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Design Strategies for Mobile Language Learning Effectiveness using Hybrid MCDM Approach

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Abstract

Generally, proposing an evaluation model is of most interest to those with a research focus in information systems. In fact, the design of information systems requires the application of designated evaluation models for identifying effective design strategies rather than predicting the design's effectiveness.. Information system success model is the latest evaluation model which implicitly reflects the evaluation criteria for configuring the design of mobile learning application. Using two mobile learning applications as examples, this study aims to extend the evaluation model by proposing a design evaluation framework for mobile learning applications and evaluating the design of two mobile learning applications by applying designated criteria. Employing the novel hybrid multi-criteria decision making which combining Decision Making Trial and Evaluation Laboratory Model (DEMATEL) and the Analytical Network Process (ANP), this research demonstrates the structure of mobile learning application in term of relationship among attributes as well as examines the value that learners' perceive with regard to designated mobile learning application. Based on this purpose, this research would contribute to discover the grammatical structure of mobile computing for learning. Accordingly, the designer could apply the structural representation as guidance in strategic design of information system.

Keywords: mobile learning application design, decision making trial and evaluation laboratory (DEMATEL), analytic network process (ANP), design structure

1. Introduction

Mobile learning applications is an emerging technology which supports language learning using operating systems such as Apple's OS and Android. In the burgeoning field of mobile communication and computing, application designers should understand strategic design information systems in order to be innovative in the field of mobile learning, particularly in the language learning domain (Godwin-Jones, 2011). Consequently, designers need to understand both behavioural paradigms and design paradigms in information systems, including the interrelationship among attributes (Hevner, March, Park, & Ram, 2004). Moreover, the essence of behavioural paradigms of information systems should be linked in a system that provides feedback on the design paradigm concerning the usefulness and ease of use of the system (Wixom & Todd, 2005). Currently, numerous labels are used to illustrate the application of information technology in learning context, for examples: computer mediated communication, learning management system, blended e-learning system, virtual learning environment, e-learning, technology mediated learning, technology assisted learning, and hypermedia learning environments. The main point of these titles is to make explicit that the design of information technology is composed of related functions, for example: learning interactions system, learning material storage system, communication system, information accessible system, etc. It is obvious that the labels are still associated with fixed rather than mobile information systems. Replicating the definition of information technology proposed by Alavi and Leidner (Alavi & Leidner, 2001), this research defines the mobile learning application as transportable information system to facilitate learning activities in term of information analysis, learning interaction, and learning material management.

In order to design effective mobile learning application, (Pentland, 2013) recommend to employ grammatical perspective as an alternative approach in information system research. This recommendation is align with the complexity in conceptualizing the "IT artifact" in information system research (Orlikowski & Iacono, 2008). Adoption of grammar concept in designing of information system, enable designer to create successful design of information system due to role of grammar in linguistic domain. According to the Linguistic discipline, the grammatical helps to clarify the precision of the sentences. Moreover, appropriate application of grammar pattern would enable reader to understand the designated holistic meaning of the paragraphs. In this sense, grammar is significantly strengthening the meaning of the sentences via the structures or how the writers connecting and structuring the word in the sentences.

Four central ideas led to this research. Firstly, the conceptual dimension of the design of web-based virtual learning environments (WBVLE) have been proposed for learning effectiveness, such as learning model, technology, learner control, content, and interaction (Picolli, Ahmad, & Ives, 2001). Explicitly, the design dimensions correspond with the design attributes designated in information system (IS) success model (DeLone & McLean, 2003) information quality, system quality, and service quality. In this setting, it is conceivable that the design dimension proposed by Picolli, Ahmad, and Ives is related to the model of DeLone and McLean. Thus, the design criteria of mobile learning applications also ensure the successful implementation of mobile learning applications. Secondly, one of the general tasks of language educators is to assess the potential of IT to improve the human learning environment (Cummins, 2000). This reflects the need of design evaluation in information systems where "the utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods" (Hevner et al., 2004). Thirdly, most of the research in information has been focused on evaluating models (Hevner et al., 2004) rather than evaluating the design. We argue that implementation of an evaluation model should not merely satisfy the focus of management of information system but also solve problems in the successful design of an information system. Fourthly, strategy in design of information system is associate with the role of grammar particularly in identification the criteria and interconnection among criteria. Thus, the identification of this structure would create benefit where Lee, Wyner, and Pentland (2008) put "define a potentially infinite set of possibilities with a finite representation" (as cited in Pentland, 2013, p. 9). Pentland argue that the application of grammatical approach in information system research should consider two following constraints: (1) "grammar is generally prescriptive" (p. 9); (2) grammar is discovered, not designed" (p. 9).

As mobile computing continues to emerge worldwide, educators need to develop optimal mobile learning applications. Optimally designed mobile learning software would assure effective knowledge delivery. Using the Chinese learning application as an example, this study aims for examining the major motivators of learner value on the design mobile learning application and evaluates the value that learners' perceive with regard to designated mobile learning application. Interest with the applicability of grammatical science in information system, this study also aims for structuring the related attributed in the design of mobile learning application.

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Due to concerns regarding the motivation issues mentioned above, it is hoped that the results of this study will contribute to supporting the work of designers of mobile learning apps in formulating their design strategies for mobile learning applications and managing their strategies based on identified related design dimensions. The implications of this research concern the configuration of the design of learning technology for learning theoretically and to enlighten the designers of learning technology regarding the design direction and innovation trends they may follow in the future. Respect to the utilization of novel hybrid multi-criteria decision making combining DEMATEL and ANP, the result of this research also contributes to the illustration of the design structure of mobile learning application particularly for Chinese language learning. This structure could be the blueprint in developing effective mobile learning application in Mandarin Chinese learning domain.

2. Information System (IS) Success Model

The IS success model involves two components – quality and user satisfaction. The overall quality is determined by three essential attributes: system quality, information quality, and service quality. This success model was originally developed based on communication theory (Shannon & Weaver, 1949) and information influence theory (Mason, 1978) which can be characterized on three levels: the technical level, semantic level, and effectiveness level. DeLone and McLean's model (DeLone & McLean, 2003) postulates that system quality measures the effectiveness level, information quality measures the semantic level, then user satisfaction, individual impact, and organizational impact [I suggest separating these three and using commas. It is rather confusing the way you have them joined with a dash now] measures the effectiveness level. However, this original IS model's success needs to be extended due to the important role of service quality in measuring the effectiveness of IS (Kettinger & Lee, 1995; Pitt, Watson, & Kavan, 1995; Wilkin & Hewitt, 1999). As previously characterized, the values relevant to the benefits are generated by the operationalization of IS, thus, it is worthwhile to adopt the three qualities as a basis for developing design criteria for mobile learning applications.

The information system success model (DeLone & McLean, 2003) also indicates the difference in the success measurements for different application contexts. DeLone and McLean strongly recommended the reason for the early development of IS success model through following statement: "no single variable is intrinsically better than another, so the choice of success variables is often a function of the objective of the study, the organizational context …" (DeLone & McLean, 1992, p. 80). This implies that different objectives for the information system application prompt different criteria evaluation. Rather than finding the best criteria, it is worthwhile to identify the existing relationship among criteria in the design decision making process.

2. Establishment of Criteria for Designing Mobile Learning Applications

In order to identify the criteria and sub criteria when designing learning apps for language learning, the iteration qualitative approach is used within the literature, academics in the information systems field, and experienced language learning apps, particularly in Chinese language learning. Content analysis has been adopted to design the criteria and sub-criteria. Following this, the literature investigation and interviews with those respondents concretely established five criteria and sixteen sub-criteria, as illustrated in Figure 1. Three key examples of the literature related to the design of information systems are also involved as the theoretical basis:: IS success model (DeLone & McLean, 2003) human-computer interaction (Gerlach & Kuo, 1991), and design of web-based virtual learning environment (Picolli et al., 2001). In addition to the literature investigation, academicians in information system and e-learning domain are also invited to translate and apply those theoretical models to be criteria and sub-criteria for evaluating the optimal design of mobile learning application for Mandarin Chinese learning. Detailed explanations of each criteria and sub-criteria are given in Table 1.

2.1 Computer Hardware and Software (D_1)

Hardware and software performs the operations of information systems when managing hardware resources and supporting programs. For example, the role of central processing unit (CPU) for information processing, and operating system (such as Apple's OS and Google's Android). Perceived IS performance significantly determines user satisfaction (Au, Ngai, & Cheng, 2008; Suh, Kim, & Lee, 1994). Subsequently, computer hardware and software concretely characterizes the system quality of an information system, which refers to desirable characteristics of an information system and may be assessed via ease of use, system reliability, system feature intuitiveness, and response times (DeLone & McLean, 1992). In this context, the experts agree that the design of hardware and software for mobile learning applications can be evaluated by the following sub-criteria: stability, speed, aesthetic visualization, and system integration.

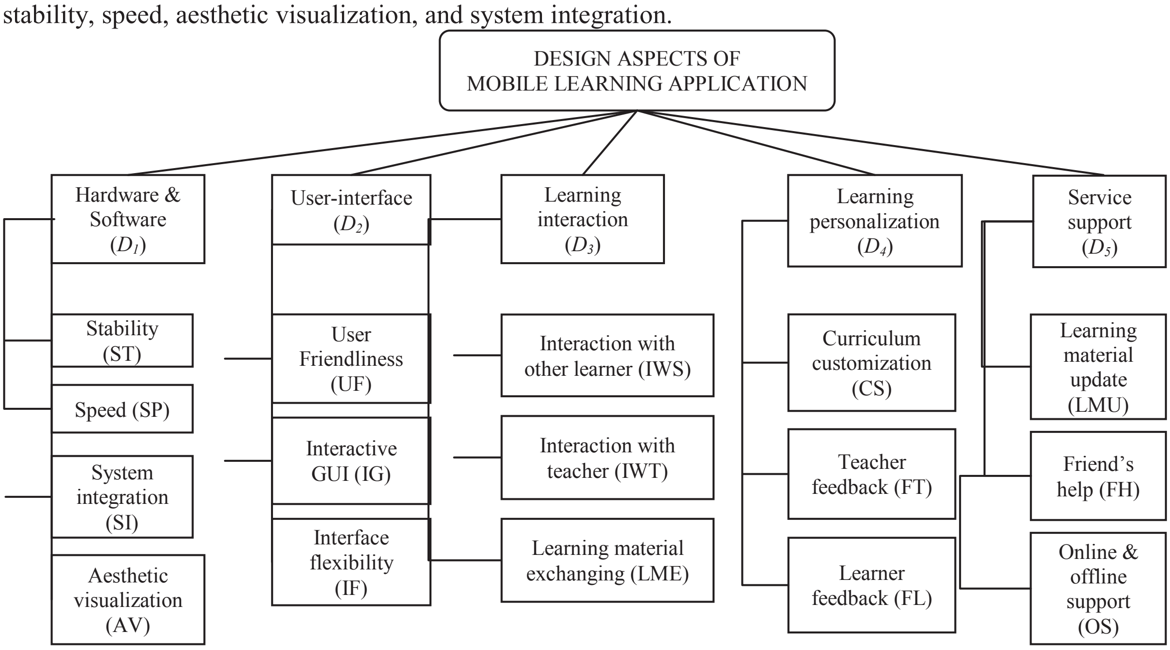

Figure 1. MCDM Framework to Evaluate the Design of Language Learning Applications

2.2 User Interface (D_2)

The designs of information systems include the user interface for mediating human-computer interactions. The interface system is arranged by a set of instruments to support system operability. Specifically, the interface system is managed by action and presentation language where the accurate selection of interface system determines system usability (Gerlach & Kuo, 1991). Unambiguously, the usability of the interface should provide an enjoyable user experience (Preece, Rogers, & Sharp, 2002). Thus, it is recommended that the design of an information system should include human-computer interaction aspects besides learning interaction aspects

(Hillman, Willis, & Gunawardena, 1994). Prior research has confirmed the significance of the interactive aspect in learning for encouraging learning satisfaction and effectiveness (Ozkan & Koseler, 2009; Shee & Wang, 2008). However, it needs to be pointed out that the interactive features should be integrated with information quality and service quality to accomplish learning effectiveness (Wang & Liao, 2008). In this context, the experts agree that the design of a user interface can be evaluated by following sub-criteria: user friendliness, interactive graphical user interface (GUI), and interface flexibility.

2.3 Learning interaction (D_3)

Beside the two design related criteria mentioned above, the effectiveness of WBVLE requires learning interactions which with appropriate mobile learning apps (Picolli et al., 2001). Three types of learning interactions have been identified in the learning environment – student-student interaction, student-teacher interaction, and student-learning materials interaction (Hillman et al., 1994; Moore, 1989; Moore & Kearsley, 1996). The active participation of learning participation and contribution are the key strategies for optimizing learning effectiveness in an e-learning environment (Romiszowski & Mason, 1996) as well as affecting learner knowledge advancement (Ritchie & Hoffman, 1997). Prior studies also agree that regular interaction among learning participants facilitates the learning experience (Garrison, 1990). However, there is concern that high levels of interaction may potentially lead to negative aspects of the communication effect in the form of feelings of isolation, anxiety, and confusion (Picolli et al., 2001). Consequently, learning interaction should be accommodated in the design of mobile learning applications to overcome those negative effects. Thus, in order to evaluate the design of learning interactions, the experts agree in the value of adopting the following sub-criteria: interaction with other learners, interaction with teachers, and learning material exchange.

2.4 Learning personalization (D_4)

The competitive advantage of information systems enables learning flexibility where learners can personalize or manage the learning phase (Picolli et al., 2001). This allows learners to manage their own learning sequence (Williams, 1996). Prior research has provided strong evidence regarding the impact of learning personalization on learning performance improvement (Merrill, 1994). Numerous theories have been applied in this study, such as: motivation theory (Keller, 1983), attribution theory (Martin & Briggs, 1986), and information processing theory (Gagné, 1985). Accordingly, experts agree that users can evaluate the design of learning personalization by following sub-criteria: curriculum customization, teacher feedback, and learner feedback.

2.5 Service support (D_5)

The successful implementation of information systems is supported by qualified service quality (DeLone & McLean, 2003). The inclusion of service quality as an IS success model instrument is due to its potential for improving the accuracy of the success of information systems when used as pedagogical tools (Pitt et al., 1995). In the learning context, service support can be demonstrated through the following attributes: course/instruction authorization, course management, budgeting institutional funding, and resources for delivering and maintenance (Ozkan & Koseler, 2009). Interestingly, this study also recognizes friend's effects as associated with service quality. This is the effect toward the user caused by recommendation of user's friend to utilize the system. Thus, the experts agree that the design of service support can be evaluated through the following sub-criteria: learning material update, friend's help, including online and offline support.

3. Research Methodology

After carefully considering the interrelationships among the various criteria, this study has applied two complementary types of multi attribute decision making. Firstly, DEMATEL serves the identification of relationship among criteria. Secondly, ANP performs weight analysis for each criterion according to established relationships using the DEMATEL approach. The detailed procedures are demonstrated in following sub-sections.

3.1 Decision-Making Trials and Evaluation Laboratory (DEMATEL)

DEMATEL was originally invented by the Geneva Research Centre of the Battelle Memorial Institute for solving complicated relationships among attributes which naturally occur in the real world (Fontela & Gabus, 1974, 1976; Gabus & Fontela, 1973). Scholars consider that the methodology enables the verification of interdependency among criteria according to characteristics of objective affairs (Wei, Huang, Tzeng, & Wu, 2010). They argue that the technique provides an advantage over other methods when visualizing the structure of complex causal relationships through matrices and digraphs. Additionally, the DEMATEL technique has been applied in a variety of domains, including airline safety, decision-making, knowledge management, operations research, project management, business policy, agriculture, consumer behavior, theory validation, and other disciplines. The procedures of DEMATEL and ANP (Ou Yang, Shieh, Leu, & Tzeng, 2008) are summarized in the following section.

Step 1: Generation of an average matrix. For evaluating the direct relationship among sub-criteria experts examined the scale of relationship intensity where the scale presents scores ranging from 0 to 4 ("0" represents "no influence" and "4" represents "very high influence"). Accordingly, each respondent provides a single matrix and by averaging all single matrices the initial average matrix A is produced, as illustrated in Figure 2. The objective of DEMATEL is to obtain a total-influence matrix to demonstrate the direct/indirect relationship among criteria in the form of an impact relationship map.

$$\begin{bmatrix} 0 & a_{12} & \cdots & a_{1n} \\ a_{21} & 0 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 0 \end{bmatrix}$$

Figure 2. Initial Average Matrix

Step 2: Generating initial influence matrix. Initial influence matrix X is obtained by normalizing the A matrix by obtaining Equation (1) and (2).

$$\boldsymbol{X} = \boldsymbol{s} \cdot \boldsymbol{A} \quad (1)$$

$$s = max\left[\frac{1}{max_{1\le i\le n}\sum_{j=1}^{n} a_{ij}}, \frac{1}{max_{1\le i\le n}\sum_{i=1}^{n} a_{ij}}\right] \quad (2)$$

Step 3: Generating the total influence matrix. The total influence matrix, or full direct/indirect influence matrix, illustrates the degree of direct/indirect relationship among dimensions. It is generated by operating equation (3) where $(I - X)(I - X) - 1 = I$. Then, the sum of each row (r) and column (c) of matrix T is calculated using equations (4) and (5). The total-influence matrix T is illustrated in Figure 3.

$$T = X\,(I - X)^{-1} \quad (3)$$

$$r = (r_i)_{n\times 1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1} \quad (4)$$

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

$$T = \begin{array}{c} \\ \\ D_1 \\ c_{11}\cdots c_{1m_1} \\ \vdots \\ D_i \\ c_{i1}\cdots c_{im_i} \\ \vdots \\ D_n \\ c_{n1}\cdots c_{nm_n} \end{array} \begin{array}{c} D_1 \\ c_{11}\cdots c_{1m_1} \\ T^{11} \\ \\ \vdots \\ T^{i1} \\ \\ \vdots \\ T^{n1} \\ \end{array} \begin{array}{c} \\ \\ \cdots \\ \\ \\ \cdots \\ \\ \\ \cdots \\ \end{array} \begin{array}{c} D_j \\ c_{j1}\cdots c_{jm_j} \\ T^{1j} \\ \\ \vdots \\ T^{ij} \\ \\ \vdots \\ T^{nj} \\ \end{array} \begin{array}{c} \\ \\ \cdots \\ \\ \\ \cdots \\ \\ \\ \cdots \\ \end{array} \begin{array}{c} D_n \\ c_{n1}\cdots c_{nm_n} \\ T^{1n} \\ \\ \vdots \\ T^{in} \\ \\ \vdots \\ T^{nn} \\ \end{array}$$

Figure 3. Total Influence Matrix

Then, the degrees of relationships among sub-criteria are obtained by finding the sum of (r+c) and (r–c). The strength of influence given and received is identified by (r+c) and (r–c). The (r+c) indicates the degree of dependency of criteria within the problem. Moreover, (r–c) quantifies the extent of a criterion in affecting others. When (r–c) is negative then the criterion affects other factors. On the other hand, a positive value of (r–c) means the criterion is affected by other criterion (Tzeng, Chiang, & Li, 2007). Thus, the cause-and-effect graph can be illustrated by plotting the data set in digraphs where (r+c) is an axis and (r–c) is an ordinate.

3.2 Combination of DEMATEL and ANP (DANP)

The analytic network process (ANP) was originally invented by Thomas L. Saaty as an extension of the analytic hierarchy process (AHP) (Saaty, 1996). Although both ANP and AHP follow similar procedures, ANP is more capable in structuring decision making problems which involve criteria interdependencies and feedback (Tzeng & Huang, 2011). The combination of DEMATEL and ANP aims at measuring the different degrees of influence among the criteria (Ou Yang, et al., 2008) rather than assuming all criteria have equal weight. Therefore, the adoption of DEMATEL technique is improving prior ANP method by adopting the full direct/indirect matrix and converts it into an unweighted supermatrix representing the real world problem instead of a single approach pairwise comparison ANP. Continuing previous DEMATEL stages, an improved ANP procedure is described in the following steps.

Step 4: Determining the unweighted supermatrix. The output of this stage is the weighted supermatrix. In this study, we call T the representation of the total influence matrix generated by sub-criteria and S as a representation of the total-influence matrix generated by criteria. The normalization of matrix T by criteria will produce a new matrix called normalized total influence matrix T as illustrated in Figure 4. After this has been accomplished, matrix T is normalized according to criteria by obtaining Equation (6) and equation (7). Afterwards, the matrix T is transposed to generate a weighted supermatrix.

$$d_{ci}^{11} = \sum_{j=1}^{m_1} t_{cij}^{11}, \; i = 1, 2, \ldots, m_1 \tag{6}$$

$$T^{\alpha 11} = \begin{bmatrix} t_{11}^{\alpha}/d_1 & \cdots & t_{1j}^{\alpha}/d_1 & \cdots & t_{1n}^{\alpha}/d_1 \\ \vdots & \ddots & \vdots & ⋰ & \vdots \\ t_{i1}^{\alpha}/d_i & \cdots & t_{ij}^{\alpha}/d_i & \cdots & t_{in}^{\alpha}/d_i \\ \vdots & ⋰ & \vdots & \ddots & \vdots \\ t_{n1}^{\alpha}/d_n & \cdots & t_{nj}^{\alpha}/d_n & \cdots & t_{nn}^{\alpha}/d_n \end{bmatrix} = \begin{bmatrix} t_{11}^{s} & \cdots & t_{1j}^{s} & \cdots & t_{1n}^{s} \\ \vdots & \ddots & \vdots & ⋰ & \vdots \\ t_{i1}^{s} & \cdots & t_{ij}^{s} & \cdots & t_{in}^{s} \\ \vdots & ⋰ & \vdots & \ddots & \vdots \\ t_{n1}^{s} & \cdots & t_{nj}^{s} & \cdots & t_{nn}^{s} \end{bmatrix} \tag{7}$$

$$T^{\alpha} = \begin{array}{c} \\ \\ D_1 \\ c_{11} \cdots c_{1m_1} \\ \\ Di \\ c_{i1} \cdots c_{im_i} \\ \\ D_n \\ c_{n1} \cdots c_{nm_n} \end{array} \begin{array}{c} \begin{array}{ccccc} D_1 & & Dj & & D_n \\ c_{11} \cdots c_{1m_1} & & c_{j1} \cdots c_{jm_j} & & c_{n1} \cdots c_{nm_n} \end{array} \\ \begin{bmatrix} T^{\alpha 11} & \cdots & T^{\alpha 1j} & \cdots & T^{\alpha 1n} \\ \vdots & & \vdots & & \vdots \\ T^{\alpha i1} & \cdots & T^{\alpha ij} & \cdots & T^{\alpha in} \\ \vdots & & \vdots & & \vdots \\ T^{\alpha n1} & \cdots & T^{\alpha nj} & \cdots & T^{\alpha nn} \end{bmatrix} \end{array}$$

Figure 4. Normalized Total-influence Matrix

Step 5: Determining the weighted supermatrix. The weighted supermatrix is calculated simply by multiplying the S and matrix W, as illustrated in equation (8). The matrix S represents the weighted supermatrix of the criteria level, which is derived by going through steps one to four above.

$$W^{\alpha} = S^{\alpha} \times W = \begin{bmatrix} s^{\alpha 11} \times W^{11} & \cdots & s^{\alpha i1} \times W^{i1} & \cdots & s^{\alpha n1} \times W^{n1} \\ \vdots & & \vdots & & \vdots \\ s^{\alpha 1j} \times W^{1j} & \cdots & s^{\alpha ij} \times W^{ij} & \cdots & s^{\alpha nj} \times W^{nj} \\ \vdots & & \vdots & & \vdots \\ s^{\alpha 1n} \times W^{1n} & \cdots & s^{\alpha in} \times W^{in} & \cdots & s^{\alpha nn} \times W^{nn} \end{bmatrix} \tag{8}$$

In order to determine the global priority matrix, limit the weighted supermatrix by operating equation:

$$\lim_{g \to \infty} (W^{\alpha})^{g} \tag{9}$$

where g represents any power value. The weighted supermatrix can be raised sufficiently by a large power of g until the supermatrix reaches a steady state condition. The global priority vectors then represent the weight of each sub-criteria.

3.3 Case Study on Chinese Learning Applications for Mobile Language Learning

Under two popular mobile operating system platform, Android and Apple iOS, numerous mobile applications have been pushed to the market with a variety of design feature, such as Pleco (www.pleco.com) and Trainchinese (www.trainchinese.com). The included features help learners to improve their skills in Mandarin Chinese using electronic media such as flashcards, audio, and writing. The two applications are similar in that both are dictionary-based applications, available for both the Android and Apple iOS platforms and have free, downloadable standard features. However, both applications have different designs in term of available features. For example, the free downloaded Pleco application has basic features such as a Chinese-English (and vice versa) dictionary database, and Chinese character identification features. On the other hand, Trainchinese application consists of five key applications for single competency training, such as: Chinese numbers, dictionary and flashcard, studying pinyin, phrasebooks, and Chinese writing software. Assuming those two apps represent two different design strategies, they can be evaluated based upon how these two alternatives contribute to the identification of key value factors in the design of mobile applications for Chinese self-learning.

3.4 Research Participant

The present research project has asked for the participation of experts with the backgrounds detailed in Table 1. They were asked to evaluate the interrelationship among criteria and sub-criteria by using the DEMATEL survey. It requires 45 to 50 minutes for an expert to complete the survey. As for the ANP survey, we invited the foreign students who taking the Chinese course in the Chinese Language Center of National Cheng Kung University to participate. In addition to taking the course, most students also have experience in using mobile learning applications. In the ANP survey they were asked to evaluate the design dimensions of both applications, Pleco and Trainchinese, through an ANP survey.

Table 1. Experts for DEMATEL Survey

Expertise	Years of Expertise (Average)	Number of experts
Professor in information system field	23.75 years	4
E-learning researcher	19 years	3
Experienced instructor in e-learning	8.75 years	4

4. Results and Discussion

4.1 Interrelationships among Criteria and Sub-criteria by DEMATEL

As part of our research framework, we developed a hierarchical structure which consists of 5 criteria and 16 sub-criteria. Accordingly, the experts were asked to evaluate the interrelationships of one attribute with another in the form of a pairwise comparison. There are eleven 16x16 matrix which resulted from the eleven factor DEMATEL survey where the average of each numerical value of the matrix generated an initial-average matrix or initial direct-influence matrix (Table 2). Then, the operation of equation (1) and (2) on the initial average matrix was used to derive the initial influence matrix *T* (Table 3) by obtaining equation (3), (4), and (5). Likewise, the total influence matrix for the criteria level could also be obtained through similar operations and generating matrix *S* (Table 4).

Table 2. Initial-average Matrix for Sub-criteria

	ST	SP	SI	AV	UF	IG	IF	IWS	IWT	LME	CS	FT	FL	LMU	FH	OS	*Sum*
ST	0.0000	3.0000	3.0000	2.1818	2.8182	2.5455	2.1818	2.3636	2.7273	2.5455	2.6364	2.1818	2.3636	3.0000	1.9091	2.7273	*38.1818*
SP	2.3636	0.0000	2.2727	2.1818	2.9091	2.4545	2.1818	2.2727	2.2727	2.2727	2.3636	2.0909	2.0909	2.4545	1.7273	2.3636	*34.2727*
SI	2.0909	2.0000	0.0000	2.2727	2.6364	2.4545	2.6364	2.6364	2.5455	2.4545	2.6364	2.4545	2.5455	2.3636	1.9091	2.0909	*35.7273*
AV	1.8182	1.6364	1.6364	0.0000	2.8182	2.8182	2.8182	2.3636	2.2727	2.4545	2.5455	2.1818	2.2727	2.3636	1.8182	1.9091	*33.7273*
UF	1.7273	1.8182	1.8182	2.4545	0.0000	2.4545	2.4545	2.6364	2.5455	2.6364	2.6364	2.3636	2.2727	2.3636	2.2727	2.4545	*34.9091*
IG	2.0000	1.9091	1.9091	2.9091	2.9091	0.0000	2.7273	2.8182	2.7273	2.6364	2.6364	2.6364	2.7273	2.4545	2.1818	2.4545	*37.6364*
IF	1.9091	2.0000	2.2727	2.5455	3.0000	3.0000	0.0000	2.7273	2.6364	2.2727	2.6364	2.3636	2.4545	2.3636	2.0000	2.3636	*36.5455*
IWS	1.5455	1.6364	1.6364	1.5455	2.1818	2.0909	2.0909	0.0000	2.0909	2.4545	2.1818	2.0909	2.6364	2.0000	2.2727	2.2727	*30.7273*
IWT	1.7273	1.6364	1.6364	1.5455	2.2727	2.0000	2.0909	1.9091	0.0000	2.0909	2.0909	2.8182	2.7273	2.1818	1.7273	2.2727	*30.7273*
LME	1.9091	1.7273	2.0000	1.9091	2.0909	2.0000	2.2727	2.3636	2.3636	0.0000	2.5455	2.0909	2.0909	2.9091	1.9091	2.0909	*32.2727*
CS	1.7273	1.7273	2.0909	2.0000	2.6364	2.2727	2.4545	2.5455	2.1818	2.3636	0.0000	2.3636	2.2727	2.7273	1.6364	1.9091	*32.9091*
FT	1.5455	1.5455	2.0909	1.9091	2.1818	1.8182	2.0000	2.4545	2.8182	2.2727	2.2727	0.0000	2.4545	2.1818	1.6364	2.1818	*31.3636*
FL	1.5455	1.5455	2.0000	2.0000	2.5455	2.0909	2.1818	2.3636	2.2727	2.2727	2.0000	2.5455	0.0000	2.0000	1.8182	2.1818	*31.3636*
LMU	2.0000	1.8182	1.8182	1.9091	2.3636	2.2727	2.2727	2.0000	2.1818	2.6364	2.1818	2.0000	2.0000	0.0000	1.6364	1.8182	*30.9091*
FH	1.2727	1.1818	1.4545	1.5455	2.1818	1.4545	1.6364	2.0909	1.8182	2.0000	1.9091	1.9091	2.4545	2.0909	0.0000	2.4545	*27.4545*
OS	2.0909	1.7273	1.8182	1.7273	2.1818	1.7273	2.0909	2.0000	1.9091	1.8182	1.9091	2.0000	2.3636	1.9091	2.2727	0.0000	*29.5455*
Sum	*27.2727*	*26.9091*	*29.4545*	*30.6364*	*37.7273*	*33.4545*	*34.0909*	*35.5455*	*35.3636*	*35.1818*	*35.1818*	*34.0909*	*35.7273*	*35.3636*	*28.7273*	*33.5455*	

Table 3. The Total-influence Matrix and Influence Index for Sub-criteria (Matrix *T*)

T	ST	SP	SI	AV	UF	IG	IF	IWS	IWT	LME	CS	FT	FL	LMU	FH	OS	*r* *(Sum)*
ST	0.3297	0.3977	0.4267	0.4227	0.5161	0.4629	0.4627	0.4830	0.4893	0.4835	0.4846	0.4634	0.4849	0.4946	0.3951	0.4674	*1.577*
SP	0.3562	0.2935	0.3759	0.3877	0.4755	0.4227	0.4237	0.4405	0.4385	0.4370	0.4383	0.4222	0.4379	0.4417	0.3579	0.4208	*1.413*
SI	0.3606	0.3538	0.3315	0.4021	0.4842	0.4361	0.4481	0.4635	0.4592	0.4554	0.4588	0.4447	0.4631	0.4537	0.3738	0.4279	*1.448*
AV	0.3382	0.3295	0.3555	0.3285	0.4670	0.4255	0.4328	0.4368	0.4325	0.4352	0.4365	0.4186	0.4361	0.4334	0.3550	0.4043	*1.352*
UF	0.3437	0.3410	0.3677	0.3968	0.4081	0.4257	0.4334	0.4526	0.4482	0.4489	0.4480	0.4321	0.4461	0.4430	0.3737	0.4262	*1.267*
IG	0.3727	0.3655	0.3943	0.4329	0.5100	0.3932	0.4680	0.4862	0.4817	0.4780	0.4770	0.4668	0.4860	0.4741	0.3955	0.4539	*1.371*
IF	0.3629	0.3602	0.3944	0.4161	0.5017	0.4568	0.3918	0.4742	0.4697	0.4597	0.4672	0.4509	0.4697	0.4620	0.3832	0.4424	*1.350*
IWS	0.3045	0.3025	0.3263	0.3365	0.4149	0.3746	0.3815	0.3431	0.3930	0.4002	0.3929	0.3826	0.4095	0.3899	0.3371	0.3799	*1.136*
IWT	0.3095	0.3033	0.3273	0.3373	0.4179	0.3733	0.3823	0.3916	0.3423	0.3925	0.3916	0.4005	0.4124	0.3949	0.3247	0.3806	*1.126*
LME	0.3270	0.3185	0.3497	0.3604	0.4315	0.3896	0.4030	0.4189	0.4170	0.3574	0.4190	0.3995	0.4143	0.4288	0.3426	0.3920	*1.193*
CS	0.3287	0.3244	0.3583	0.3696	0.4524	0.4035	0.4149	0.4312	0.4208	0.4236	0.3644	0.4135	0.4264	0.4322	0.3428	0.3951	*1.204*
FT	0.3102	0.3059	0.3429	0.3511	0.4224	0.3753	0.3866	0.4106	0.4172	0.4031	0.4022	0.3379	0.4126	0.4012	0.3278	0.3843	*1.153*
FL	0.3108	0.3065	0.3415	0.3543	0.4318	0.3825	0.3916	0.4095	0.4055	0.4040	0.3968	0.4010	0.3529	0.3978	0.3329	0.3852	*1.151*
LMU	0.3196	0.3113	0.3352	0.3500	0.4248	0.3844	0.3911	0.3982	0.4006	0.4098	0.3985	0.3854	0.3995	0.3457	0.3261	0.3740	*5.954*
FH	0.2700	0.2640	0.2917	0.3048	0.3766	0.3255	0.3361	0.3587	0.3504	0.3537	0.3506	0.3434	0.3689	0.3559	0.2514	0.3500	*5.252*
OS	0.3087	0.2965	0.3216	0.3311	0.4033	0.3558	0.3707	0.3816	0.3776	0.3741	0.3755	0.3695	0.3918	0.3766	0.3278	0.3133	*5.675*
c (Sum)	*1.385*	*1.375*	*1.490*	*1.541*	*1.420*	*1.276*	*1.293*	*1.154*	*1.152*	*1.150*	*1.163*	*1.152*	*1.192*	*1.078*	*0.905*	*1.037*	
r+c	2.9615	2.7879	2.9378	2.8929	2.6870	2.6468	2.6436	2.2899	2.2786	2.3434	2.3676	2.3049	2.3426	7.0323	6.1569	6.7126	
r–c	0.1921	0.0388	-0.0416	-0.1893	-0.1526	0.0956	0.0570	-0.0173	-0.0259	0.0432	0.0409	0.0002	-0.0411	4.8757	4.3462	4.6382	

Table 4. The Total-influence matrix and Influence Index of Criteria

	D_1	D_2	D_3	D_4	D_5	*r (Sum)*	*r + c*	*r - c*
Hardware & software (D_1)	0.4996	0.5099	0.4897	0.4656	0.5367	2.5015	6.6170	-1.614
User interface (D_2)	0.8663	0.5310	0.6592	0.6384	0.6539	3.3488	6.6234	0.0742
Learning interactions (D_3)	0.9914	0.8117	0.5791	0.7534	0.7751	3.9107	6.9608	0.8606
Learning personalization (D_4)	0.9722	0.8085	0.7539	0.5539	0.7583	3.8468	6.8132	0.8804
Service support (D_5)	0.7860	0.6134	0.5682	0.5552	0.4608	2.9836	6.1684	-0.2012
c (Sum) =	4.1155	3.2746	3.0501	2.9664	3.1848			

The impact relationship map is constructed by defining the sum of row (*r*) and column (*c*) based on the total-influence matrix of sub-criteria (Table 3) and criteria (Table 4). The influence index (*r*+*c*) and (*r*–*c*) are plotted in the graph where (*r*+*c*) represents the axis and (*r*–*c*) represents the ordinate. The results of the causal and affected sub-criteria and criteria are illustrated in Figures 5 and 6, respectively.

4.2 Weighting of Criteria by DANP

Using the results from the DEMATEL analysis as given above, the weighted supermatrix can be generated by following the procedure explained in step 5 above. The operation of Equation 9 at the weighted supermatrix is generating the global weight of each sub-criterion as listed under global weight column on Table 6.

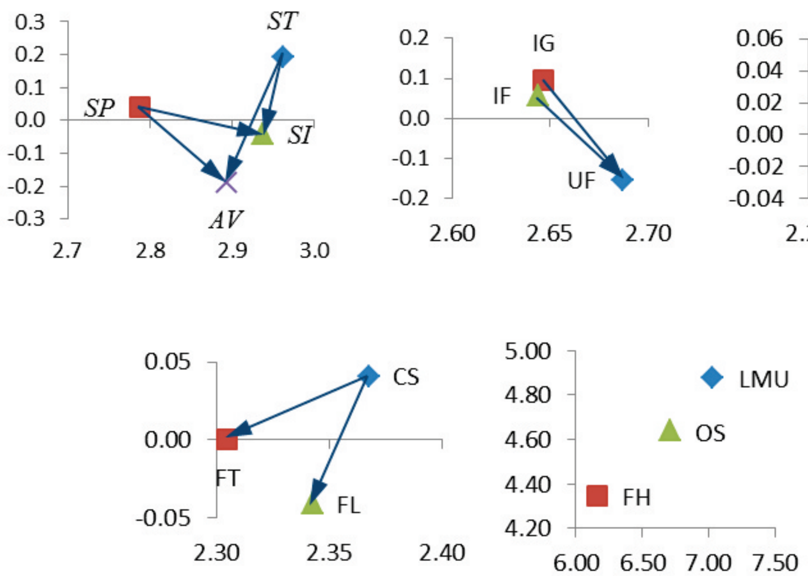

Figure 5. Impact-relations Map for Sub-criteria

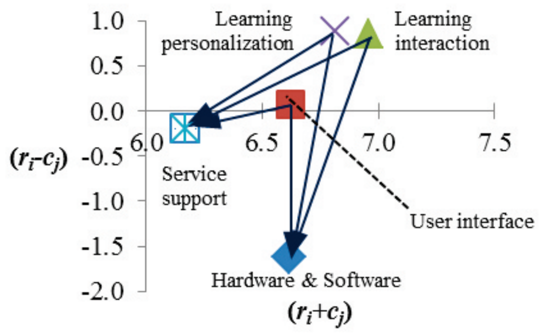

Figure 6. Impact-relations Map for Criteria

4.3 Discussions

In this section we discuss the recommendations based on prior results of empirical studies for obtaining novel multi-criteria decision making. There are two recommendations which can be proposed: firstly, based on the interrelationship among criteria and sub-criteria, and secondly, according to the global weight of the sub-criteria design strategy of selected mobile language learning apps.

Firstly, the impact relationship map of the criteria (Figure 6) demonstrates the interrelationship among the motivators of the design aspect of the mobile learning applications. Understanding this network may guide the design decision makers to manage the potential response of learners and, as a result, adapt their design strategy appropriately. The DEMATEL analysis demonstrates four important design aspect of mobile learning apps with the highest ($r+c$), as follows: learning interactions, learning personalization, user interface, and hardware and software. The inclusion of hardware and software is required due to the insignificant differences of both ($r+c$) values. This is a logical conclusion because effective pedagogical activity should involve rigorous learning interactions. Also, the results show that the experts fully understand the field of learning information systems. Moreover, the design of service support and quality of hardware and software are driven by the three aspects mentioned above. Thus, it is recommended that the design aspect of service support and design of hardware and software should not be created independently but should be conceived of as part of a comprehensive design strategy of mobile learning applications. On the other hand, the high value of ($r–c$) in learning personalization attributes indicates that its role is a strong causal force or motivator in the design of mobile learning applications, followed by learning interactions and the user interface. This indicator may not be surprising for two reasons. Firstly, learning personalization reflects the user's preference to use mobile learning application for supporting personal asynchronous learning. Secondly, this also confirms the validity of the respondents' expertise where they prioritize the learning function of mobile learning applications as such learning personalization and learning interaction. The network relation map of sub-criteria level factors exhibits the significance of motivators in the learning material update (highest ($r+c$)) in the design of mobile learning applications followed by online and offline support and friend's help. These results are in line with a case study of this research on Chinese learning application where learners were regularly exposed to packages of Chinese vocabulary, including reading sounds and writing strokes. This also demonstrates that the study materials and access to service for troubleshooting are essential in designing applications. In addition, the three sub-criteria are also associated as primary causes when we consider the high value of ($r–c$). Thus, it is recommended that the three sub-criteria should be managed independently and designers should focus on learning material updates sub-criteria. It is reasonable since the troubleshooting issues may be solved by maintaining regular software updates.

Table 5. Design Strategies Analysis

Pleco.com					Trainchinese.com				
Sub-criteria	**Global Weight**	**Survey Average**	**Utility**	**Local Rank**	**Sub-criteria**	**Global Weight**	**Survey Average**	**Utility**	**Local Rank**
ST	0.0560	2.2083	0.1236	13	ST	0.0560	2.3333	0.1306	9
SP	0.0548	2.3750	0.1302	9	SP	0.0548	2.4583	0.1348	7
SI	0.0598	2.5000	0.1495	4	SI	0.0598	2.5833	0.1545	4
AV	0.0622	2.1667	0.1348	8	AV	0.0622	2.4167	0.1503	6
UF	0.0682	2.5833	0.1761	1	UF	0.0682	2.7917	0.1903	1
IG	0.0611	2.5000	0.1527	2	IG	0.0611	2.5833	0.1578	3
IF	0.0624	2.0000	0.1247	12	IF	0.0624	2.4167	0.1507	5
IWS	0.0607	1.8333	0.1112	14	IWS	0.0607	1.7917	0.1087	11
IWT	0.0565	2.2083	0.1247	11	IWT	0.0565	1.7083	0.0965	14
LME	0.0601	2.2917	0.1378	6	LME	0.0601	1.7500	0.1052	12
CS	0.0587	1.7917	0.1052	15	CS	0.0587	2.0833	0.1223	10
FT	0.0572	1.8333	0.1049	16	FT	0.0572	1.7083	0.0977	13
FL	0.0597	2.5000	0.1492	5	FL	0.0597	1.5833	0.0945	16
LMU	0.0676	1.8750	0.1267	10	LMU	0.0676	2.5000	0.1689	2
FH	0.0558	2.4167	0.1348	7	FH	0.0558	1.7083	0.0953	15
OS	0.0643	2.3333	0.1499	3	OS	0.0643	2.0417	0.1312	8
Total Utility			2.1361		Total Utility			2.089	
Global Rank			1		Global Rank			2	

Secondly, the comparison of both mobile learning applications indicate that Pleco application strategy is superior, with the highest user friendliness utility following by higher marks for the other two sub-criteria, system integration and online and offline service. On the other hand, the Trainchinese application strategy was ranked second with the user friendliness as the highest utility followed by learning material updates and system integration. However, both Pleco and Trainchinese applications have similar weightings, with a close gap in the rankings of each total utility (Pleco: 2.1361 and Trainchinese: 2.089). This is an interesting finding given that the utility of Trainchinese application is substantial in term of user friendliness and system integration compared to Pleco. The priority of user friendliness as the core motivator of mobile learning applications is aligned with currently popular beliefs in information system domains in which user friendliness is enhanced to ease use and usefulness.

5. Conclusions

The design selection of mobile learning applications is the important issue in the management of information systems. Design decisions involve intricate processes in establishing a range of uncertain criteria and may vary across different contexts of mobile learning applications. In this study we extended the design dimension of web-based virtual learning environment (Picolli et al., 2001) which is related to IS success model (DeLone & McLean, 1992, 2003). In this research we developed the criteria and sub-criteria that align with learners' values for the design of mobile learning applications used in a Chinese learning context. An empirical study was used to demonstrate the application of a novel hybrid MCDM approach combining DEMATEL and ANP. Rather than only selecting the best design, we also identify the interrelationship among criteria and sub-criteria of the design of mobile learning application which illustrate the structure or grammar of mobile learning application design. Thus, this study can contribute to understanding the relationship among design aspects of mobile learning applications. The focus on core values of the mobile learning application design is thus of key importance to strategic designers of mobile learning applications. Strategies that leverage the weights of the motivators of user value, as revealed in this paper, may have significant impact on users' intention to adopt mobile learning technology.

This research developed a decision making framework for designing mobile learning application based on the IS success model. According to the empirical results, numerous relationships among criteria and sub-criteria occur which need further verification. This research adopts the mobile learning application for Chinese learning as a case study which supports asynchronous learning. Hence, investigation into the design of mobile learning to support asynchronous learning would create value in the domain of mobile learning.

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