ABSTRACT
There has been an enormous increase in the use of mobile learning (M-Learning) systems in many fields due to the tremendous advancement in information and communication technologies (ICTs). Although, there are many frameworks that have been developed for identifying and categorizing the different components of M-Learning systems, most of them have some limitations, drawbacks, and no support for evaluating the success factors (global weights) of the system criteria. In this paper, a comprehensive hierarchical framework is developed for identifying and categorizing all components that may affect the development and deployments of cost-effective M-Learning. Furthermore, due to the hierarchical structure of the framework, analytic hierarchy process (AHP) techniques can be used to quantitatively estimate the success factors of the system criteria. In order to demonstrate the benefits and flexibility of the framework, the success factors of the different system criteria are evaluated for different sets of preferences using an interactive software tool, namely, SFacts, which is developed for calculating the success factors of the criteria of any hierarchical framework.

Categories and Subject Descriptors
k.3.1 [Computing Milieux]: Computer Uses in Education, Mobile Learning.

General Terms
Measurement, Performance, Design.

Keywords
M-Learning; success factors; analytic hierarchy process (AHP); fuzzy AHP; fuzzy extended analysis (FEA).

1. INTRODUCTION
Electronic learning (E-Learning) is broadly defined as learning through electronic devices (e.g., desktop/laptop computers, smart phones, CD/DVD players, … etc.), which was first emerged in the late 80s as a contender to classical face-to-face learning [1, 2]. It is also referred to as distance learning (D-Learning) [3]. In the 90s, a new form of learning was emerged, namely, the mobile learning (M-Learning). It emerges mainly due to the impressive development in computer and communication technologies, which led to the production of powerful mobile devices; the expansion of wireless communications, the tremendous advancement in Internet protocols; the affordability of mobile devices; and the demands for continuous business and social communications [4-7].

M-Learning is generally defined as learning through relatively small-size, low-power, and low weight devices, which can accompany users anytime/anywhere; e.g., laptops, notebooks, mobile phones, smart phones, personal digital assistants (PDAs), Tablet PCs, e-Books, palmtops, and any other mobile microprocessor-based information technology devices that may be use in learning [2, 6]. The main elements of M-Learning are mobile technologies, mobile devices, wireless protocols, wireless language, and wireless applications. They all together allow mobile application to be developed [8]. These elements can be categorized into hardware and software components as shown in Figure 1.

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Many frameworks have been developed during the last two decades to help with identifying and categorizing the components of M-Learning, such as the framework for the rational analysis of mobile education (FRAME) [3], the Helsinki university of technology model [10], the conceptual framework for M-Learning design requirements model [11]. Most of these frameworks have their limitations and they do not support quantiative or numerical evaluation of the success factors of their components. They can only evaluate the success factors through distributed questionnaire that includes a certain set of questions asked to the system users. Such type of evaluation is not enough to enable the system stakeholders (researchers, developers, and managers) to identify the critical success factors; neither provides the impact of the variation in these factors.

This paper presents a comprehensive hierarchical framework for identifying and categorizing all components that may affect the development and deployments of cost-effective M-Learning. Three distinct levels are considered in this framework, the first one includes the main system criteria, and these are: mobile devices, quality, and learners’ requirements constraints. Each of them is subsequently accommodate a number of sub-criteria denoted as level two criteria, and each sub-criterion is further alienated into sub-sub-criteria (level three criteria), except the learners’ requirements constraints, which is concluded at level two.

Due to the hierarchical structure of the framework, the analytic hierarchy process (AHP) based techniques (such as: the conventional AHP, fuzzy AHP (FAHP), fuzzy extend analysis (FEA), and α-cut-based) can be used to quantitatively evaluate the success factors of the system components. The detail derivation and implementation of these techniques in an interactive and user-friendly software package, SFactors, are given in [1], which is used to demonstrate the benefits of the framework, and evaluate the success factors (global weights) of the M-Learning criteria for different sets of preferences (relative importance).

Based on previous studies in [12, 13], it is believed that the main criteria that must be considered in designing and implementing a successful M-Learning are:

1. Mobile device constraints.
2. Quality of services and applications.
3. Learners’ requirements.

This section introduces the main theme of this paper. The rest of this paper is organized as follows: The proposed model is described in Section 2. Section 3 provides a brief introduction to SFactors. Evaluation procedure, results, and discussions are presented in Section 4. Finally, in Section 5, based on the results obtained, conclusions are drawn and recommendations for future work are pointed-out.

2. THE FRAMEWORK

This section presents the detail description of a framework for M-Learning. It can be easily recognized that there are a number of criteria (components, requirements, and constraints) that may constraint the design of a successful M-Learning. In developing this framework, first, all criteria that influence the efficiency and performance of the system are identified. Second, each group of criteria is related to a certain representative category. Finally, the categories are structured in a hierarchical framework as shown in Figure 2.

![Figure 2. Standard hierarchical framework.](image)

The proposed framework can be explained as follows:

1. The overall goal or objective, which is declared as M-Learning system, is laid at the first (highest) level of the hierarchy.
2. The main criteria that may constraint the design and performance of the system and consequently affect its success factors gathered at the second level.
3. The sub-criteria for each of the second level criteria are collected at the next level and so on for sub-sub-criteria.
4. The lowest level contains the candidate alternatives.

Therefore, in the proposed framework, these criteria are laid at the second level in the system hierarchy as shown in Figures 3 to 6. In what follows, a description is given for each of the above criteria.
1. **Software constraints.** Software can be decomposed into three different types: operating system (OS), development environment, and applications. From user point of view the most important software constraint is the application, which, in turns can be decomposed into user interface and pedagogical materials. In this framework, the software constraints are considered as a combination of the two points of views, these are: (i) standardized OS, and (ii) user-friendly interface.

2. **Hardware constraints.** Mobile device hardware constraints can be decomposed into: (i) small screen, (ii) small multifunction keypads, (iii) limited computational power, (iv) limited memory, (v) limited battery lifetime, (vi) non volatile capacity, (vii) display resolution, (viii) graphical limitation, and (ix) complicated text input mechanisms.

3. **Network constraints.** Network constraints can be decomposed into: (i) limited bandwidth, (ii) low connection stability, (iii) limited security, (iv) converge, (v) interference, (vi) high delay, (vii) frequent disconnection, and (viii) roaming capabilities.

### 2.2 Quality of Services and Applications

The quality constraints can also be discussed from three points of views. These are: hardware, software, and network qualities. In the context of software/hardware engineering, although there are several different definitions for quality, the definition stated by the ISO 9126 standard is the most appropriate, in which it measures how well software/hardware is designed (quality-of-design), and how well the software/hardware conforms to that design (quality of conformance). Whereas quality of conformance is concerned with implementation, quality of design measures how valid the design and requirements are in creating a worthwhile product. Quality in the ISO 9126 standard concerns with: usability, functionality, system reliability, efficiency, maintainability, and portability. Each of these sub-criteria is also disintegrated into a number of sub-sub-criteria as shown in Figure 5.

1. **Usability.** The system must be implemented in such a way to allow easy understanding of its functioning and behavior. The usability decomposed into six sub-criteria, (i) understandability, (ii) learnability, (iii) friendliness, (iv) operability, (v) playfulness, and (vi) ethics.

2. **Functionality.** The system must include all the necessary features to accomplish the required task. Functionality can be decomposed into a number of sub-criteria, these include: (i) accuracy, (ii) suitability, (iii) compliance, (iv) interoperability, and (v) privacy.

3. **Reliability.** The system must maintain a specified level of performance in case of software faults with the minimum crashes possible. Sensitive data should be protected and correctly recovered. Reliability can be decomposed into a number of sub-criteria, these include: (i) fault tolerance, (ii) crash frequency, (iii) recoverability, (iv) maturity, and (v) security.

4. **Efficiency.** System response-time must be fast enough to satisfy user needs. Long waiting times result in reduced user interest, de-motivation and boredom leading to unwillingness to use the system. The system should be adaptable to different mobile devices and technologies. Fast access to information must be examined throughout the system’s life to ensure user requirements are continuously met, and the application remains useful.

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**Figure 3.** The main criteria of proposed M-Learning framework.

**Figure 4.** The components of the mobile device constrains.

### 2.1 Mobile device constraints

Mobile devices interact with services offered by learning platforms through specially developed applications, the interaction between mobile learners and service providers is accomplished through different mobile devices and wireless networks. Thus, the mobile device constraints are decomposed into three sub-criteria, namely, software, hardware, and network Figure 4. A brief description is given for each sub-criterion and their sub-sub-criteria.
4. Efficiency can be decomposed into a number of sub-criteria, these are: (i) response time, (ii) different vendor, (iii) quality, (iv) network speed, and (v) bandwidth.

5. Maintainability. Due to rapid technological changes maintainability is so important factors, especially in the area of Internet and mobile engineering, the demanding requirements for continuously updated material, and for easy system modifications and enhancements. It can be decomposed into four sub criteria: (i) changeability, (ii) serviceability, (iii) reparability, and (iv) testability.

6. Portability. Portability is defined as the ability of the mobile application to be installed and run by any mobile device as well as to be adaptive to different specified environments. It can be decomposed into: (i) different environment, and (ii) different mobile.

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2.3 Learners’ Requirements

The individual communication and interaction among instructors and users is very important and can be easily created in real application where face-to-face communication exists. The sharing of information, experiences and views forms an indispensable part of the learning process and is very effective in disseminating knowledge and establishing a community of learners. Learners should be able to maintain their individuality and differentiation while participating in the online mobile community, thus allowing them to express their personal preferences and abilities, as well as motivating and inspiring them. As shown in Figure 6, learners’ requirements can be decomposed into:

1. Identification of learners’ needs. M-Learning should be shaped according to the predefined learners’ needs and course required pedagogical outcome. The learners’ needs vary depending on socio-cultural background, education level, skills and competences acquired from previous education and training.

2. Structuring of the pedagogical material. Pedagogical material should be constructed to facilitate the successful transfer of the required knowledge. Customization of the material according to its recipients increases and retains user interest and reinforces knowledge transfer.

3. Enhancement of the M-Learning environment. The M-Learning environment can be used either complimentary or in parallel to the E-Learning environment. In either case, the M-Learning environment should adhere to the basic mechanisms and functions of the real environment.

4. Motivation for learner participation. Learners are not always willing to use the virtual environment for a number of reasons, such as the difficulty of using the mobile device, the non-intuitive nature of the environment, the provision of reduced interactivity, the language understanding level of the learner, …, etc.

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Figure 5. The components of the quality constraints.

Figure 6. The components of the learner’s requirements constraints.
5. **Tutorials.** M-Learning should be able to offer the learners a basic problem solving mechanism; such as on-line tutorials, contact with the instructor, references, resources materials’, and even access to a technical helpdesk would offer learners support and help.

6. **Collaborative mechanisms.** In the virtual environment, the learners can be easily isolated and separated from the rest of the class. This can be prevented in the real classroom by using face-to-face communication. In the virtual classroom, student isolation can be avoided, by organizing and operating in an online collaborative basis, with the establishment of learners groups and the use of collaborative work. In this manner, the learners are encouraged to participate and communicate through the electronic environment.

7. **Supporting tools.** Vocational training requires different solutions than academic training and undergraduate training. Tools and components can be utilized to enhance M-Learning more efficiently.

8. **Combination of learning processes.** The most important learning processes are identified as follows: analysis, synthesis, reasoning, judging, problem solving, collaboration, simulation, evaluation, presentation and relation. These processes should be used dynamically for constructing the learning scene for each course/student.

3. **THE SUCCESS FACTORS**

   **CALCULATION TOOL (SFacts)**

   SFacts is an interactive software package (tool) that is developed to quantitatively evaluate the success factors of M-Learning. SFacts utilizes four evaluation AHP-based techniques, these are: the AHP, FAHP, FEA, and α-cut-based techniques. The detail description and implementation of these techniques can be found in [1]. The tool is developed using.Net technology. It can be used by decision makers to estimate the success factors of their systems and investigate the effect of the criteria that may affect developing a successful M-Learning system. The main features of SFacts include:

   1. Has a user-friendly graphical user interface (GUI).
   2. Developed using an object-oriented approach so that it can be easily modified to incorporate new evaluation techniques or factors.
   3. Quantitatively evaluate the success factors of any hierarchy structured process using AHP techniques.
   4. Include enough help to enable users to make the right choices.

5. Demand little resource in terms of speed and memory.
6. Enter new project or retrieve an existing one.
7. Select the evaluation technique (AHP, FAHP, FEA)
8. Enter the number of criteria at each level (up to 99 criteria at the main (second) level).
9. Enter the name of each criterion (sub-criterion, sub-sub-criterion, and so on) and select value for its relative importance from drop down menu.
10. Proceed to calculation to estimate the global weight for each criterion and rank the criteria accordingly from the one with the highest weight to the one with the lowest, i.e., from the most important to the least important.
11. All input and computed parameters are stored in a database using Microsoft Access format and can be retrieved for further processing any time later.

4. **RESULTS AND DISCUSSIONS**

   In order to demonstrate the flexibility of the proposed comprehensive M-Learning framework and the effectiveness of SFacts in evaluating the critical success factors of M-Learning, we set a scenario for evaluating the success factors of system main criteria (C1, C2, C3) for three sets of preferences (relative importance). The main objectives of this scenario are investigating the effects of the actual relative importance of each criterion on the global weights (ranking), and comparing the estimated global weights using different AHP-based techniques (AHP, FAHP, and FEA).

   The relative importances of the three criteria are summarized as follows:

   1. Case #1: C1 has a strong importance relative to C2 and moderate importance relative to C3.
   2. Case #2: C1 has a very strong importance relative to C2 and moderate importance relative to C3.
   3. Case #3: C1 has an extreme importance relative to C2 and moderate importance relative to C3.

   The numerical values of the elements of the pairwise comparison matrix vary according to the evaluation technique. The pairwise comparison matrices of C1, C2, and C3 for the above cases for the AHP, FAHP, and FEA techniques are given in Table 1.

   Following the construction of the pairwise comparison matrices, SFacts was used to compute the relative weights of the main criteria using each of the three AHP-based techniques. The computed weights are listed in Table 2.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Case #1</th>
<th>Case #2</th>
<th>Case #3</th>
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<tbody>
<tr>
<td>C1</td>
<td>1</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>C2</td>
<td>1/5</td>
<td>1</td>
<td>1/3</td>
</tr>
<tr>
<td>C3</td>
<td>1/3</td>
<td>3</td>
<td>1</td>
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<th>Fuzzified pairwise comparison matrices for the FAHP technique (Cases #1 to #3)</th>
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<td>C1</td>
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<th>Fuzzified pairwise comparison matrices for the FEA technique (Cases #1 to #3)</th>
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<td>C1</td>
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<td>C2</td>
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<td>C3</td>
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The main outcomes of this scenario are discussed below. All the techniques showed that as the importance of C1 is increasing from strong importance to extreme importance, its individual weight increases relative to the other two criteria, which comes in line with the common sense of the decision maker. Furthermore, this increase is not only paid by one of the other criteria, but it is shared between them; despite the fact that the relative importance of C1 to C3 was remained unchanged. But in microscopic level analysis of the relative importance of the three criteria, C3 is positively changed relative to C2. This can be explained in this way: C3 keeps the same importance relative C1, which is increase relative to C2, means the relative importance of C3 to C2 should increase.

Decision makers usually based their decisions on the differences between the computed weights. As these differences increase more decisive and comfortable decisions can be taken. For this scenario, a better decision can be taken using FEA, then the AHP. For FAHP, due to the way of constructing the fuzzified pairwise comparison matrices, where non-optimistic preferences for the importance were chosen, the computed weights have little differences between them (e.g., for Case #1, the weights for C1, C2, C3 are 0.3750, 0.1857, and 0.3158, respectively). Thus, difficult decision needs to be taken. The whole picture is changed when the fuzzified pairwise comparison matrices were constructed with optimistic preferences for the FEA techniques.

5. CONCLUSIONS

This paper presented a detail description of a new and comprehensive hierarchical framework that considered and categorized all criteria affecting the development and deployments of cost-effective M-Learning. The framework is so simple and straightforward as it can be easily used to add or remove any criteria that may affect system performance. Using the AHP-based evaluation tool (SFacts), the global weights for the system criteria can be estimated and ranked from the one with the highest weight (most important) to the one with the lowest (least important). This in fact what decision makers is looking for, so they can based their decisions on and make their planning according to the weight and importance of the criterion. Ranking the system criteria is so important, because the estimated global weight can only give a limited indication on the actual importance of the criterion, and it will be more helpful if it is compared against the weights of other criteria.

This paper considers the analysis of the main level criteria, it is highly recommended to perform further investigations to analyze the performance of M-Learning considering various sets of preference to the system low level criteria.

6. REFERENCES


| Table 2. Comparing the computed weights for Cases #1 to #3 using the AHP, FAHP, and FEA techniques. |
|---|---|---|---|---|---|---|---|
| Criteria | AHP | FAHP | FEA | AHP | FAHP | FEA | AHP | FAHP | FEA |
| C1 | 0.6333 | 0.3750 | 0.5734 | 0.6687 | 0.4286 | 0.6724 | 0.6923 | 0.5217 | 0.7582 |
| C2 | 0.1062 | 0.2857 | 0.0512 | 0.0882 | 0.2500 | 0.0000 | 0.0769 | 0.1538 | 0.0000 |
| C3 | 0.2605 | 0.3158 | 0.3754 | 0.2431 | 0.3158 | 0.3276 | 0.2308 | 0.3158 | 0.2418 |
| Total weight | 1.000 | 0.9765 | 1.000 | 1.000 | 0.9844 | 1.000 | 1.0000 | 0.9913 | 1.0000 |
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