Available online at www.sciencedirect.com
ScienceDirect
Computers & Education 51 (2008) 1205–1226
COMPUTERS & EDUCATION
www.elsevier.com/locate/compedu

Toward interactive mobile synchronous learning environment with context-awareness service

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Received 16 April 2007; received in revised form 18 November 2007; accepted 19 November 2007

Abstract

Mobile synchronous learning is a new challenge in the e-learning domain. While popular mobile communication devices, such as cell phones, cannot directly accommodate traditional synchronous content due to the major limitation of display size, other constraints also restrict convenient interactions while using mobile devices in a synchronous learning environment. These problems have motivated the authors of this study to design a context-awareness synchronous learning system and to develop a corresponding pedagogical framework. Different than existing synchronous learning strategies, the proposed system enhances the feedback mechanism and implements an enhanced model for achieving mobile interaction in a synchronous learning environment. The enhanced model is named Interactive Service Module, which enables interactions between teachers and students via short message delivery. In the proposed synchronous learning environment, different kinds of learning devices are used to access the same source of synchronous content simultaneously. To accommodate the diversity of devices, several content styles have been developed and an appropriate style can be selected to a learner via a decision mechanism. This mechanism is based on fuzzy weighted average technique to measure the average computational power for each device. Finally, questionnaires were used to evaluate the usability of the proposed synchronous learning environment, and the results indicate that our system can facilitate synchronous learning by enabling students to access lessons conveniently and efficiently from a wide variety of locations, using common mobile communication devices.

Keywords: Architectures for educational technology system; Distance education and telelearning; Interactive learning environments

1. Introduction

In recent years, the distance learning environment has been enriched by significant progress in the field of Information Technologies (IT). Unlike traditional in-class learning, distance education aims at bringing learning

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0360-1315/$ - see front matter
doi:10.1016/j.compedu.2007.11.009

activities off campus freed from the restrictions of time and space (Frederick, Michael, Kelly, & Schrader, 2001; Greville, 1989). With regards to time, distance learning can be classified as either asynchronous or synchronous distance learning. Asynchronous distance learning uses electronic materials to deliver information to learners at anytime and anywhere. Instructors and learners can engage in educational activities easily and flexibly through a uniform access medium (Chen, Huang, & Chu, 2005; Huang, Chen, Cheng, & Chu, 2004; Huang, Chen, Huang, Jeng, & Kuo, 2008; Jaffee, 1997; Jeng, Huang, Kuo, Chen, & Chu, 2005; Wu & Hiltz, 2004). Although asynchronous learning is beneficial for distance education, it has some limitations which have been identified by previous researchers (Chou, 1999; Leidner & Jarvenpaa, 1995; Lim & Benbasat, 1997; Sloane, 1997; Wulf, 2000). First of all, asynchronous learning suffers from a lack of real-time interaction, and it is difficult to supplement lessons with additional material, tailored to the needs of each particular group of learners. Consequently, contextual interaction and just-in-time response are not included in an asynchronous learning activity. In addition, it needs standardized materials to achieve platform-independent course exchange and reuse.

Contrary to asynchronous distance learning, synchronous distance learning requires teachers and students to work together, albeit at a specific time, and focuses on reconstructing the traditional in-class learning environment over the Internet (Yang & Liu, 2007). Although the synchronous system limits students' access to course material by requiring teachers and students to interact in real-time, the fact that they can actually interact is seen as a great advantage. In a synchronous learning environment, learners can raise a question at any time and teachers can respond promptly to reinforce or extend students' learning (Contreras-Castillo, Pérez-Fragoso, & Favela, 2006; Hrastinski, 2006). In addition, synchronous distance learning provides opportunities for group discussion, peer tutoring and brain-storming (Deshpande & Hwang, 2001; Huang, Chen, Kuo, & Jeng, 2008). As cognitive psychologists have suggested, referencing Dual Coding Theory (Tan, Parsons, Hinson, & Sardo-Brown, 2003), learning efficiency is enhanced by engaging both visual learning and verbal learning, both of which are possible in a synchronous learning environment, as instructors can ask learners to answer particular questions with text, graphics or audio. Naturally, this situation can also be achieved in asynchronous learning environments where the instructors can apply authoring tools to produce various learning course materials which fit to the Dual Coding Theory and the learners can immerse in visual learning and verbal learning from the learning course materials through a uniform access medium.

The rapid growth of wireless bandwidth and handheld devices has facilitated the use of multimedia in mobile applications. In 2003, JISC (Joint Information System Committee) has raised *e-Learning innovation programme* to fund mobile-related ICT (Information and Communication Technology) projects (JISC, 2007). At the same time, several distance learning platforms have extended their services to support mobile activities (Chen, Kao, & Sheu, 2003). Additionally, authoring tool providers have designed new authoring functions for mobile content creation (Jokela, 2003; Pan, Kastner, Crow, & Davenport, 2002). These changes have given a rise in a novel research topic in the domain of digital learning: mobile learning, so named since it brings learning activities out of classroom, and in the mobile learning environment, learners are free learners to access lessons at any time, from any location. (Markett, Arnedillo, Weber, & Tangney, 2006; Motiwalla, 2007; Virvou & Alepis, 2005). Distance learning and mobile learning complement traditional educational methodologies, and they complement each other to accommodate learners via an m-learning service (Chang & Sheu, 2002).

Initially, the mobile learning researchers focused on applying distance learning techniques to mobile devices instead of desktops. Learners studied the sequence of instruction developed and experimented by transforming traditional distance education into a form more suitable for a mobile learning environment (Sharples, 2000). The requirements for mobile learning environment include tailored contents, technologies, and suitable pedagogies. Seppälä and Alamäki (2003) investigated the use of short messages to link up teachers and students instantaneously. However a drawback to their system was that the instructor could not conveniently solicit feedbacks from the learners because of the small keypad found on learners' mobile devices, which made the keying process very inefficient. An appropriate feedback mechanism for the mobile user was therefore required to overcome this obstacle. Additionally, due to the variety of learning devices used in any given learning environment, the question of how to deliver the proper adapted learning content was of critical importance. To address this concern, the context-awareness technique (Abowd, Dey, Orr, & Brotherton, 1998) was used. In previous research, the term "context" has been defined in several ways. In essence, context can be seen as a location or time, an activity, an environment, an object or an identity (Byun & Cheverst, 2001). Note that the term "context" is used in this article to refer to the learning device and the location (different locations have different network supports) of the users. In general, context-awareness learning service consists of several technologies, which can be identified as either hardware or software sensor technologies. Hardware sensor technology focuses on students who use mobile devices in a smart sensor room, and uses the sensors to identify students, their location and behaviors (Gellersen, Schmidt, & Beigl, 2002; González-Castaño, García-Reinoso, Gil-Castiñeira, Costa-Montenegro, & Pousada-Carballo, 2005). By way of contrast, software sensor technology tries to adopt artificial intelligence methodology to provide students with better learning experiences. Innovations such as the network bandwidth manager, the student's learning behavior analyzer and our current research project belong to the second category of technology (Univ, 2004; Yang, 2006).

It is the lack of opportunity for interaction and synchronous activities in mobile learning has motivated the authors of this study to develop a context-awareness synchronous learning system. In our learning environment, students can use a mobile device or a desktop to participate in learning activities such as online discussion and synchronous instruction. The pedagogical framework of this study also enhances the feedback process of successful synchronous learning strategy (Chen et al., 2005) with mobile interactive services. With the service provided by the so-called Interactive Service Module, teachers are able to use a mobile web page, a short message, and a friendly user interface to solicit information from students and thereby determine their status in regards to acquisition of course material. Using such information, teachers can then adapt the style, pace and even content of their lessons during synchronous instruction. Furthermore, the context-awareness synchronous learning system can dynamically adapt the style of content delivery by considering the given learning conditions, such as screen size, network bandwidth, multimedia processing power, and memory size of the students' hardware. In order to sense the content style precisely, the system uses a weighted average method to calculate the mean computation power of the learning device, and gives the device with more power a richer learning content presentation style. It is, however, difficult to judge the status of these conditions. For instance, for a given network bandwidth with 128k bit/sec, it is hard to rate the level of network bandwidth of strong, average, or weak classes. The reason is that people usually base their evaluation upon their previous experiences, and the same bandwidth may be rated differently by different thought processes. Since an attribute's level cannot be determined by a single criterion, we need an intelligent method to make such a judgment and to determine the most appropriate content style for a particular type of learner. Therefore, the system employs fuzzy decision making technology to achieve this purpose. In this work, the levels of attributes are modeled by a fuzzy membership function, and Fuzzy Weighted Average (FWA) algorithm (Lee & Park, 1997) is utilized to compute the mean power of learning devices. Furthermore, the Euclidean distance (Dobois & Prade, 1980) is used as a similarity function to determine the most appropriate content style. As a result, learners receive the synchronous learning materials with selected content style to achieve context-awareness content delivery.

Some experiments were also conducted to evaluate the usability of our system. Feedback from students and teachers indicates that the enhanced feedback process could increase the students' willingness to participate interactively during synchronous learning. In addition, teachers reported that the enhanced feedback process is more efficient than a chat-based feedback process.

The remainder of this article is organized as follows. Section 2 gives an overview of pedagogical principle for synchronous learning, as well as introducing the enhanced learning feedback mechanism. Section 3 illustrates our system architecture and the design of the context-awareness approach. The usability evaluation results are shown in Section 4. Finally, Section 5 summarizes the conclusions of this study and indicates our direction for further study.

2. The pedagogic framework for mobile synchronous learning

The efficiency of a learning environment is determined by the adapted learning strategy used in the environment (Khalifa & Lam, 2002). Although there are tools to assist learners in a variety of learning situations, the synchronous distance learning currently is still lacking in terms of appropriate pedagogy and learning strategies. Chen, Ko, Kinshuk, and Lin (2005) first proposed a successful synchronous learning model, which described the synchronous instruction scenario and its benefits (Chen et al., 2005). Chen's learning model combined objectivism (teacher-centric) and constructivism (learner-centric) learning theories (Johannes, 2006). The first part of the synchronistic instruction model is constructed according to objectivism learning theory, in which learners passively receive knowledge from an instructor. The second part of the model consists of constructivist activities (discussion and Q&A), which allow students to control the pace of their learning and construct personal knowledge. Our study, based on Chen's synchronous learning model, proposes a live instruction model, which is suitable for our context-awareness synchronous learning system (see Fig. 1). In the model, students use desktops, laptops, PDA's, or cellular phones to participate in the context-awareness synchronous learning environment. Meanwhile, the teacher explains the lecture materials and interacts with students synchronously. During online instruction, students can discuss questions with a teacher and each other, and the teacher can give additional explanations to rectify any misunderstanding or to reinforce a learning objective. After teaching a lesson, the teacher can either field questions from students, or evaluate students' learning by questioning them. Using feedback from students, the teacher can then either provide further remediation or deliver the next segment of lecture material.

Generally speaking, mobile devices lack a friendly text key-in interface, and this can create a barrier to interaction during online synchronous learning. In our synchronous learning model, we have enhanced the student opinion feedback process to better suit mobile learning condition (see procedures and decision in gray color of Fig. 1), and this innovation is the major difference between Chen's synchronous learning model and our own.

Fig. 2 shows the details of the enhanced student feedback model – the Interactive Service Module, which illustrates how the teacher and students interact with each other. Due to the restrictions of most mobile

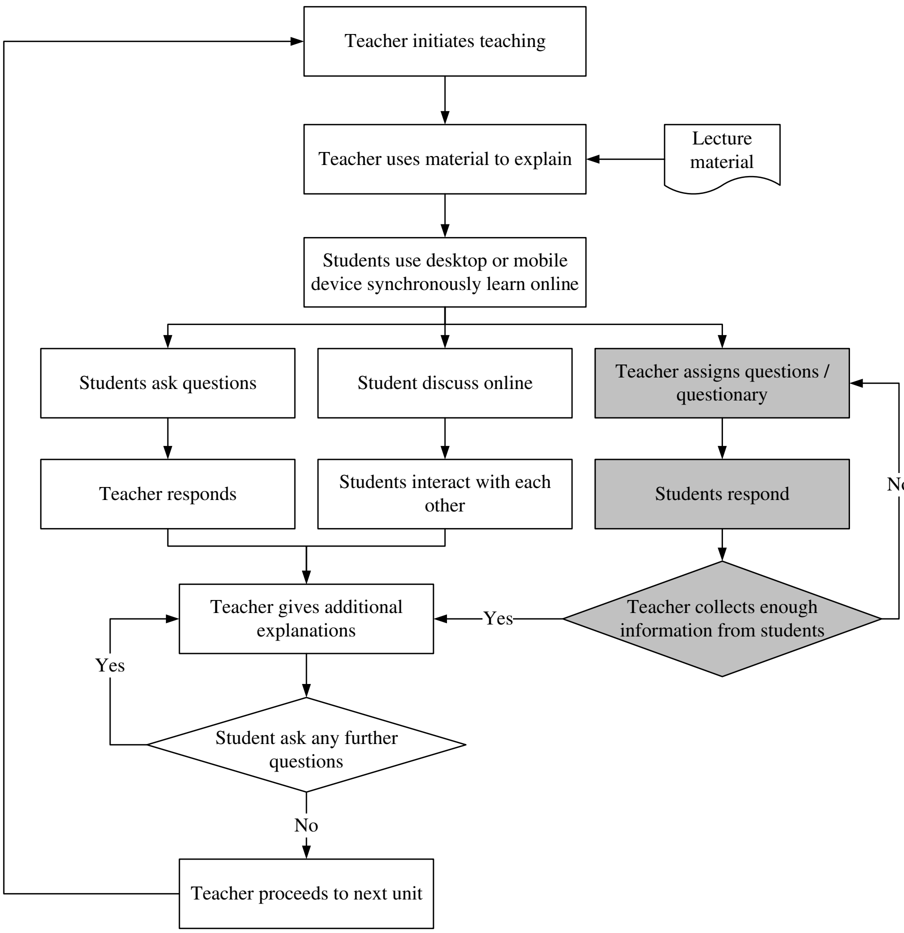


Fig. 1. Mobile synchronous live instruction scenario.

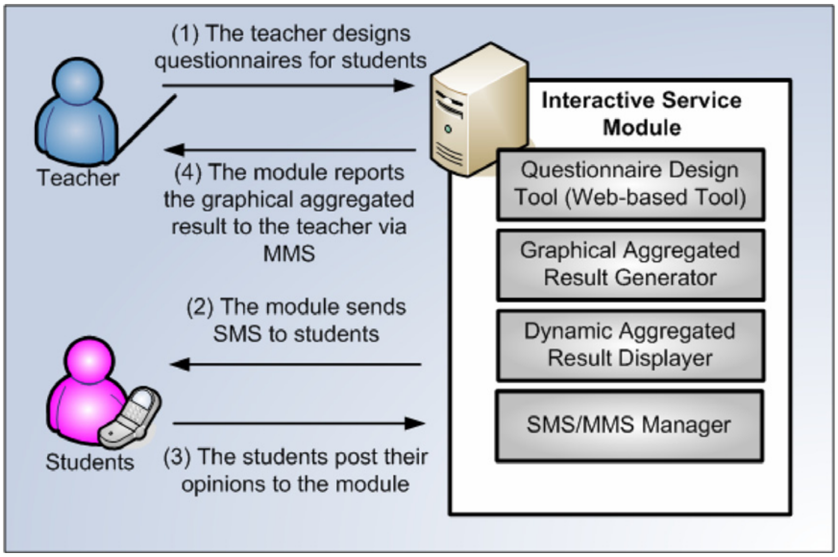


Fig. 2. The communication processes of Interactive Service Module.

devices' keypad, especially cellular phones, keying in words is not easy. Therefore, a typed interactive solution, such as a chat room, is not suitable for mobile interaction. We have developed a friendly feedback process in which students can send their opinions to the instructor without keying in complex sentences or words. During the synchronous instruction process, the instructor can design a multimedia question/questionnaire by using the web-based Questionnaire Design Tool (see Fig. 3). Following that, the Interactive Service Module sends an SMS message to invite students to participate in the interactive event. The message contains a hyper-link to a voting page, where students can use a series of choices to reply to a teacher's question or present their own opinions (see Fig. 4). During the voting stage, teacher and students can observe the visualized dynamic replying/voting results through the Dynamic Aggregated Result Displayer, which would display the results of questions to the teacher and students in real-time manner (see Fig. 5). Finally, the feedback results would be

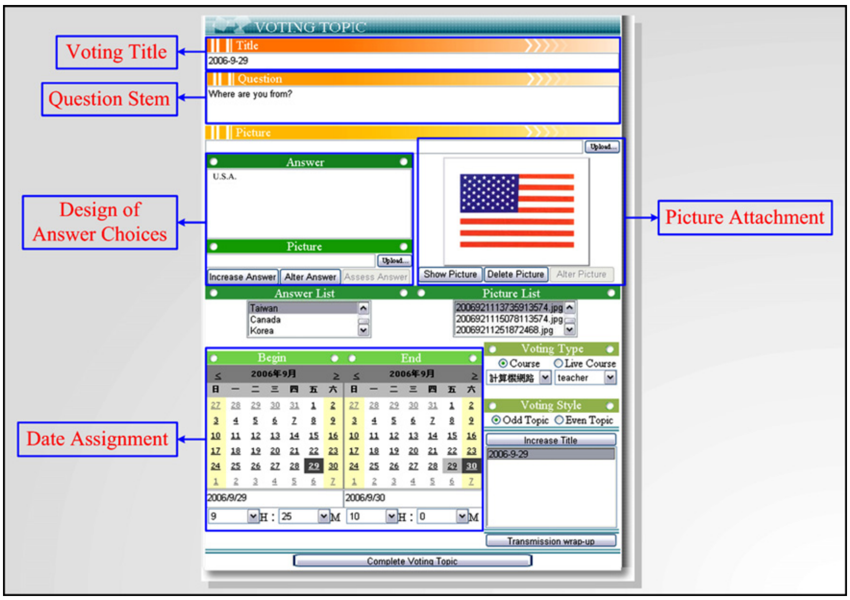


Fig. 3. The user interface of Questionnaire Design Tool.

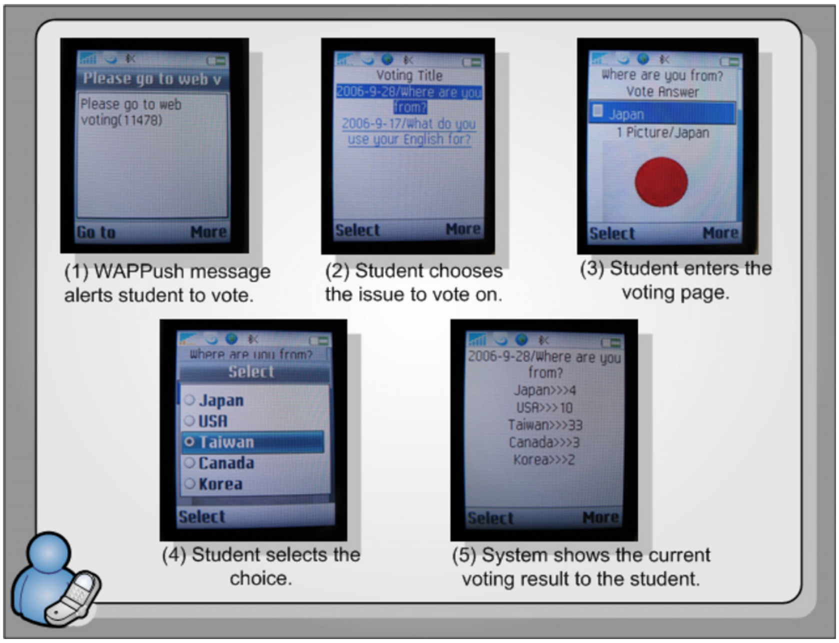
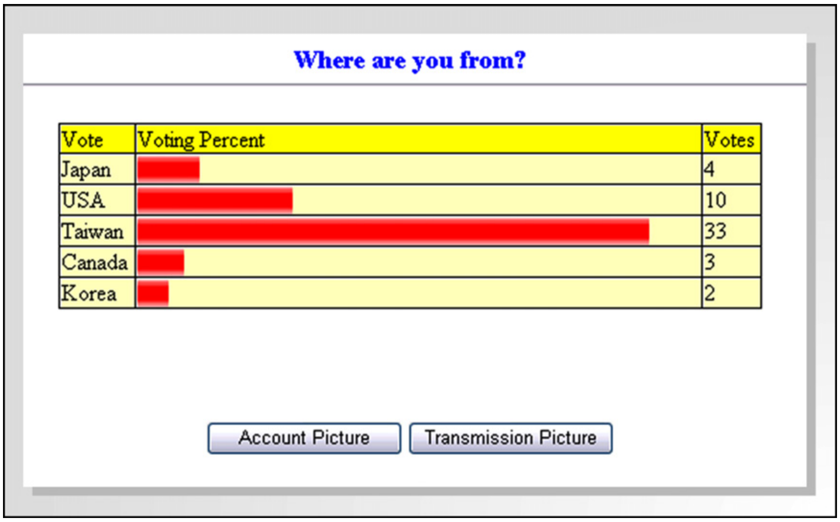


Fig. 4. The entire process of the student interacting with the instructor over mobile network.



Vote	Voting Percent	Votes
Japan		4
USA		10
Taiwan		33
Canada		3
Korea		2

Fig. 5. A web-based example of the Dynamic Aggregated Result Displayer.

generated as a bar chart and sent to teacher by MMS message for further reference (see Fig. 6). The instructor receiving the message can therefore use the feedback to adjust her teaching style, speed of delivery, and so on, in a real-time manner. Students can perform the entire interactive task by using a cellular phone's navigation keys without keying in complex sentences, and this feature would undoubtedly aid mobile interaction in a synchronous learning environment.

3. The context-awareness synchronous learning environment

The synchronous learning environment requires adequate upload bandwidth to deliver the video stream and multimedia contents. If the synchronous learning architecture cannot support enough bandwidth for both

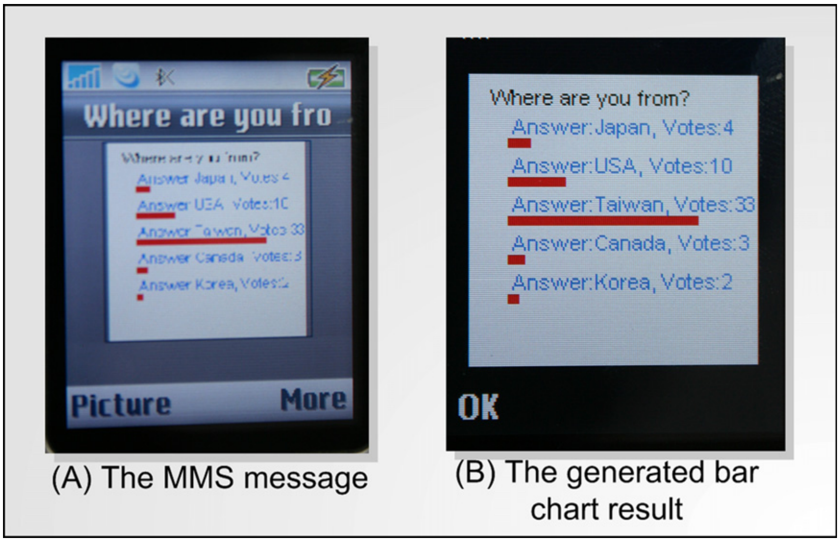


Fig. 6. The MMS message and the generated bar chart result: (A) the MMS message; (B) the generated bar chart result.

teacher and students, then the delivery of the video stream will not be continuous and the multimedia content may be lost. In order to resolve this problem, we have designed a three-layer architecture for synchronous online instruction. Our synchronous learning architecture (see Fig. 7) consists of three parts, which are the Instructor, Learning Platform, and the Learner. In the Learning Platform layer, the Interactive Service includes the Interactive Service Module (introduced in Section 2) and an online chat room for the interactive portion of synchronous learning. Additionally, the Interactive Service cooperates with Context-awareness Content Gateway as a mediator to deliver the learning stream and allows teacher and students to interact on it without a direct connection. Such a design holds most network load on the Learning Platform and relieves clients of the pressure of having to load it. In the architecture, the Internet environment of teacher can be a broadband LAN environment or home-use ADSL, the Learning Platform must be constructed in a broadband network environment, while the students can participate with any device that can access the Internet. Table 1 shows the clients' minimum bandwidth requirements.

Synchronous online instruction is constrained by time restrictions. To participate in a lesson, the teacher and students have to log on to the online classroom during a specific time period. Generally speaking, the

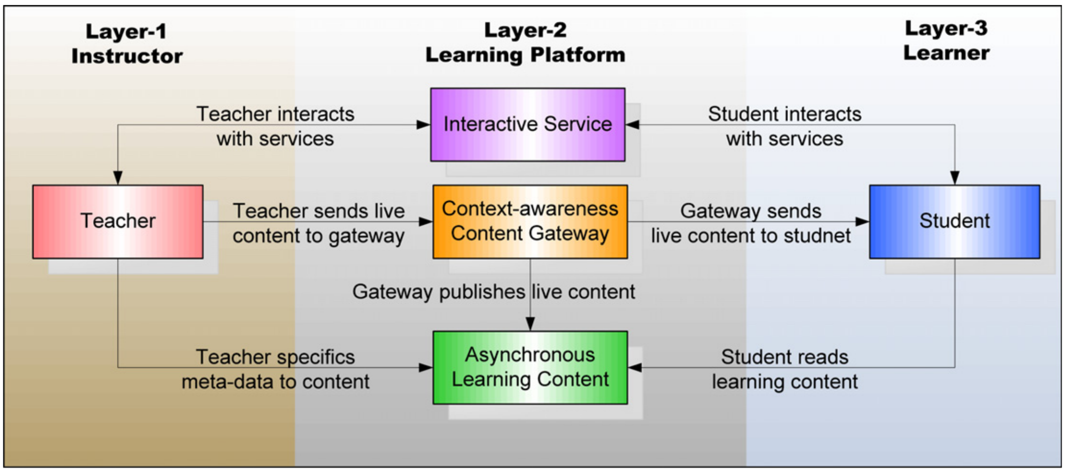


Fig. 7. A three-layer architecture for context-awareness synchronous learning environment.

Table 1
The minimum bandwidth requirement

	Download	Upload
Teacher client	14.8	17.2
Student client	14.4	0.3

Unit: KB/s.

online instruction content cannot be stored for reusing after a synchronous learning activity. If any students did not participate in the original event, they would have no opportunity to acquire the knowledge from the synchronous instruction session. There is, therefore, a need to somehow save the online instruction content in order to eliminate the time restrictions currently associated with synchronous learning. To this end, we have designed an agent program in our Context-awareness Content Gateway to record the synchronous teaching process. The agent program monitors and records the teacher's teaching behavior, and directly produces the asynchronous learning course when the on-line classroom is done. Additionally, the SCORM (2004) standard is used in the course generation process for inter-platform course exchange. Finally, the completed course of study could then be published on the Learning Platform for further asynchronous distance learning.

4. The design of context-awareness content gateway

Nowadays, digital and network technologies facilitate interaction in synchronous learning systems. Students can use convenient web-based virtual classrooms to access course content quickly and efficiently, and communicate with the instructor in a natural and meaningful way.

Modern mobile devices, especially cellular phones and smart phones have the capacity to take pictures, send and receive SMS/MMS (Short Message Service/Multimedia Message Service) messages, and play video streams through 3G (3rd Generation), GPRS (General Packet Radio Service), wi-fi, and other wireless networks. Although mobile devices have such power, it is still difficult to use them to for a sustained period of time in synchronous distance education. The main reason for this apparent drawback is that the mobile devices' size and its architecture are quite different than a desktop, and the mobile devices' specifications are not unified. For this reason we have proposed a Context-awareness Content Gateway to deliver the appropriate style of digital content to learners according to the conditions of the learning environment. The core of the Context-awareness Content Gateway is the design of the decision engine, which actually matches the traditional computer science problem – Multi-Attributive Decision Making (MADM) (Ribeiro, 1996). To resolve the problem, this study applies the Fuzzy Weighted Average technique (Dong & Wong, 1987) to perform the multi-attributive decision making model. In this section, we will first show the drawbacks of the mobile devices, and then proceed from the shortcomings to select our decision attributes, and finally, based on the decision attributes, develop the digital content styles and the decision model.

Synchronous learning on the desktop system has been widely discussed in previous researches (Kies, Williges, & Rosson, 1997; Wang, 2004), and these works have produced excellent results in the synchronous learning domain. Therefore, our study focuses on mobile synchronous learning and integrates previous research results to create a context-awareness synchronous learning system. After assessing some popular cellular phones, we found the following common drawbacks that hinder mobile synchronous learning using cell phones.

1. *Software does not integrate well.* During synchronous instruction, learning content and instructor's video stream are usually presented simultaneously. A desktop's browser can easily integrate a video stream player and call on appropriate applications to handle learning content. Conversely, the cellular phone's browser can only display recognized files, and if the file needs a specific application to open, the application will replace the browser and occupy the entire screen.
2. *The embedded web browser is not powerful enough.* After examining cellular phone's browsers, we discovered that almost all embedded browsers do not support xml interpreting, and only some java script functions can work correctly. This condition limits the development of mobile web sites. In general, learning portal developers would like to put more computation load on to reduce server's load. Owing to the increase in desk-

top's speed, the learning client which captures more computation load will bring more benefits, such as Web 2.0 and AJAX technologies, ensuring, for instance, that the student's client interface will be more user-friendly and have more flexibility. However, to develop a mobile web site it is necessary to reduce the complexity of the page as much as possible. As mentioned above, java script and xml may not work correctly on the cellular phone's browser, and resulting interface is quite boring, and unlikely to motivate students to participate interactively in the learning environment. Therefore, the development of an interesting, truly interactive interface using cell phones or mobile devices becomes an issue worthy of further investigation.
3. *The input interface is not user-friendly.* Some researches and reports indicate that the cellular phone's keypad is not a good interface to key in text (Georgiev, Georgieva, & Smrikarov, 2004). Most cellular phones have only twelve keys (number key from 0 to 9, and keys of "*" and "#") on the keypad, and these keys have to handle all input tasks, including letters, numbers, punctuation and other actions. To key in the alphabet using the 12 keys may be relatively easy with English language text, but the task becomes quite onerous and inconvenient when keying in text in other languages, such as Chinese. Consequently, a chat room styled interaction mechanism is not a viable option for such devices. In this article, we describe a simpler feedback mechanism, which allows students to give their opinions to their teachers, using only the navigation key (see Section 2).
4. *The screen size is too small.* Because cellular phones have such small screens and cannot display much information, mobile web sites usually use a flow-layout to present the content. Generally speaking, most synchronous learning systems display an instructor's video stream and lecture notes simultaneously. However, the video stream player and lecture note displayer are exclusive applications, and they cannot be shown on the cellular phone's screen at the same time. Moreover, the lecture notes may include text and graphics, and the original layout is unlikely to be accommodated by cellular phones. Consequently, the instructor needs to redesign a special version of the lecture notes for cellular phones, and these may be produced by a special design tool or a layout translator. Either solution naturally increases the cost of producing the mobile content.
5. *The battery life is limited.* Turning on the backlight of display panel and execution of the communication module usually consume most battery resources of cellular phones. However, these two parts are the necessaries when learning by mobile devices. During m-learning, communication module is utilized to download lectures, which are then passed to the display panel for achieving information transmission. Such high power consuming situation would be more obviously when students are participating in the synchronous learning by cellular phones. Therefore, it suggests that instructors should take care each session's time and reminds participators to recharge their batteries before joining in synchronous learning activities.

For the above reasons, we see that different learning devices have different features and performance modes which can affect instructional quality, and by extending the quality and quantity of learning that can occur. Therefore, we selected the essential attributes of the learning devices under study to build our decision model. Fig. 8 shows the hierarchical structure of the decision problem and its criteria, which are learning device's screen size, network bandwidth, multimedia processing power, and memory size. Each criterion has its rating, r_i, which is associated with the measured value of the attribute. For instance, if a screen size is larger than 800×600, thus the rating value belongs to the level – Very Good. Furthermore, in the decision model (see Fig. 8), each criterion has been assigned a relative importance parameter, w_i, which is used to adjust the weight of each criterion to the decision goal. Based on the FWA proposed by Baas and Kwakernaak (1977), the criteria can be synthesized by Eq. (1), and the fuzzy average $\bar{r}$ is the resultant result of the input criteria. In our decision model, the $\bar{r}$ presents the mean computation power of the learning device, and it is used to judge which alternative is appropriate to present the learning content for the given learning device. The fuzzy membership functions of rating and relative importance are shown in Figs. 9 and 10 with respectively. Note that a fuzzy membership function can be used to represent the extent to which a value from a domain is included in a fuzzy concept such as "low relevant", "high performance", and so on. In addition, each fuzzy concept can be represented in a formula form. For instance, the fuzzy concept "Average" of Rating in Fig. 9 (a triangle curve) can be mapped to the formulas of "Average" of Rating in Table 2. In this case, the transformation between the triangle curve and the formula can be done by solving the linear equations (Wikipedia, 2007). Based on the formula-formed fuzzy membership functions, computers can then perform the operations between fuzzy

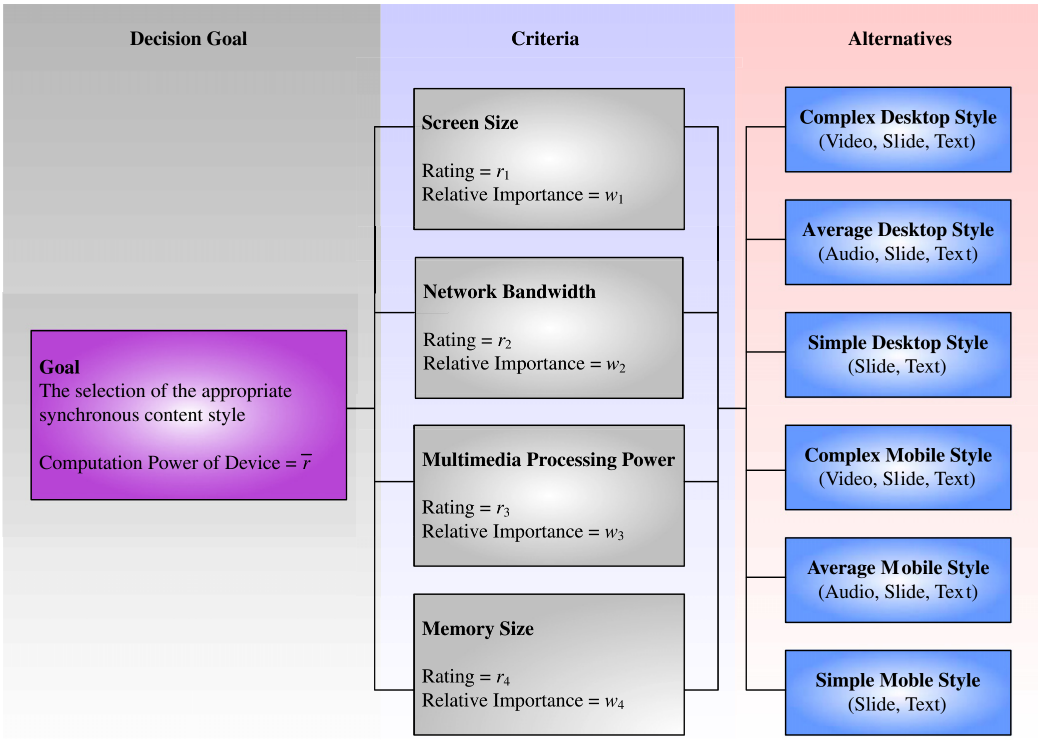


Fig. 8. The hierarchical structure of our decision problem.

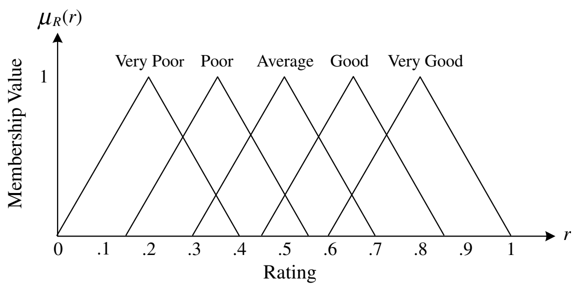


Fig. 9. The membership functions of rating level.

concepts, such as weighted average and so on. Notice that the membership functions in this prototype system are defined based on empirical rule. Readers who are interested in reproducing the context-awareness content gateway can redefine their own fuzzy membership functions based on the requirements of alternatives and the corresponding criteria:

$$\overline{r} = \frac{\sum_{i=1}^{n} w_i r_i}{\sum_{i=1}^{n} w_i} \tag{1}$$

In the decision model, the alternatives are the learning content presentation styles which consist of similar learning materials (e.g. audio, video, slide, and text), but which have quite different content presentation layouts. The alternative requiring the heaviest computation power is the Complex Desktop Style, and the least demanding learning content style is the Simple Mobile Style. All alternatives' membership functions are shown in Fig. 11. According to Fig. 8, the Complex Mobile Style consists of text, content slides, and the synchronous instructional stream. Similar to Complex Mobile Style, the Average Mobile Style adopts instructional audio

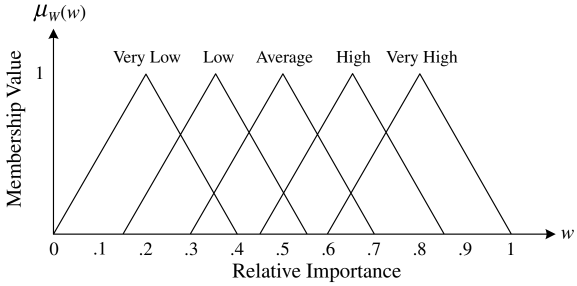


Fig. 10. The membership function of relative importance.

Table 2
The definitions of membership function

Category	Class	Membership function
Alternative	Simple mobile	$= \begin{cases} 8a, 0 \leqslant a \leqslant 0.125 \\ 2 - 8a, 0.125 \leqslant a \leqslant 0.25 \end{cases}$
	Average mobile	$= \begin{cases} 8a - 1.2, 0.15 \leqslant a \leqslant 0.275 \\ 3.2 - 8a, 0.275 \leqslant a \leqslant 0.4 \end{cases}$
	Complex mobile	$= \begin{cases} 8a - 2.4, 0.3 \leqslant a \leqslant 0.425 \\ 4.4 - 8a, 0.425 \leqslant a \leqslant 0.55 \end{cases}$
	Simple desktop	$= \begin{cases} 8a - 3.6, 0.45 \leqslant a \leqslant 0.575 \\ 5.6 - 8a, 0.575 \leqslant a \leqslant 0.7 \end{cases}$
	Average desktop	$= \begin{cases} 8a - 4.8, 0.6 \leqslant a \leqslant 0.725 \\ 6.8 - 8a, 0.725 \leqslant a \leqslant 0.85 \end{cases}$
	Complex desktop	$= \begin{cases} 8a - 6, 0.75 \leqslant a \leqslant 0.875 \\ 8 - 8a, 0.875 \leqslant a \leqslant 1 \end{cases}$
Rating	Very poor	$= \begin{cases} 5r, 0 \leqslant r \leqslant 0.2 \\ 2 - 5r, 0.2 \leqslant r \leqslant 0.4 \end{cases}$
	Poor	$= \begin{cases} 5r - 0.75, 0.15 \leqslant r \leqslant 0.35 \\ 2.75 - 5r, 0.35 \leqslant r \leqslant 0.55 \end{cases}$
	Average	$= \begin{cases} 5r - 1.5, 0.3 \leqslant r \leqslant 0.5 \\ 3.5 - 5r, 0.5 \leqslant r \leqslant 0.7 \end{cases}$
	Good	$= \begin{cases} 5r - 2.25, 0.45 \leqslant r \leqslant 0.65 \\ 4.25 - 5r, 0.65 \leqslant r \leqslant 0.85 \end{cases}$
	Very good	$= \begin{cases} 5r - 3, 0.6 \leqslant r \leqslant 0.8 \\ 5 - 5r, 0.8 \leqslant r \leqslant 1 \end{cases}$
Relative importance	Very low	$= \begin{cases} 5w, 0 \leqslant w \leqslant 0.2 \\ 2 - 5w, 0.2 \leqslant w \leqslant 0.4 \end{cases}$
	Low	$= \begin{cases} 5w - 0.75, 0.15 \leqslant w \leqslant 0.35 \\ 2.75 - 5w, 0.35 \leqslant w \leqslant 0.55 \end{cases}$
	Average	$= \begin{cases} 5w - 1.5, 0.3 \leqslant w \leqslant 0.5 \\ 3.5 - 5w, 0.5 \leqslant w \leqslant 0.7 \end{cases}$
	High	$= \begin{cases} 5w - 2.25, 0.45 \leqslant w \leqslant 0.65 \\ 4.25 - 5w, 0.65 \leqslant w \leqslant 0.85 \end{cases}$
	Very high	$= \begin{cases} 5w - 3, 0.6 \leqslant w \leqslant 0.8 \\ 5 - 5w, 0.8 \leqslant w \leqslant 1 \end{cases}$

instead of video stream, and the Simple Mobile Style separates the multimedia stream from itself. Figs. 12 and 13 show the snapshot of the Complex/Average/Simple Mobile Styles on different mobile devices respectively Fig. 13. Resembling in the structure of mobile-based presentation style, the Complex Desktop Style is the superset of the other two desktop content styles, of which snapshots are shown in Fig. 14. Finally, Fig. 15 shows the instructor teaching console for context-awareness synchronous learning environment. It consists of instructor's video stream, the lecture notes, chat-room and the control panel. In addition, we adopted Web 2.0

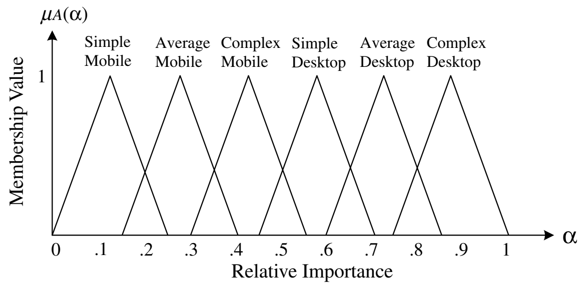


Fig. 11. The membership functions of alternatives.

Fig. 12. The snapshot of Complex Mobile Style on mobile device: (A) the video stream; (B) the slide picture; (C) the text.

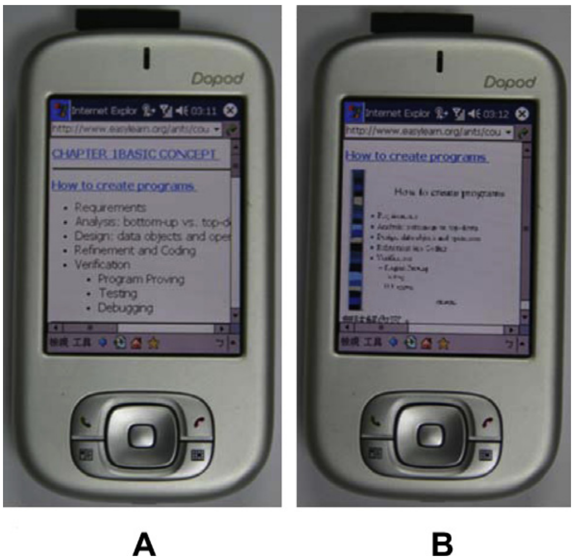


Fig. 13. The snapshot of Average and Simple Mobile Styles on PDA: (A) the text; (B) the slide picture.

technology – AJAX to enrich the friendliness and the flexibility of user interface (O'Reilly, 2005). Unlike previous synchronous instructional environments, teachers do not pre-install programs in their computers and

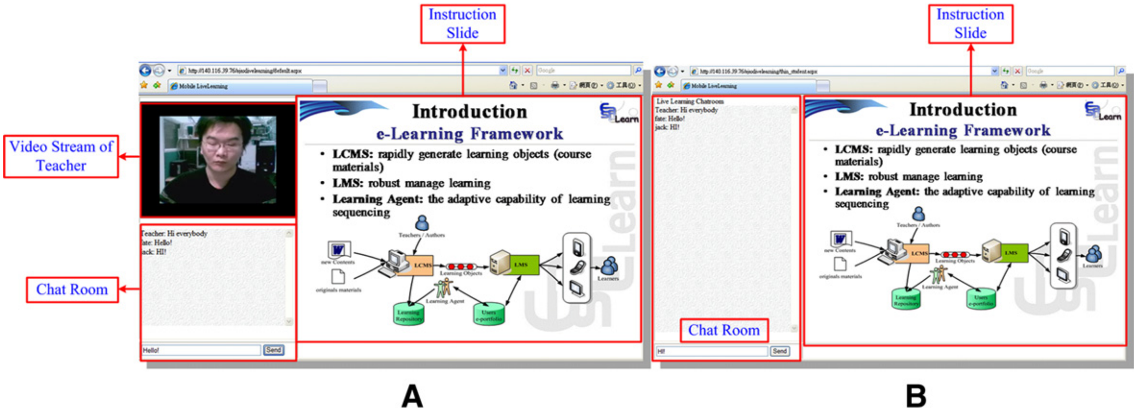


Fig. 14. The snapshot of Complex/Average/Simple Desktop Styles on desktop browser: (A) The Complex Desktop Style; (B) The Average and Simple Desktop Styles.

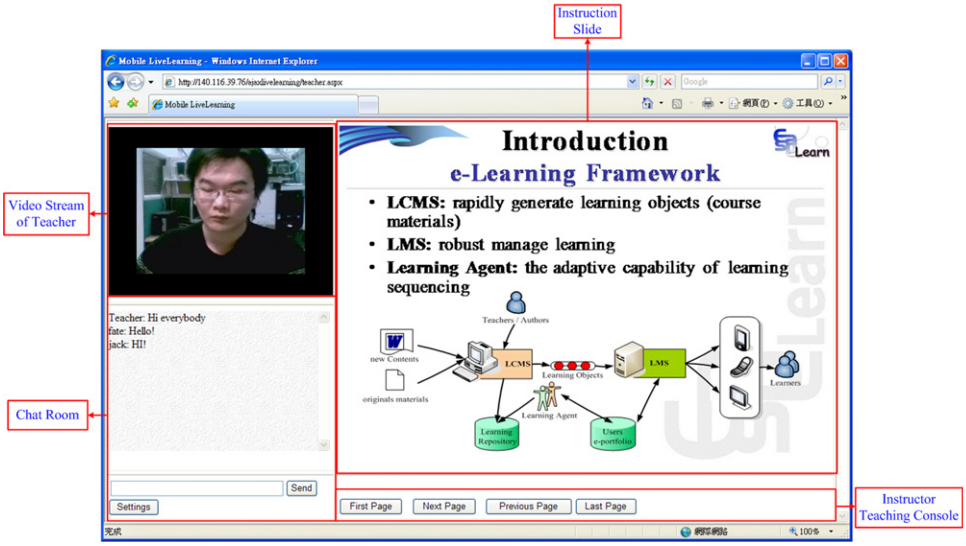


Fig. 15. The snapshot of the instructor teaching console on desktop browser.

they can manipulate the instructional console easily by Web 2.0 technology. Through the Web 2.0-based instructional console, teachers can broadcast their video stream to each student and manipulate the slide control panel to page up/down the lecture notes. They can also communicate with learners via the chatting window more smoothly. The desktop-based content styles are constructed by using AJAX technique, and the friendly interface increases the likelihood of student participation in the synchronous learning classroom.

Owing to the calculation of FWA (Dong & Wong, 1987). The $O(2^n)$ of computation time is required to produce a result. Hence, it has adopted the EFWA (Efficient Fuzzy Weighted Average) technique to replace FWA algorithm. The EFWA has improved the efficiency of the FWA algorithm, and it requires only $O(n \log n)$ of computation time to generate the weighted average result, $\bar{r}$. Referring to Figs. 9–11, Table 2 arranges the membership functions of rating levels, relative importance, and the alternatives. In Table 2, the interval of each membership function is used by EFWA for interval analyzing to compute the resultant result, $\bar{r}$. After obtaining the resultant fuzzy weighted average, it has to compare the distance between weighted average and alternatives. The approximate Euclidean distance (Dobois & Prade, 1980; Ross, Sorensen, Savage, & Carson, 1990), as Eq. (2), is adopted to be the measurement to determine the distance. In Eq. (2), the parameter X represents the resultant fuzzy membership function ($\bar{r}$), the parameter A represents the pre-defined fuzzy membership function (alternatives), and the function d is the Euclidean distance, which presents the distance between X and A. Therefore, according to the decision goal, the appropriate solution is the alternative, which minimizes the Euclidean distance d. Readers who are interested in the details of the calculation process can read Appendix A, where we have provided an illustrative example to explain the entire decision process in more detail.

$$d(X,A) = \sqrt{(X^{\alpha=0}_{\text{lower-bound}} - A^{\alpha=0}_{\text{lower-bound}})^2 + (X^{\alpha=1} - A^{\alpha=1})^2 + (X^{\alpha=0}_{\text{upper-bound}} - A^{\alpha=0}_{\text{upper-bound}})^2} \quad (2)$$

5. Evaluation

The context-awareness synchronous learning environment was designed with learning strategies and pedagogical frameworks in mind. It enables students to participate in synchronous learning environments using different kinds of devices and facilitates interaction between teachers and students. To verify the usability of the system, we surveyed ten teachers and one hundred students from the National Cheng Kung University (NCKU) and the Southern Taiwan University of Technology (STUT) using questionnaires. More specifically seventy students were from NCKU and remaining students were from STUT. Before completing the questionnaires, the students were asked to use desktop, PDA, and cellular phone at least once to join in a synchronous learning activity. The questionnaires evaluated the efficiency of teacher functions and verified the system's usability from the students' perspective. Finally, the questionnaires indicated some improvements needed to maximize the effectiveness of learning with mobile devices.

As shown in Table 3, 60% of the teachers agreed that the web 2.0 based synchronous teaching console is useful to manipulate, and 90% of the teachers think that the chat-room is useful for evaluating students' progress and gaining insight into any specific problems they may be experiencing. They also agreed that the Interactive Service Module can efficiently collect opinions from mobile and desktop learners. Teachers especially were interested in observing the Dynamic Aggregated Result Displayer, which provides teachers with students' opinions presented in a real-time manner. The messages of questionnaire results are used as a point of reference for teachers in planning future synchronous instruction, and most teachers hoped that duplicates of the results could also be sent to them via email. Some instructor's feedback indicated the questionnaire design process was too long, especially when using multimedia questionnaires. The multimedia questionnaire requires instructors to upload all used images, and this step could cost a lot of time when many images are needed or if the upload bandwidth is insufficient. The problem can be resolved by pre-designing questionnaires before synchronous instruction, but this solution cannot provide just-in-time response when teachers encounter unexpected questions. Nevertheless, instructors still rated the efficiency of gathering feedbacks via text-based questionnaires quite highly.

Table 3
The evaluation results of instructors

#	Question	Very useful	Useful	Moderate	Useless	Very useless	Average
1	How do you rate the manipulation of the Web 2.0 styled synchronous teaching console	2 20%	4 40%	3 30%	1 10%	0 0%	3.7
1	How do you rate the usefulness of discussing with students by chat-room	4 40%	5 50%	1 10%	0 0%	0 0%	4.3
2	How do you rate the usefulness of the facility of the Questionnaire Design Tool	0 0%	4 40%	4 40%	2 20%	0 0%	3.2
3	How do you rate the usefulness of the facility of the Dynamic Aggregated Result Displayer	4 40%	5 50%	1 10%	0 0%	0 0%	4.3
4	How do you rate the usefulness of the learners' feedback messages	3 30%	4 40%	3 30%	0 0%	0 0%	4.0
3	How do you rate the usefulness of collecting feedbacks from learners by Interactive Service Module	3 30%	5 50%	2 20%	0 0%	0 0%	4.1

Table 4
The evaluation results of learners

#	Question	Desktop	PDA	Cellular phone
1	How do you rate the manipulation of synchronous learning console	4.6	3.6	2.8
2	How do you rate the convenience of learning device	2.1	2.7	4.2
3	How do you rate the usefulness of discussing learning problems by chat-room	4.1	3.5	1.5
4	How do you rate the usefulness of responding your learning state by Interactive Service Module	3.9	3.3	4.3
5	How do you rate the appropriateness of the obtained learning content style (includes asynchronous and synchronous)	4.8	4.4	4.1

Scale: very useless 1 2 3 4 5 very useful.

Table 4 reveals the effectiveness of each learning function on different kinds of devices. Not surprisingly, students indicated that desktop technology can perform all system functions in an acceptable manner, and it is only in terms of convenience that desktops got a lower grade than mobile devices. Comparing PDA and cellular phone, learners complained that these devices are difficult to manipulate when they needing to frequently switch functions between programs. Nevertheless, they also indicated that if the requirements of the teaching process could be restricted to the use of a single function then the difficulty would be mitigated. Based on the feedback, we asked a teacher to do one more synchronous instruction according to our proposed learning strategy, which is to say, that instruction be followed by discussion but not interwoven with it. We then reexamined students' opinions and discovered the mobile learners responded more positively to the reconfigured instructional event. Their responses confirmed the usability of the proposed mobile synchronous learning strategy. From a convenience perspective, students praised cellular phone's accessibility and mobility. In terms of popularity learners rated desktops as highly as cell phones, but much lower than cell phones in terms of mobility. PDA rated highly in terms of mobility, but only a few of our respondents owned one, decreasing their accessibility quotient. Although PDAs are currently not popular, they still perform better than cellular phone and their use might become more widespread in the future in the form of the Smart phone or PDA phone. Similar to previous research results (Yang & Liu, 2007), Desktop and PDA learners thought that discussion in the chat-room is conducive to learning problem solving. However, students also maintained that the chat-room can quickly become confusing if there are too many threads going at one time, and that chat-rooms would benefit from an instructor to moderate the discussion. By way of contrast, cellular phone learners cannot easily interact with peers in a chat-room due to the unfriendly input interface and the insufficient function power of the phone. Most students using cell phones indicated that they prefer using Interactive Service Module to instead of chat-room interaction. In addition, they thought although the chat-room is beneficial for online problem solving, they preferred the simplicity of the interaction function when learning by cellular phone. Finally, most students agreed that their obtained learning content styles (includes asynchronous and synchronous) were appropriate and beneficial to learners who want to learn at their own convenience, in a variety of different environments.

Unlike traditional mobile learning systems, this project is integrated with interactive learning activities, which focus on raising the interest level of mobile learners and increase their level of engagement in synchronous learning. Table 5 reveals the benefits to mobile learners while using our system. Seventy percent of the mobile students agreed that learning with appropriate opportunities for interaction increased their motivation to learn using a mobile device. In addition, some of the students also indicated that, were the mobile learning functions more friendly, they would prefer learning with mobile device over learning with a desktop, because of the increased level of flexibility afforded by the mobile device. They appreciated the ability to acquire knowledge on demand (asynchronously), without the need to sit front of a desktop at certain time (synchronously). Moreover, compared to chat-room styled interactions, students thought the Interactive Service Module provided them with a simpler way to interact with teacher, and this increased their willingness to participate more interactively while engaged in mobile synchronous learning. Furthermore, learners believed that interactive synchronous learning was more efficient than text-based study. However, they also stated that

Table 5
The improvements result of mobile synchronous learning

#	Question	Very approvable	Approvable	Neutral	Opposing	Very opposing	Average
1	Comparing to traditional read-based styled mobile learning, the interactive synchronous learning activity increased your motivation when learning by mobile device	4 4%	66 66%	21 21%	7 7%	2 2%	3.63
2	The activity – “teacher assigns questions/questionnaire” increased your will of joining interactive activities during mobile synchronous learning	37 37%	45 45%	17 17%	1 1%	0 0%	4.18
3	Comparing to traditional read-based styled mobile learning, the interactive mobile synchronous learning increased your learning efficiency	19 19%	43 43%	31 31%	3 3%	4 4%	3.70

traditional, in-class teaching was best and that distance learning was, at best, a supplement. Certainly, over the course of the experiment, teachers and students made many useful comments and we will continue refine the system using their feedback.

6. Conclusions

This research is based on synchronous learning pedagogy (Chen et al., 2005) in which we enhanced the students' feedback process to achieve synchronous mobile interaction. According to the feedback process, this work implemented an Interactive Service Module to assist teacher in determining students' opinions. With the Interactive Service Module, learners are not required to key in complex text, and these features increases the likelihood of learners' online interaction by using mobile learning devices. Additionally, the Interactive Service Module cannot only be used in synchronous learning environment, but also can be applied to traditional in-class instruction. In a traditional classroom setting, teachers often ask students questions to determine the level of comprehension in the class. However, because of time restrictions, only a few students have the opportunity to present their responses to the teacher for feedback and/or evaluation. Under these circumstances, teachers can use Interactive Service Module to pose a question and garner responses from a larger number of students. Similarly, the Interactive Service Module can also be used for in-class real-time responses, voting, attendance checking, and classroom based testing with minimal time costs. Although the applications of enhancing in-class interaction are mature (Draper & Brown, 2004; Interwrite Learning, 2007; JISC funded project - University of Strathclyde, 2004; Nicol & Boyle, 2003; TurningPoint, 2006), our system still advances in that it do not require special handsets or pre-installed software to perform the interactions.

Another benefit of this work is the design of the Context-awareness Content Gateway. The content gateway has been built in a three-layer learning environment, which enables a teacher and students to join in a synchronous virtual classroom using a network of a variety of bandwidths. Furthermore, for each upcoming student session, the content gateway would automatically deliver the appropriate learning stream to the learner by analyzing current learning conditions. The Efficient Fuzzy Weighted Average technique provides the system with a comprehensible way to efficiently measure the power of learning devices, and deliver the proper learning style. Contrary to synchronous learning in the past, students can participate in a synchronous learning activity without high-end learning devices, and this substantially lowers the cost threshold of distance learning. In addition, the proposed Context-awareness Content Gateway is a general framework that can apply to other learning management systems to support the content adaptation service.

According to different learning devices, the lecture content would automatically accommodate to learners' devices before disseminating. Such content adaptation function is commendable, however it also derives another controversial issue: if students hold different learning devices to participate in the same synchronous learning activity, do they share similar learning experience? The answer is negative, since brick devices can only display simple media such as text and image, but flashy PDAs can handle fruitful multimedia and scripts. Nevertheless, our system still offers the minimum of contents just-in-time to learners who hold brick devices, and fortunately these learners could access the full version of asynchronous content later when they are at home or have stronger devices.

In this work, readers may discover that there is a conflict exists between m-learning and synchronous learning. The former stresses that it is not restricted to a location or time but the latter is only free from the location condition. Concerning this, we think that the principle of synchronous learning is to emphasize that the participants can real-time interact with each other. However, owing to the time condition, some students cannot participate in a virtual classroom during certain time period such as they are taking bus or engaging in their own businesses. In such situation, our system provides an opportunity that allows students engage in synchronous learning activities even though they cannot sit in front of computers. Moreover, these students can access the complete lecture asynchronously after the synchronous lecturing session. To sum up the previous notes, our system fuses the advantages of m-learning and synchronous learning to build a more convenient synchronous learning environment, where students can choose mobile devices as an alternative way to take synchronous course instead of sitting in front of their desktops.

Our system has another advantage derived from the saved on-line discussion record, which can be utilized to improve the synchronous learning. Based on the metacognition theory (Flavell, 1979; Schoenfeld, 1992a), the instructors and students can go through the discussion record to develop their own metacognitive strategies to help them perform better synchronous instruction and acquire better learning efficiency. From the viewpoint of instructors, they can realize the situation of the virtual classroom (interaction, discussion, and so on) in depth by referring to the discussion record. In addition, the instructors can then rely on the information to self-regulate their instruction strategies and further to refine the strategies to fit for the dynamics of synchronous learning. On the other hand, the discussion record would also assist students in rehearsing and reorganizing something what they learnt.

Finally, in addition to continuously refine the proposed system, our future research direction is to extend the scope of the system to a ubiquitous manner. In this work, the definition of context focuses on the attributes of learning devices. Such definition literally helps authors with developing the content adaptation service for the interactive synchronous learning. However, the scope of context would become wider if we zoon out our view from the m-learning to the u-learning. In ubiquitous learning environment, the context not only focuses on devices but also on the ambient objects, such as available services, locations, peers, resources, states of learners, and so on. Although the integration of these objects would increase the complexity of the entire learning environment, it might also create new applications, new learning scenarios, new instructional strategies, and other novelties impact on learning.

Acknowledgement

This work was supported in part by the National Science Council (NSC), Taiwan, ROC, under Grant NSC 95-2221-E-006-307-MY3, NSC 95-2221-E-006-306-MY3, and NSC 96-2524-S-032-001.

Appendix A

This appendix section provides an example to illustrate the decision process of the Context-awareness Content Gateway. The content gateway has adopted the EFWA (Lee & Park, 1997) algorithm as its main decision mechanism. In order to make this article self-contained, following paragraph will first introduce the EFWA algorithm, and then give an example to demonstrate how it work. The reader who is interested in the complete algorithm development and its theory can further read (Lee & Park, 1997) to obtain more detailed information.

Definition. The input a, b, c, and d are the intervals of fuzzy membership functions, and the output is the intervals of resultant fuzzy membership function. Additionally, the δ_{S_i} and the ζ_{S_i} can be calculated by Eqs. (3) and (4) with respectively.

$$\delta_{S_i} = \frac{(a_1 - a_i)e_1 + (a_2 - a_i)e_2 + \cdots + (a_n - a_i)e_n}{e_1 + e_2 + \cdots + e_n} \tag{3}$$

$$\zeta_{S_i} = \frac{(b_1 - b_i)e_1 + (b_2 - b_i)e_2 + \cdots + (b_n - b_i)e_n}{e_1 + e_2 + \cdots + e_n} \tag{4}$$

Algorithm EFWA Lee and Park, 1997.

1. Sort a's in non-decreasing order. Let $(a_1, a_2, \ldots, a_n)$ be the resulting sequence. Let *first* := 1 and *last* := n.
2. Let δ-threshold := $\lfloor(\mathit{first} + \mathit{last})/2\rfloor$. For each $i = 1, 2, \ldots, \delta$-threshold, let $e_i := d_i$ and for each $i = \delta$-threshold $+ 1, \ldots, n$, let $e_i := c_i$. For an n-tuple $S = (e_1, e_2, \ldots, e_n)$, evaluate $\delta_{S_{\delta-\text{threshold}}}$ and $\delta_{S_{(\delta-\text{threshold}+1)}}$.
3. If $\delta_{S_{\delta-\text{threshold}}} > 0$ and $\delta_{S_{(\delta-\text{threshold}+1)}} \leqslant 0$ then $L = f_L(e_1, e_2, \ldots, e_n)$ and go to Step 4; otherwise execute the following step.
   3.1 If $\delta_{S_{\delta-\text{threshold}}} > 0$, then *first* := δ-threshold + 1; otherwise *last* := δ-threshold, and go to Step 2.
4. Sort b's in non-decreasing order. Let $(b_1, b_2, \ldots, b_n)$ be the resulting sequence. Let *first* := 1 and *last* := n.
5. Let ζ-threshold := $\lfloor(\mathit{first} + \mathit{last})/2\rfloor$. For each $i = 1, 2, \ldots, \zeta$-threshold, let $e_i := c_i$ and for each $i = \zeta$-threshold $+ 1, \ldots, n$, let $e_i := d_i$. For an n-tuple $S = (e_1, e_2, \ldots, e_n)$, evaluate $\zeta_{S_{\zeta-\text{threshold}}}$ and $\zeta_{S_{(\zeta-\text{threshold}+1)}}$.
6. If $\zeta_{S_{\zeta-\text{threshold}}} > 0$ and $\zeta_{S_{(\zeta-\text{threshold}+1)}} \leqslant 0$ then $U = f_U(e_1, e_2, \ldots, e_n)$ and stop; otherwise execute the following step:
   6.1. If $\zeta_{S_{\zeta-\text{threshold}}} > 0$, then *first* := ζ-threshold + 1; otherwise *last* := ζ-threshold, and go to Step 5.

Example. In this example, it assumes a learner uses a 3G cellular phone to participate into a synchronous learning environment. The Ratings of the used 3G cellular phone's attributes and the Relative Importance are shown in Table 6. Notice that, in Table 2, values of Rating are related to Fig. 9 and values about Relative Importance are related to Fig. 10, and the parameter sets of r_i and w_i are the triangle values of membership functions (Figs. 9 and 10) with respect to $\alpha = 0$ and 1 (the α-cuts is the interval analysis technique (Dong & Wong, 1987)).

Before stating the EFWA algorithm, it chooses two values for α, viz. 0 and 1 to initial the input values. For $\alpha = 0$, the intervals of $r_{i=1\text{–}4}$ are $[a_1 = 0.15, b_1 = 0.55]$, $[a_2 = 0.45, b_2 = 0.85]$, $[a_3 = 0.3, b_3 = 0.7]$, and $[a_4 = 0, b_4 = 0.4]$, and the intervals of $w_{i=1\text{–}4}$ are $[c_1 = 0.45, d_1 = 0.85]$, $[c_2 = 0.3, d_2 = 0.7]$, $[c_3 = 0.6, d_3 = 1]$, and $[c_4 = 0, d_4 = 0.4]$. Notice that the r_i shows here have not been sorted yet. The computational procedure is shown as followings:

Step 1: Sort a's into non-decreasing order, and the resulting sequence is $[a_1 = 0, b_1 = 0.4]$, $[a_2 = 0.15, b_2 = 0.55]$, $[a_3 = 0.3, b_3 = 0.7]$, $[a_4 = 0.45, b_4 = 0.85]$. So $(a_1, a_2, a_3, a_4) = (0, 0.15, 0.3, 0.45)$, *first* := 1, *last* := 4.

Step 2: δ-threshold := $\lfloor(1 + 4)/2\rfloor = 2$, $S = (d_1, d_2, c_3, c_4) = (0.85, 0.7, 0.6, 0)$, then evaluating δ_{S_2} and δ_{S_3}, the evaluating results as shown in Eqs. (5) and (6).

$$\delta_{S_2} = \frac{(0 - 0.15) \times 0.85 + (0.15 - 0.15) \times 0.7 + (0.3 - 0.15) \times 0.6 + (0.45 - 0.15) \times 0}{0.85 + 0.7 + 0.6 + 0} = -0.0174 \tag{5}$$

$$\delta_{S_3} = \frac{(0 - 0.3) \times 0.85 + (0.15 - 0.3) \times 0.7 + (0.3 - 0.3) \times 0.6 + (0.45 - 0.3) \times 0}{0.85 + 0.7 + 0.6 + 0} = -0.1674 \tag{6}$$

Table 6
The input values related to 3G cellular phone

Criteria	Rating	Relative importance
Screen size	Poor, r_1 (0.15, 0.35, 0.55)	High, w_1 (0.45, 0.65, 0.85)
Network bandwidth	Good, r_2 (0.45, 0.65, 0.85)	Average, w_2 (0.3, 0.5, 0.7)
Multimedia processing power	Average, r_3 (0.3, 0.5, 0.7)	Very high, w_3 (0.6, 0.8, 1)
Memory size	Very poor, r_4 (0, 0.2, 0.4)	Very low, w_4 (0, 0.2, 0.4)

Step 3: Since $\delta_{S_2} < 0$ and $\delta_{S_3} < 0$, execute the following step:

Step 3.1: Let *last* := δ-threshold = 2, and go to Step 2.

Step 2: δ-threshold := $\lfloor(1+2)/2\rfloor = 1$, $S = (d1, c2, c3, c4) = (0.85, 0.3, 0.6, 0)$, then evaluating δ_{s_2} and δ_{s_3}, the evaluating results as shown in Eqs. (7) and (8).

$$\delta_{S_1} = \frac{(0-0)\times 0.85 + (0.15-0)\times 0.3 + (0.3-0)\times 0.6 + (0.45-0)\times 0}{0.85+0.3+0.6+0} = 0.1286 \tag{7}$$

$$\delta_{S_2} = \frac{(0-0.15)\times 0.85 + (0.15-0.15)\times 0.3 + (0.3-0.15)\times 0.6 + (0.45-0.15)\times 0}{0.85+0.3+0.6+0} = -0.0214 \tag{8}$$

Step 3: Since $\delta_{S_1} > 0$ and $\delta_{S_2} \leqslant 0$, $L = f_L(d_1, c_2, c_3, c_4) = a_1 + \delta_{S_1} = 0 + 0.1286 = 0.1286$. Hence, the min f_L is 0.1286 and go to Step 4.

Step 4: Sort b's into non-decreasing order, and the resulting sequence is $[a_1 = 0, b_1 = 0.4]$, $[a_2 = 0.15, b_2 = 0.55]$, $[a_3 = 0.3, b_3 = 0.7]$, $[a_4 = 0.45, b_4 = 0.85]$. So $(b_1, b_2, b_3, b_4) = (0.4, 0.55, 0.7, 0.85)$, *first* := 1, *last* := 4

Step 5: ζ-threshold := $\lfloor(1+4)/2\rfloor = 2$, $S = (c_1, c_2, d_3, d_4) = (0.45, 0.3, 1, 0.4)$, then evaluating ζ_{S_2} and ζ_{S_3}, the evaluating results as shown in Eqs. (9) and (10).

$$\zeta_{S_2} = \frac{(0.4-0.55)\times 0.45 + (0.55-0.55)\times 0.3 + (0.7-0.55)\times 1 + (0.85-0.55)\times 0.4}{0.45+0.3+1+0.4} = 0.0942 \tag{9}$$

$$\zeta_{S_3} = \frac{(0.4-0.7)\times 0.45 + (0.55-0.7)\times 0.3 + (0.7-0.7)\times 1 + (0.85-0.7)\times 0.4}{0.45+0.3+1+0.4} = -0.0558 \tag{10}$$

Step 6: Since $\zeta_{S_2} > 0$ and $\zeta_{S_3} \leqslant 0$, $U = f_U(c_1, c_2, d_3, d_4) = b_2 + \zeta_{S_2} = 0.55 + 0.0942 = 0.6442$. Hence, the max f_U is 0.6442 and stop. Accordingly, the interval for $\alpha = 0$ is [0.1286, 0.6442], in which each point is corresponding to the end points of the triangle representing the membership function.

Above process found the upper and lower bounds of synthetic membership function, and the following process will conduct the triangle value with respect to $\alpha = 1$. For $\alpha = 1$, the intervals of $r_{i=1-4}$ are $[a_1 = 0.35, b_1 = 0.35]$, $[a_2 = 0.65, b_2 = 0.65]$, $[a_3 = 0.5, b_3 = 0.5]$, and $[a_4 = 0.2, b_4 = 0.2]$, and the intervals of $w_{i=1-4}$ are $[c_1 = 0.65, d_1 = 0.65]$, $[c_2 = 0.5, d_2 = 0.5]$, $[c_3 = 0.8, d_3 = 0.8]$, and $[c_4 = 0.2, d_4 = 0.2]$. Notice that the r_i shows here have not been sorted yet.

Step 1: Sort a's into non-decreasing order, and the resulting sequence is $[a_1 = 0.2, b_1 = 0.2]$, $[a_2 = 0.35, b_2 = 0.35]$, $[a_3 = 0.5, b_3 = 0.\ 5]$, $[a_4 = 0.65, b_4 = 0.65]$. So $(a_1, a_2, a_3, a_4) = (0.2, 0.35, 0.5, 0.65)$, *first* := 1, *last* := 4.

Step 2: δ-threshold := $\lfloor(1+4)/2\rfloor = 2$, $S = (d_1, d_2, c_3, c_4) = (0.65, 0.5, 0.8, 0.2)$, then evaluating δ_{S_2} and δ_{S_3}, the evaluating results as shown in Eqs. (9) and (10).

$$\delta_{S_2} = \frac{(0.2-0.35)\times 0.65 + (0.35-0.35)\times 0.5 + (0.5-0.35)\times 0.8 + (0.65-0.35)\times 0.2}{0.65+0.5+0.8+0.2} = 0.0384 \tag{11}$$

$$\delta_{S_3} = \frac{(0.2-0.5)\times 0.65 + (0.35-0.5)\times 0.5 + (0.5-0.5)\times 0.8 + (0.65-0.5)\times 0.2}{0.65+0.5+0.8+0.2} = -0.1116 \tag{12}$$

Step 3: Since $\delta_{S_2} > 0$ and $\delta_{S_3} \leqslant 0$, $L = f_L(d_1, d_2, c_3, c_4) = a_2 + \delta_{S_2} = 0.35 + 0.0384 = 0.3884$. Hence, the min$f_L$ is 0.3884, and according to the $a_i = b_i$ (where i = 1–4, when $\alpha = 1$), it can conclude that the min $f_L = f_U = 0.3884$. For $\alpha = 1$, the obtained interval result is [0.3884, 0.3884] which corresponds to the center of the triangle. Consequently, with the intervals for $\alpha = 0$ and 1, the resulting membership function is determined and is plotted in Fig. 16.

As the result shown in Fig. 16 is fuzzy membership function, it applies Euclidean distance (as shown in Eq. (2)) to determine the closest membership function (from Fig. 11) for performing the decision goal. Following shows how to adopt the Euclidean distance to determine the proper style. Eq. (13) calculates the distance between resultant membership function (Fig. 16) and the membership function of Complex Mobile Style (Fig. 11).

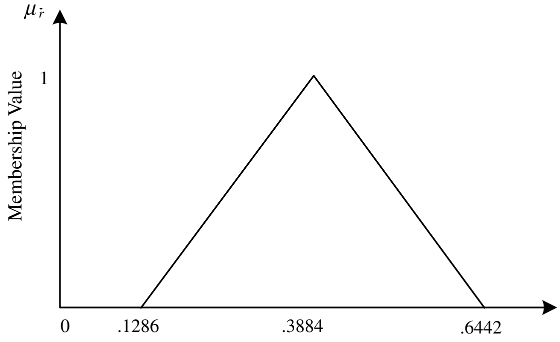


Fig. 16. The resultant membership function.

$$d(\bar{r}, A_{\text{Complex Mobile}}) = \sqrt{(0.1286 - 0.3)^2 + (0.3884 - 0.425)^2 + (0.6442 - 0.55)^2} = 0.1990 \quad (13)$$

Based on the measured results, the other Euclidean distances are $d(\bar{r}, A_{\text{Simple Mobile}}) = 0.4912$, $d(\bar{r}, A_{\text{Average Mobile}}) = 0.2701$, $d(\bar{r}, A_{\text{Simple Desktop}}) = 0.3758$, $d(\bar{r}, A_{\text{Average Desktop}}) = 0.6147$, and $d(\bar{r}, A_{\text{Complex Desktop}}) = 0.8657$. After measuring all of the Euclidean distances between resultant membership function and all alternatives, the Context-awareness Content Gateway determines the Complex Mobile Style is the closest alternative, and should be applied to present learning content.

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