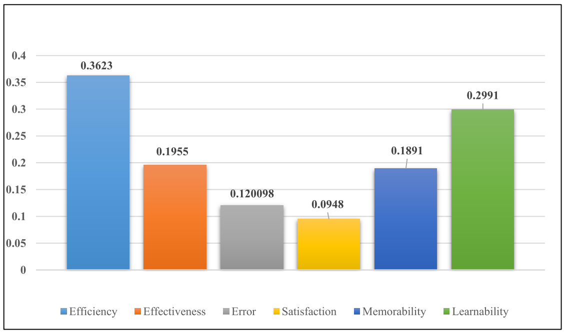

FIGURE 4. Final weights of the UFs regarding the usability of the VU.

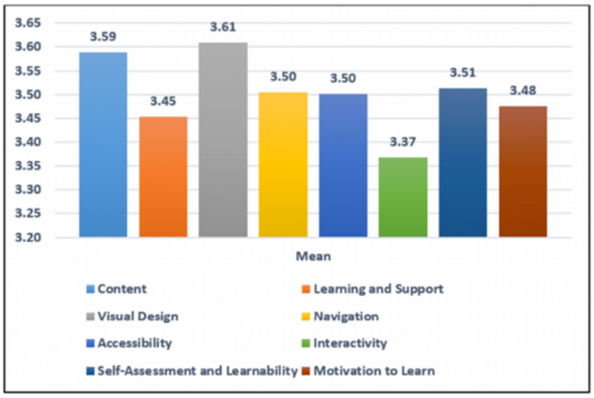

FIGURE 5. Values of eight usability criteria derived by Elmagzoub et. al., [65].

to specific usability factors. According to our findings, efficiency, learnability, effectiveness and memorability are the most important UFs that affect users' attitudes towards e-learning and have not received much attention in the past. This is consistent with the concerns listed in the research by Chiong and Jovanovic [61]. For example, the positive performance of usefulness, navigation and understandability had more persuasive power than their poor performance, while the low performance of accessibility, friendliness and reliability had a greater relative influence. These results are consistent with those from Lee and Cheung's [62]. In addition, privacy, security and interactivity always have a significant impact on satisfaction, both for positive and negative results. Interactivity has the greatest influence on overall satisfaction of all website features. However, it was found to lead to lower overall satisfaction when it exceeds the threshold of positive performance. This is in line with the findings of Sundar, Kalyanaraman and Brown [63]. They claimed that exceptionally high interactivity is not inherently beneficial.

In particular the most recent research work [64], the authors studied the student's continuance intention. They found the strongest positive effect of perceived usefulness on student' intention to continue e-learning. More surprisingly, their findings, contrary to much of the literature, show that satisfaction level had a non-significant effect on students' intentions and attitudes to continue with the LMS. This is in line with our study Figure 4.

In relation to the specific UFs, it was found that group agreement is indifferent when identifying users and experts during requirements elicitation and that it is worth reflecting on the importance of efficiency, learnability and reliability (no errors). Effectiveness and satisfaction are also of great importance and should not be overlooked. Ease of use, speed of access, timeliness, accuracy and availability have a negative impact on satisfaction, while active control and detail have more or less the same impact on performance, with increased interactivity reducing satisfaction. To summarize, the proposed model simulates to evaluate the importance of UFs in the requirements analysis phase during the system development life cycle. This is in line with [34] in which the authors referred to usability as a quality requirement that should be established in the early stages of system design. As a result, this study concludes that the analysis and analytical framework of UFs in particular help to improve the understanding of e-learning system usability issues and their acceptability. To ensure the validity of our findings, a comparative analysis is conducted with a recent study.

A. COMPARATIVE ANALYSIS OF THE PROPOSED APPROACH

In this section we are presenting a comparative analysis of the proposed study with relatively latest study done by Elmagzoub et. al., [65]. The results of our approach and Elmagzoub et. al.,'s approach are presented in graphical form in Figures 4 and 5, respectively. Elmagzoub et. al., worked to find students' perception about usability of the e-learning courses by considering the usability in term of eight criteria: Content, Learning and Support, Visual Design, Navigation, Accessibility, Interactivity, Self-Assessment & Learnability and Motivation to Learn. The study [65] has focused only eight criteria that are counted as sub-criteria of main UFs in our proposed research (see Figure 3). Whereas we worked with six main criteria and thirty one sub criteria. According to our proposed findings, efficiency is the most important UF and the authors of the work [65] concluded that accessibility is the second most important criterion for using e-learning systems. Analytically looking at our results, accessibility is a sub-criterion of efficiency. While navigation criteria defined in [65] also comes under controllability which is again a sub-criterion of efficiency in this study. So, if collectively assessed, the efficiency found in Elmgazoub's work would be top notch and consistent with our results.

Learnability is the second most important UF according to our perspective. Consequently, here again the analysis shows that Elmgazob's defined criteria of "Self-Assessment and Learnability" and "Learning Motivation" combined under our defined core criteria "Learnability" will rank second. The same case is with other factors mentioned in Figure 5. Furthermore, a tabular comparison highlighting the excellency of our proposed approach over Elmagzoub's approach is given in Table11.

TABLE 11. Comparative analysis of the proposed approach.

Evaluation criteria	Elmagzoub et. al., (2019)	Proposed approach
No. of criteria handled	8	29
Tolerant to uncertainty and ambiguities,	No	Yes
Handling large data sets.	No	Yes
Requirements to perform analysis	Far much rigid	Less rigid
Interpretability	No	Yes

This comparative analysis validates the applicability of the proposed approach as it covers more attributes with greater convenience and accuracy than other methods found in the literature. Furthermore, since the importance of UFs varies in each case, consistency of final decision is substantiated by sensitivity analysis in the next section.

B. SENSITIVITY ANALYSIS

Typically in MCDM problems, the data contain imprecise and changeable facts. Hence, in several applications, sensitivity analysis in MCDM is vital to confirm the consistency of ultimate decision. (and different scenarios can be visualized which are supportive to observe the impact of changing on criteria to final alternative rank [66]. Here too, sensitivity analysis is presented to strengthen the applicability of the proposed approach as the importance of UFs differs from person to person and area to area. With the help of it decision maker can perceive how the priorities of resulting factors would change Fig 6.

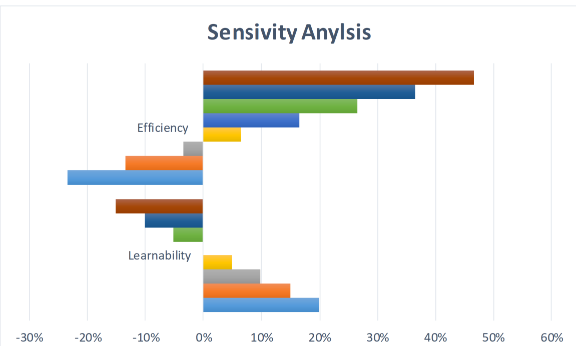

FIGURE 6. Sensitivity analysis results.

The results of the sensitivity analysis showed that the systematic change occurred with a change in a criterion that ultimately affected the outcome. A requirement analyst faces great difficulty in deciding on a particular criterion how important it is to consider or ignore. Uncertainty of background factors, causes problems in taking appropriate decision and following appropriate design strategies. In conclusion, measuring the extent to which a factor is important or weighted demonstrates the practicality of the proposed technique. Consequently, the UFs decision framework can be implemented and extended to other real-life web applications with necessary alignment according to different situations.

Finally, it is important to discuss the limitations of the study so that other researchers can apply the model to achieve better results. The study was conducted on board and via the internet, using data and requirements from students enrolled in the 2020 summer session. This may influence the results with other target groups (students). In the future, we will attempt to generate more comprehensive results and a detailed inventory of URs and attributes of URs with their relative importance by utilising a broader audience for specific information systems. A comparative study on the expectations of students of different ages from different geographical areas studying within the VU system can be conducted to show the differences in student interest. In addition, the web content such as page design, layout, visual effects and graphics are not addressed in depth. Of course, we will consider these aspects in the future as it is also extremely important to work on the web content to improve the overall user experience. In addition, we intend to expand our project to reach consensus on the requirements in the requirements analysis phase by applying the multi-criteria decision making techniques mentioned in [67] and [68] and involving more users consisting of more experts and stakeholders.

V. CONCLUSION AND FUTURE WORK

Determining the reflected understanding of system users with regard to the usability of any online system is not possible without a suitable technique. Methods and techniques are commonly used to evaluate the usability of online systems. However, they have some limitations, which have already been discussed. More importantly, the evaluation is carried out when the system is developed, installed and used. The proposed approach, on the other hand, is employed to determine the usability at the requirements analysis stage in order to develop a user-friendly VU system with minimal usability issues. This research was conducted to determine and measure the weights of the UFs to confirm the most important URs with individual factor values for a more acceptable VU setup. The FAHP technique presented in this study was applied to URs in the requirements analysis phase to weight and rank the associated UFs. Among the compelling advantages of ranking UFs is that it enables the software developer to develop a suitable software architecture by focusing on URs with greater weight without wasting time and within budget constraints. This saves a lot of effort, time and cost in the system development phase. For this reason, this study is an important contribution to the development of an efficient and effective VU system with appropriate usability. It is also helpful in resolving conflicts in later stages of system development when URs are classified in earlier stages of system development. Our focus is on usability, which we find problematic in most e-learning systems. The other web content such as layout, graphics, page design and the information presented on the pages must also be considered. Of course, it is also extremely important to work on the web content to improve the overall user experience. In the future, we will address all the key aspects that have the greatest impact on users' ability to use the virtual university system. Based on this, it will be quite easy to understand and manage the differences in designing an online education system.

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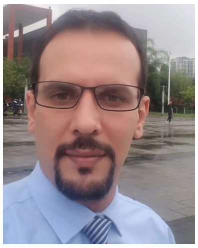

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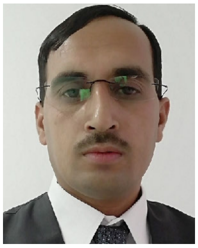

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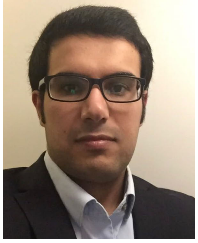

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