Computers & Education 57 (2011) 2212–2223

Contents lists available at ScienceDirect

Computers & Education

journal homepage: www.elsevier.com/locate/compedu

Accumulating and visualising tacit knowledge of teachers on educational assessments

Tzone-I Wang [a], Chien-Yuan Su [a,*], Tung-Cheng Hsieh [b]

[a] Department of Engineering Science, National Cheng Kung University, Tainan 701, Taiwan, ROC
[b] Department of Multimedia and Game Science, Taipei College of Maritime Technology, Taipei 111, Taiwan, ROC

ARTICLE INFO

Article history:
Received 13 December 2010
Received in revised form
29 June 2011
Accepted 30 June 2011

Keywords:
Applications in subject areas
Architectures for educational technology system
Elementary education
Human–computer interface
Improving classroom teaching

ABSTRACT

Assessments, embedded with teachers' implicit (i.e. tacit) domain knowledge, play an important role in evaluating 'comprehension of a subject. The knowledge on the importance of both the concepts and their relationships of a subject, if captured, made explicit, and shared around, may greatly help teachers construct more effective assessments. This study establishes a methodology to accumulate tacit knowledge of specific topics from collected assessments by using an implicit knowledge extraction mechanism and, visualises the overall importance distribution of concepts by using knowledge maps for helping teachers compile their assessments. Several two stage experiments, scheduled for one semester, were conducted in the third grade natural science courses at elementary schools in Taiwan. Eighteen teachers who actually teach the courses participated in the experiments, and thirty students were in each course. In the first stage, teachers compiled assessments without using IKMAAS's knowledge map features while in the second stage, they did use them. System usage records, questionnaires and interview results were used for evaluating the usability of the methodology and the satisfaction of using IKMAAS. The results indicate the potential of the methodology, as each of the teachers agreed that the visualised assessment knowledge helped them to comprehend the proportions of concepts they intended to test easily and, additionally, helped them to clearly notice concepts they may have ignored. Yet the results in this study also show the potential of using knowledge maps and knowledge accumulating methodology in pedagogy paradigm.

1. Introduction

The abundance of widely available computer-related technologies has had a significant impact on educational settings and educational assessment. The benefits of computer-based assessment are immediate, unbiased and accurate scoring; enhanced feedback; decreased economic costs of manual data input; convenient individualised administration and improved test security. These innovations will surely be beneficial given that the computer has the ability to do all of the routine work involved in test administration (Kveton, Jelinek, Voboril, & Klimusova, 2007).

At present, many assessment systems or tools have been built to assist educators in creating and managing tests in the primary and secondary education environments in Taiwan. Instructors usually use these tools to harness freely shared item banks to edit, select, arrange, and administer their test items and test sheets. In this context, how they determine a proper concept-item proportion is a critical part of the development of a test sheet (Yin, Chang, Hwang, Hwang, & Chan, 2006). Teachers might create improper proportions and relationships between concepts and test items when developing test sheets, perhaps due to ignorance or subjectivity (Panjaburee, Hwang, Triampo, & Shih, 2010). In addition, they may encounter difficulties in the allotment of course concepts and test items, and by neglecting key points in the curricula, they may assess course concepts disproportionately in their assessments (Su & Wang, 2010). The whys and wherefores of such difficulties are twofold. First, even veteran teachers might forget to test some important concepts without a visual overview of the distribution of concepts covered by the test items. Second, novice teachers, without much assessing experience, may not appreciate the relative importance of concepts to be tested and may fail to arrange the test items with a proper ratio reflective of the relative importance of these concepts. Yang and Chan

* Corresponding author.
E-mail address: n9897108@mail.ncku.edu.tw (C.-Y. Su).

0360-1315/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.compedu.2011.06.018

(2008) have ever indicated that a multi-expert approach is a more effective means of recognising and rejecting incorrect solutions and suggestions compared to a single-expert approach. Moreover, information and knowledge reuse minimises the need to refer explicitly to past projects, reduces the time and cost involved in solving problems, and improves the quality of solutions during the construction of assessments (Lin, Wang, & Tserng, 2006). Several enabling activities should be performed to help attain the eventual goal of experience and knowledge reuse: experience and knowledge should be preserved and managed; restated activities should be captured, modelled, stored, retrieved, adapted, evaluated and maintained; and assessments should promote knowledge acquisition, sharing and application so as to achieve innovation (Lin et al., 2006). Therefore, knowledge acquired by the collaboration of teachers about the relative importance of and the relationships between course concepts should be an effective tool for helping inexperienced teachers, especially when experienced teachers cooperate to combine their assessment knowledge and experience into one knowledge base (Nevin, Thousand, & Villa, 2009; Panjaburee et al., 2010). When captured knowledge is reused and shared among teachers, it can enhance the construction process and decrease the time and cost of problem solving as well as improve the quality of solutions. Novice teachers can then employ valuable assessment knowledge taken from multiple expert teachers to determine a more accurate distribution of concepts to be assessed via the test items.

Although the sharing of assessment experiences and knowledge does not guarantee effective learning and teaching, it helps to develop a knowledge base for assessment that is more applicable to real educational assessment settings. Assessment enhancement depends largely on how teachers make sense of sharing their experience, their perception of how suitable the experiences of others are to new teaching contexts and how they adjust their own teaching practises to meet the perceived demands of new contexts (So, Pow, & Hung, 2009). However, most assessment project-related problems, solutions, experiences and know-how reside in the head of the teacher during the assessment-construction phase. This implicit knowledge is usually abstract and unstructured and is normally not documented or stored in any system database. Capturing implicit assessment knowledge and turning it into a form of explicit knowledge is important for preserving implicit knowledge as assessment properties as well as for executing knowledge management.

One of our studies built a prototype assessment system, called the Knowledge Map Assisting Assessment System (KMAAS) to assist primary school teachers in creating assessments (Su & Wang, 2010). It automatically performs concept extractions from course materials, analysis their relative importance, and classifies collected test items to establish their associations with the concepts. The KMAAS helps teachers analyse and reorganise their own collections of test sheets and test items and provides a search method for retrieving concept-associated test items from an item bank. Teachers may refer to an automatically constructed knowledge map with concrete weights that show the relative importance of course concepts and their interrelationships in the specified testing range, and they may also refer to another knowledge map that shows the current proportion of concepts embedded in the items on a test sheet and is updated in real-time when test items are rearranged. All of their assessments, which implicitly contain their valuable knowledge and experience, are kept in the test sheet bank. This sheet bank is a preliminary assessment knowledge base for sharing among teachers. One critical issue is how to define and implement a methodology to further extract and integrate teachers' assessment knowledge and experience as well as how to visualise and share this knowledge.

This study proposes a knowledge accumulation and sharing methodology to capture and manage teachers' assessment knowledge when they are compiling assessments to benefit their future assessment work. This methodology is realised in the KMAAS as a knowledge management framework that carries out the acquisition and conversion of teachers' assessment knowledge and allows it to be shared among teachers, assisting them in assessment tasks. The revised Internet-based KMAAS operates in two phases. The first is to automatically extract and compile teachers' knowledge on assessment tasks and specific subjects based on their item-selecting records. The second is to calculate and transform item and course concept probability distribution into knowledge maps that displays the teachers' accumulated assessment knowledge. These visual overviews constructed and presented by the framework are used for item-selection assistance that supports teachers in their compilation of assessments.

The remainder of this paper is organised as follows. The relevant literature is reviewed in the next section. A description of the architecture of the Internet-based KMAAS and its modules, as well as the experiments and the corresponding results, are discussed in the next two sections. Finally, conclusions and future work are presented in the last section.

2. Review of the literature

Most classroom assessments involve test items that teachers have constructed by themselves. Teachers usual play a critical role in determining assessments, and they strive to find suitable specific weights in accordance with course goals on course assessments. Meng, Ye, Roy, and Padilla (2007) argue that certain goals should be taken into account when developing a test within a certain discipline. These goals include the following:

- To identify the scope of knowledge points and their distribution proportions in a test;
- To identify the distribution of teaching requirements, which can be represented by Bloom's taxonomy;
- To identify the difficulty distribution (e.g., a test consisting of 10% very difficult test items, 20% difficult items, 40% medium difficulty items, 20% easy items; and 10% of very easy items);
- To identify the structure of a test (i.e., the types of test items and the quantity and score of each type).

To fulfil these goals, valuable implicit assessment knowledge and experience are definitely among the decisive elements.

2.1. Implicit assessment knowledge and knowledge management

Carroll and Moody (2006) proposed that the percentage of points per topic/concept on the test should be directly related to the percentage of instruction time spent on that objective. Thorough coverage of the content can be ensured by outlining the main topics and balancing questions from each topic/concept studied. Teachers think like assessors who must judge what students should know, understand, and be able to do as well as what understanding is worthy, what enduring understanding is desired, and how to determine whether students have achieved the desired results and met the standards (Shepard, 2000). Teachers must rely on advice, opinion, experience, and common sense to direct them when constructing classroom tests that produce reliable and valid scores (Frey, Petersen, Edwards, Pedrotti, & Peyton, 2005). Cizek, Fitzgerald, and Rachor (1995) surveyed 143 elementary and secondary school teachers and found that assessment practises "were highly variable and unpredictable from characteristics such as practise setting, gender, years of experience, grade level or familiarity with assessment policies in their school district". They concluded that "many teachers seemed to have individual assessment policies that reflected their own individualistic values and beliefs about teaching". Wang (2000) also argued that teacher-made assessments convey teachers' ideas and beliefs. As icebergs hidden under sea level, these beliefs often determine the teachers' instructional and assessment practises. Xu and Liu (2009) assent that teachers' experiences with assessment reveal that their knowledge is not a static end product but rather a highly complex, dynamic, and ongoing process. They also argue that teachers' knowledge of assessment develops along a temporal continuum in the sense that teachers usually use their prior assessment experience to inform their current assessment practises, which, in turn, further informs their future plans. More recently, researchers also suggests that teachers do not use externally prescribed standards alone as a basis for judgement; they also turn to their own implicit knowledge and beliefs, especially when conflicts arise between their personal assessment and standardised criteria (Arkoudis & O'Loughlin, 2004; Davison, 2004).

Implicit knowledge and beliefs about assessment are generally highly personal, context-specific, and difficult to formalise, record, and articulate; they house in teachers' brain, such as expertise, intuition, understanding, or professional insight formed as a result of experience, and is then internalised as tacit knowledge. Conversely, explicit knowledge, including reports, articles, manuals, pictures, images, video, audio and software, refers to codified knowledge that is easily expressible, verbal, and simple to codify. It is transmittable in formal systematic language and is easily transferred using Information Technology (IT) (Mitri, 2003; Polanyi & Sen, 2009). Zhao (2010) further mentioned that tacit knowledge has yet to become explicit knowledge, which is often acquired through the long-term accumulation of the knowledge of individual teachers. It is usually difficult to express with words, and it cannot be transmitted to others or spread very easily. Namely, if this knowledge can be made explicit, properly described and explained, and freely articulated, teachers will use and acquire it easily thereafter.

Knowledge management involves capturing tacit knowledge and transforming it into explicit knowledge for further sharing. Tacit knowledge management can be facilitated through technologies commonly used in knowledge management systems, such as databases, Internet architectures, artificial intelligence, and decision support techniques (Mitri, 2003). Some knowledge acquisition techniques are useful for eliciting tacit knowledge and knowledge discovery techniques involving data mining and induction. These techniques can help to create new knowledge by identifying patterns and relationships in data repositories. School knowledge accumulation is the accumulation of the results of knowledge applications and innovations within schools by school members, equipment entities, and technical documents.

In the present study, we argue that information gleaned from teachers' classroom assessment procedures can be thought of as school knowledge to be managed in the sense that assessment knowledge, experience and know-how reside in the heads of individual teachers. Furthermore, assessment knowledge accumulated during the assessment-construction phase from multiple members of the same curricula domain can be more valuable. Implicit knowledge is normally not documented or stored in a system database. Therefore, methods of capturing and integrating teachers' individual experiences and tacit knowledge, transforming it into explicit knowledge, and spreading it to teacher organisations is an important task for executing school knowledge management and for preserving implicit knowledge as valuable school property.

2.2. Knowledge visualisation and knowledge map

Knowledge visualisations, including rule bases (O'Leary & Selfridge, 1999), semantic networks (Kuwata & Yatsu, 1997) and frame representations (Gaines & Shaw, 1995), have been utilised in knowledge management systems and are useful for knowledge codification, search and retrieval. According to conjoint retention theory (Verdi & Kulhavy, 2002), features and structural information can facilitate both the coding and later recall of accompanying texts. Visualised features aid in recall when they are visually distinct and drawn in such a way that they activate prior knowledge about the represented place. Structural knowledge establishes a spatial frame that references visual features and verbal knowledge to enable efficient comprehension. Increasing research has produced evidence suggesting that the use of graphic structure to represent knowledge of a focused topic has gained increasing attention in various fields. This knowledge representation framework denotes terms, concepts, or basic knowledge elements through notes in the graph and facts, propositions, or associations by linking two or more nodes to reflect their relationships with each other (Tseng, Chang, Rundgren, & Rundgren, 2010). Larkin & Simon describe how diagrams, in comparison to texts, can offer more efficient support for comprehension and problem solving. Maps are a form of knowledge visualisation that may lower the cognitive load needed to add new associations to those already linked with previously encountered concepts by allowing a more efficient visual search than text passages (Larkin & Simon, 1987). The framework of maps has been shown not only to increase text recall (Abel & Kulhavy, 1986) but also to help better organise, display and understand knowledge. Several representational methods exist for maps, including the knowledge map, cognitive map, knowledge networking chart, list chart, category map, topic map and concept map (Yang, 2007). These maps are similar to each other in knowledge representation but are different in their specific details and application objectives (Tseng et al., 2010).

Davenport and Prusak observed that the development of a knowledge map involves locating important knowledge in the organisation and then publishing a list or several pictures showing where to find it (Davenport & Prusak, 2000). Knowledge maps (O'Donnell, Dansereau, & Hall, 2002) are diagrams that represent ideas as node-link assemblies, which involve the display of acquired knowledge and relationships. The knowledge in a knowledge map may involve various shared contents, such as text, graphics, videos, models and data. The relationships among them are determined by linking concepts or topics discovered from this shared content. Knowledge map techniques serve as a tool for human beings to better understand the structure of important knowledge or competence and their relationships to people, groups or other organisational units that create, hold, seek, distribute or apply the knowledge (Liu, Li, & Lv, 2009). Node-link knowledge maps have drawn significant interest among educational researchers (Nesbit & Adesope, 2006). They are often used as media for constructive learning activities and as communication aids in lectures, study materials, and collaborative learning (Cañas et al., 2003). More importantly, however, knowledge maps can serve as a means of navigating the required knowledge. They have the advantage of simplifying the relational complexity of information and structuralizing information and knowledge (Shaw, 2010).

Knowledge maps are not only effective knowledge management tools for knowledge navigating and searching but they also specify captured knowledge and its relationships and display them in ordered and friendly forms (Mertins, Heisig, & Vorbeck, 2003). Knowledge maps play important roles in implementing knowledge management by transferring certain aspects of knowledge into a graphic form that is easily understood by end-users. All captured knowledge can be summarised and abstracted through a knowledge map. Knowledge maps gather explicit and collected knowledge, which can be shared and can facilitate the emergence of tacit knowledge of new relationships (Yang, 2007).

In summary, knowledge maps can help to facilitate information research in a specific domain. Moreover, using knowledge maps can help present concept–item relationships of the assessment scope in a more structured manner so that teachers can easily construct their assessments (Su & Wang, 2010). Because of these features, a knowledge map can assist teachers by serving as a tool allowing them to see key concepts quickly, identify important processes and gain insight into associated behaviours. It is important to realise that teachers working on assessment projects act just like knowledge workers who facilitate the collection and management of knowledge from past, current, and even future assessment projects. To enhance knowledge usage, teachers must innovatively utilise the knowledge created and accumulated through historic assessment projects. They must also share this knowledge across future assessment projects, a task which presents the challenge of how to reuse past knowledge and experiences to shorten assessment projects and reduce overhead costs for both the present and the future. Our aim in this study is to utilise knowledge management and knowledge maps to solve the problems mentioned above and to enhance assessment performance.

3. The methodology and the system architecture

This section describes the knowledge accumulation and extraction methodology and the architecture of the Internet-based KMAAS (IKMAAS) assessment system, which uses knowledge maps to display teachers' accumulated assessment knowledge. IKMAAS draws tacit assessment knowledge from teachers' historical assessments and refines, converts, and employs this knowledge to assist teachers in assessment compilation and test item arrangement.

3.1. Knowledge accumulation and visualisation methodology

One of the most important functions of IKMAAS is to automatically accumulate and extract teachers' assessment experience and knowledge of specific courses. After being compiled and saved in an assessment bank, a test sheet has a configuration of the proportions of test items to each concept. The configuration keeps exactly the item-selecting records of its creator in a specific range of a course and the proportions are exactly reflective of how the creator sees the importance of each concept (i.e., her/his assessment experience and knowledge) in the course range. Thus, each of the test sheets in the assessment bank becomes a source of assessment knowledge. Such proportions of test items to each concept in every test sheet of a course range are accumulated and calculated as weight appraisal that reflect the common consensus of all of the teachers on the importance of each concept in the course range. Each of the concepts keeps a weight to reflect its degree of importance. KMAAS have established the cold-start weight of each concept automatically (Su & Wang, 2010). The weight of a concept may change when a completed test sheet is put into the assessment bank. It all begins when a teacher selects a course range and the number of test items for an assessment. All the concepts within the range are shown in the first knowledge map, with their weight percentiles given to show their relative importance. Eq. (1) normalises a concept weight to its percentage, in which there are n concepts found in the selected range, CWP_a is the weighted percentile of concept a, and CW_a is the original concept weight of a.

$$CWP_a = \frac{CW_a}{\sum_{i=1}^{n} CW_i} \times 100\% \tag{1}$$

According to the weight percentile of all the concepts and the number of test items given by the teacher, IKMAAS calculates and recommends for each concept a proper number of test items to test in the assessment. After a test sheet is compiled, the number of test items given by the teacher to test for a concept might be different from what IKMAAS recommends. To adjust the weights of all the corresponding concepts in the accumulated assessment knowledge base, into which the assessment knowledge of the test sheet is fused, the proportion of test items to each concept on the test sheet must be examined and a dynamic weighting adjustment for each concept be computed. Eq. (2) computes the dynamic weighting adjustment for each concept, in which x is the number of test items that IKMAAS suggests for concept a, which is at least 1; y is the number of test items given by a teacher for concept a; and m is the number of test items for the assessment given by the teacher.

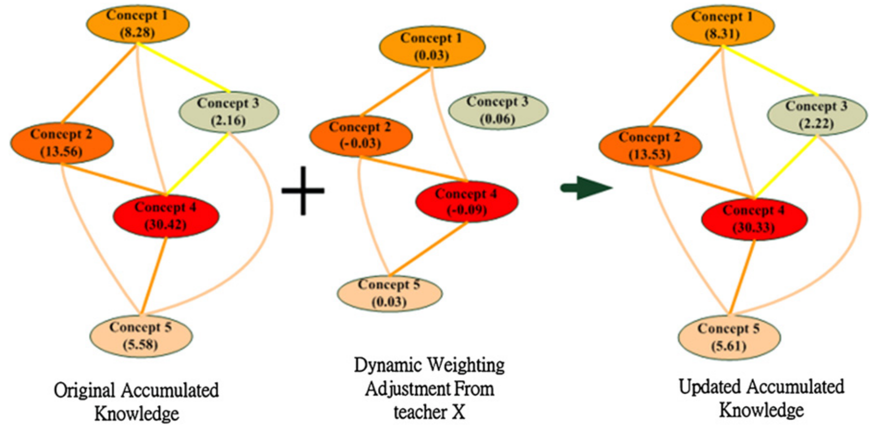
$$DWA_a = \frac{y - x}{m^* 100} \sum_{i=1}^{n} CW_i \tag{2}$$

Negative DWA_a indicates that a teacher sees a concept less important and gives fewer test items than what IKMAAS suggests, in which case the weight of the concept will be decreased, and vice versa. The new weight of concept a is then its original weight plus DWA_a as in Eq. (3).

$$CW_{a(new)} = CW_a + DWA_a \tag{3}$$

CW_a is the original weight of concept a and $CW_{a(new)}$ is the new weight of concept a. The total summation of all the concept weights in the selected range will remain the same and will only be redistributed to the concepts. An example of computations by Eq. (1–3) is shown in Fig. 1. When teacher X selects a course range for assessment and decides to use 20 test items to test the students, the IKMAAS refers to the original weighted percentile of the, in this case, 5 concepts ($CWP_{1–5}$) in the range and gives the item number suggestions, i.e. $C_1 = 3$, $C_2 = 5$, $C_3 = 1$, $C_4 = 9$, $C_5 = 2$. Teacher X refers to the suggestions but finally gives the items for $C_1 = 4$, $C_2 = 4$, $C_3 = 4$, $C_4 = 5$, $C_5 = 3$. The variation in item numbers triggers Eqs. (2) and (3) to update the concept weights of the five concepts accordingly.

Another statistic is used to examine all of the test items in the assessment bank and calculate the relationship closeness between each concept pair by recording the probability of their simultaneous appearance in test items. Such information in a selected range of a course will be presented to teachers when they select the range for an assessment. This kind of knowledge reflects the common consensus of all of



Concepts	*CW*	*CWP*	Number of items suggested by IKMAAS	Number of items given by a teacher	Dynamic weighting adjustment	$CW_{(new)}$	$CWP_{(new)}$
C1	8.28	13.80%	3	4	0.03	8.31	13.85%
C2	13.56	22.60%	5	4	-0.03	13.53	22.55%
C3	2.16	3.60%	1	4	0.06	2.22	3.70%
C4	30.42	50.70%	9	5	-0.09	30.33	50.55%
C5	5.58	9.30%	2	3	0.03	5.61	9.35%
Total	60.00	100%	20	20	0.00	60.00	100%

Fig. 1. An example of knowledge accumulation.

the teachers on how close two concepts are related and the tendency these two concepts are tested together in a test item. The Apriori Algorithm is simplified in this study for calculating the probability of simultaneous appearance of each pair of concepts and its parameters, the minimum support and the item sets, are set to 1 and 2 respectively. Fig. 2 demonstrates an example with three test items which test concepts {A, B, C}, {A, B, D} and {B, C} respectively in a same assessment; it shows the first two steps that find the supports of each pair of concepts. The first step is to find the support for each concept, which turns out to be 2, 3, 2, 1 for concept A, B, C, D, and finds out the concepts with support 0, which, in this case, does not happen. Because the supports of the four concepts are all larger than the minimum support 1, they all are entered into the second step that pairs all the concepts, finds their supports, and filters out the pair with support 0 as well, which, in this case, does not happen either.

The next step is to calculate for a concept the value of confidence on the other, and vice versa, in a pair by Eq. (4).

$$Confidence(A \rightarrow B) = P(B|A) = \frac{(Support - Count(A \cap B))}{(Support - Count(A))} \tag{4}$$

where, *Confidence(A→B)* is the confidence that concept *A* has on concept *B*.

Both *Confidence(A→B)* and *Confidence(B→A)* are calculated, but to keep the knowledge map used to show the relationship strengths between concepts simpler and clearer only the minimum between them is used with the assumption that one of them is supposed to be the major concept to be tested in the test item. As seen in Fig. 2, concept *A* has support 2 whereas *B* has 3, so Eq. (4) yields *Confidence(A→B)* to 1 and *Confidence(B→A)* to 0.67, which is minimum and is then chosen as the relationship strength between concepts *A* and *B*. All the concept pairs left in Fig. 2 go through the same calculations too.

Minimum support count=1

Sample Database	
TID	Item ID
Paper 1	{A,B,C}
Paper 2	{A,B,D}
Paper 3	{B,C}

C_1	
Item set	Supp
A	2
B	3
C	2
D	1

L_1	
Item set	Supp
A	2
B	3
C	2
D	1

C_2	
Item set	Supp
{A,B}	2
{A,C}	1
{A,D}	1
{B,C}	2
{B,D}	1
{C,D}	0

L_2	
Item set	Supp
{A,B}	2
{A,C}	1
{A,D}	1
{B,C}	2
{B,D}	1

The process is stopped since itemsets=2

Fig. 2. An example of support calculation.

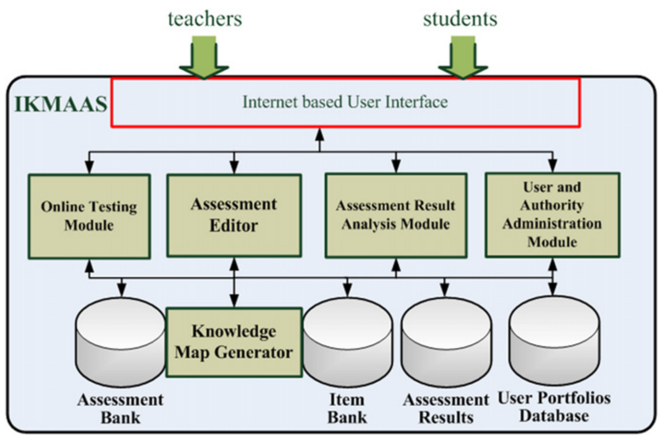


Fig. 3. The architecture of the IKMAAS.

IKMAAS manages these accumulated assessment knowledge for all the concepts in a course and renews it when there is a new test sheet goes into the bank. It uses two knowledge maps to graphically reveal the two accumulated assessment knowledge in a specific range to help teachers making decisions when they are creating assessments for that range.

3.2. The IKMAAS architecture

The architecture of the IKMAAS, as shown in Fig. 3, comprises four main modules: the Assessment Editor, the Online Testing Module, the Assessment Result Analysis Module, and the User and Authority Administration Module. Two Internet-based user interfaces, one for teachers and one for students, allow users to interact with various modules of the system to access all of the designated functions of the IKMAAS.

3.2.1. Assessment editor

The Assessment Editor is the core of the system, which uses two knowledge maps generated by the Knowledge Map Generator to offer appropriate information for teachers to use in guiding their assessment compilations. The first knowledge map explicates teachers' accumulated assessment knowledge by showing the importance weights of all of the relevant concepts and their interrelationships. The weight of a concept represents the importance of the concept according to all teachers who are using the IKMAAS; this importance is reflected in the average number of test items selected for the concept by the teachers. The second map shows the current concept distribution on the test items on the test sheet being compiled. These maps can help teachers develop a comprehensive understanding of the relative importance of the concepts and their proportions among the test items. It can also assist them in making decisions regarding test item-selection and creation. After a teacher selects a test range, all concepts within it are presented in the first knowledge map, with concept weight percentiles given to show their relative importance. During compilation, test sheets are analysed in real-time by the Knowledge Map Generator to produce the second knowledge map (described above). This knowledge map allows the compiler to select the appropriate number of test items from the Item Bank.

3.2.2. Knowledge map generator

A knowledge map is a graphical presentation method that expresses the concepts and their interrelations within a specific context. Nodes represent concepts, and labelled links represent the relationships between the concepts. In this study, the keywords listed in the

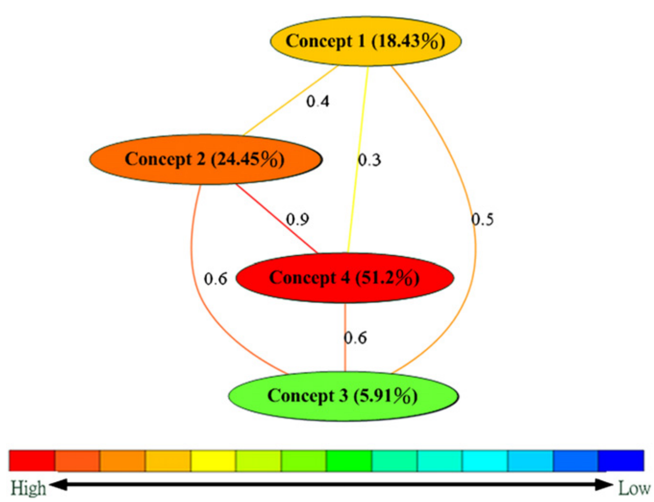


Fig. 4. Colour-marked concepts in the knowledge map.

textbook or teaching materials are used as nodes to represent concepts to construct knowledge maps for an assessment range in a given curriculum. Knowledge maps are generated by Graphviz and indicate the importance of concepts using the colour marks shown in Fig. 4 (concepts marked with colours on the left hand side of the colour bar are more important).

3.2.3. Online testing module

This module allows students to use online tests for practise. In addition, it allows teachers not only to schedule official online tests for students but also to manage the item bank. Only authorised pupils who are registered for a course are given access to official tests. Each test sheet can be taken online with or without time limits. This module offers additional options, such as random question ordering, login restrictions, and tools to prevent students from copying their peers' answers.

3.2.4. Assessment result analysis module

This module analyses and collects assessment results after students complete the tests. It provides essential statistics, including total score, answer outcome and corrections. If the configuration option is set, it will give detailed feedback, including explanations for correct and incorrect answers. It also collects students' assessment results for each test in the assessment portfolio and supports knowledge map analyses to help teachers understand students' mistakes so that they can make corrections on future tests.

3.2.5. User and authority administration module

This module allows administrators or teachers to manage users and their authority in the system, such as users' personal details, domain teacher group membership and authorisation. Teacher groups are arranged and managed in accordance with different disciplines to collect peer teachers' assessment knowledge. The module allows teachers to choose whether to share their own test items and assessments at the single-subject level.

4. System operations

The operational IKMAAS gives teachers all the conveniences to construct their assessments and accumulate, manage and share their assessment knowledge. Teachers can reuse, edit, and create test items, compile assessments, and share assessment knowledge. The user interface has two parts: one for students and one for teachers. The web-based IKMAAS is accessible in anytime and from anywhere. An example on an assessment compilation regarding the natural science course of the third grade in a Taiwan primary school is shown in Fig. 5. A teacher can arrange an assessment in four steps. Step one selects the scope of a course or the learning material to be tested and determines the maximum number of test items within the assessment scope. Step two involves selecting test items from an item bank. Items related to the testing scope appear in an item table (as shown in lower part of Fig. 5), which also contains information about learning goals, subjects, themes, difficulty levels and the skill levels according Bloom's cognitive taxonomy. Some real-time statistics about the selected test items, including the number of concepts covered and the numbers of test items in different indexes of Bloom's cognitive taxonomy, difficulty, and discrimination, will appear just below the item table for the teachers' reference. An extra option allows teachers to modify selected test items or to create new ones using an item editor (as shown at the bottom of Fig. 5). At the same time, this step uses two knowledge maps displaying the accumulated assessment knowledge that is designed to help teachers compile their test sheets. The example shown in the highest frame of Fig. 3 reveals how all teachers who use the IKMAAS rate the relative importance of the relevant concepts in the selected test range. Oval nodes in the figure represent concepts, and the percentile numbers within them are their degrees of relative importance. When this number is higher, it means that teachers more often selected or created test items to test that concept. The number labelled on the link between two concepts represents how often the two concepts are tested together in the same assessment. For each concept, these numbers provide teachers with suggestions on how many test items should be arranged, selected from the item bank or created on-site as well as advice on how the concepts should be organised. Of course, teachers are free to make their own choices as to the number of test items for each concept; their decisions, however, will later affect the accumulated assessment knowledge. Another knowledge map, shown in the second frame of Fig. 5, provides teachers with an analysis of the accumulated results of assessments within the same selected range. The number in a concept node represents the percentage of students who incorrectly answered test items for this concept; when the number is higher, more students misunderstood the concept. The number labelled on the link between two concepts represents how often the two concepts are misunderstood together in the same assessment. Step three is to generate an assessment for the students after all of the test items are arranged. An assignment is transformed into online quizzes or a printable test sheet. It can be saved in the Assessment Bank for sharing with other teachers. Teachers can then use these documents to create additional assignments by editing test items according to their needs.

The Assessment Result Analysis Module of the IKMAAS also provides helpful information for teachers by utilising a knowledge map that shows the proportion of misunderstood concepts in some specific courses (as shown in Fig. 6). Such information is produced from the accumulation of assessment results taken from either online quizzes or classroom tests; it provides important statistics that will help teachers assist their students in the future.

The students' user interface allows students to receive feedback immediately after finishing an online test. An essential statistical table presents the total score and the proportion of correct to incorrect answers.

5. Evaluation and discussion

The IKMAAS has being operational for one and a half years, and actually used for compiling many school assessments. While, to precisely evaluate the feasibility of the IKMAAS, several experiments scheduled for one semester (over four months) were conducted in the third grade natural science courses at elementary schools in Taiwan. Eighteen teachers currently teaching or having taught the courses participated in the experiments, and each of the courses has about thirty students enrolled. Two stages were scheduled and were alternately conducted on four different subjects within the courses. In the first stage, teachers used the IKMAAS to compile assessments without using the knowledge map features. In the second stage, teachers used the IKMAAS and the various knowledge maps available. Evaluations of the experiments included system usage records, questionnaires and interviews with all of the teachers. These data were collected to examine

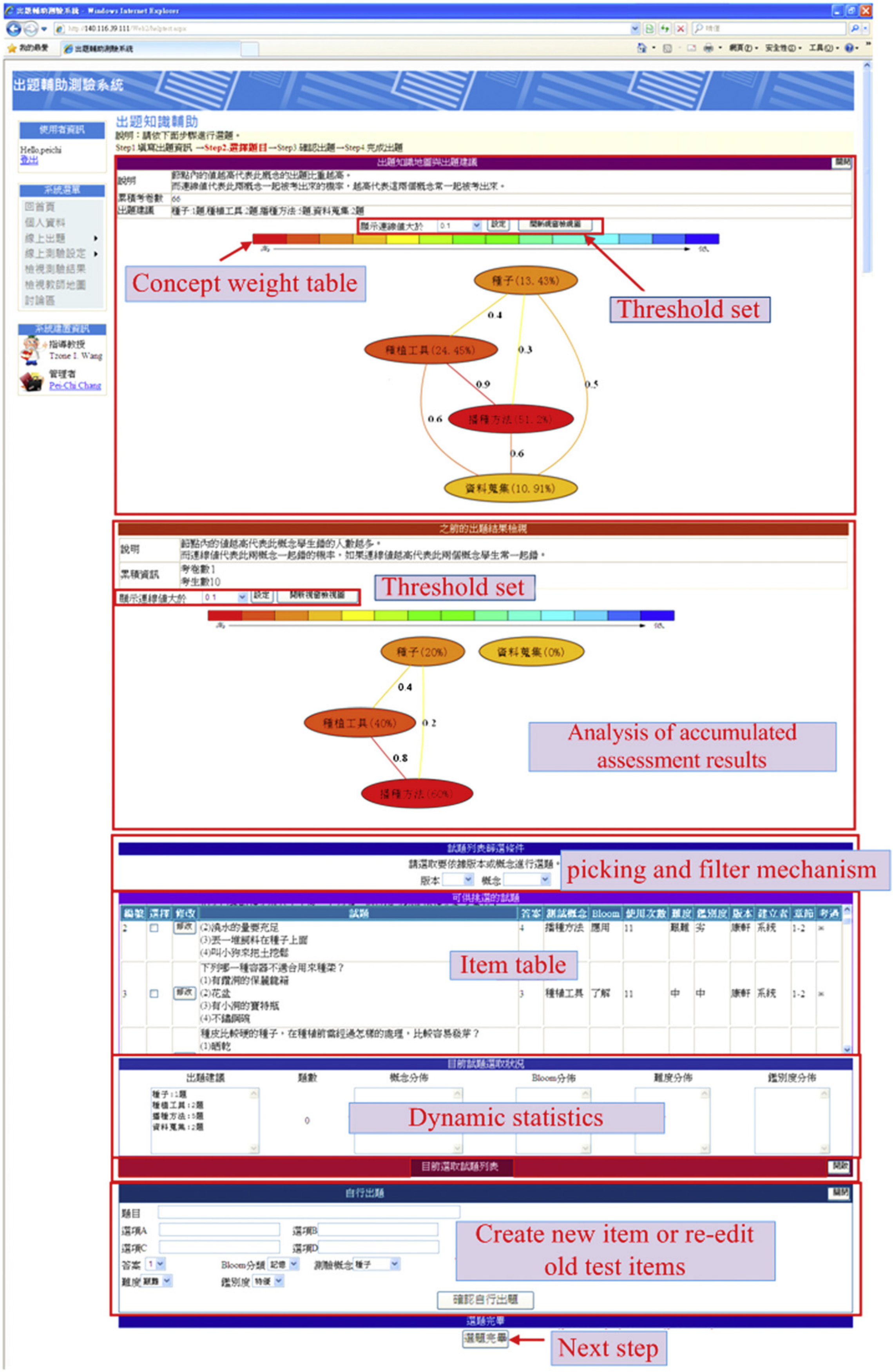


Fig. 5. The process teachers follow when using the teacher interface.

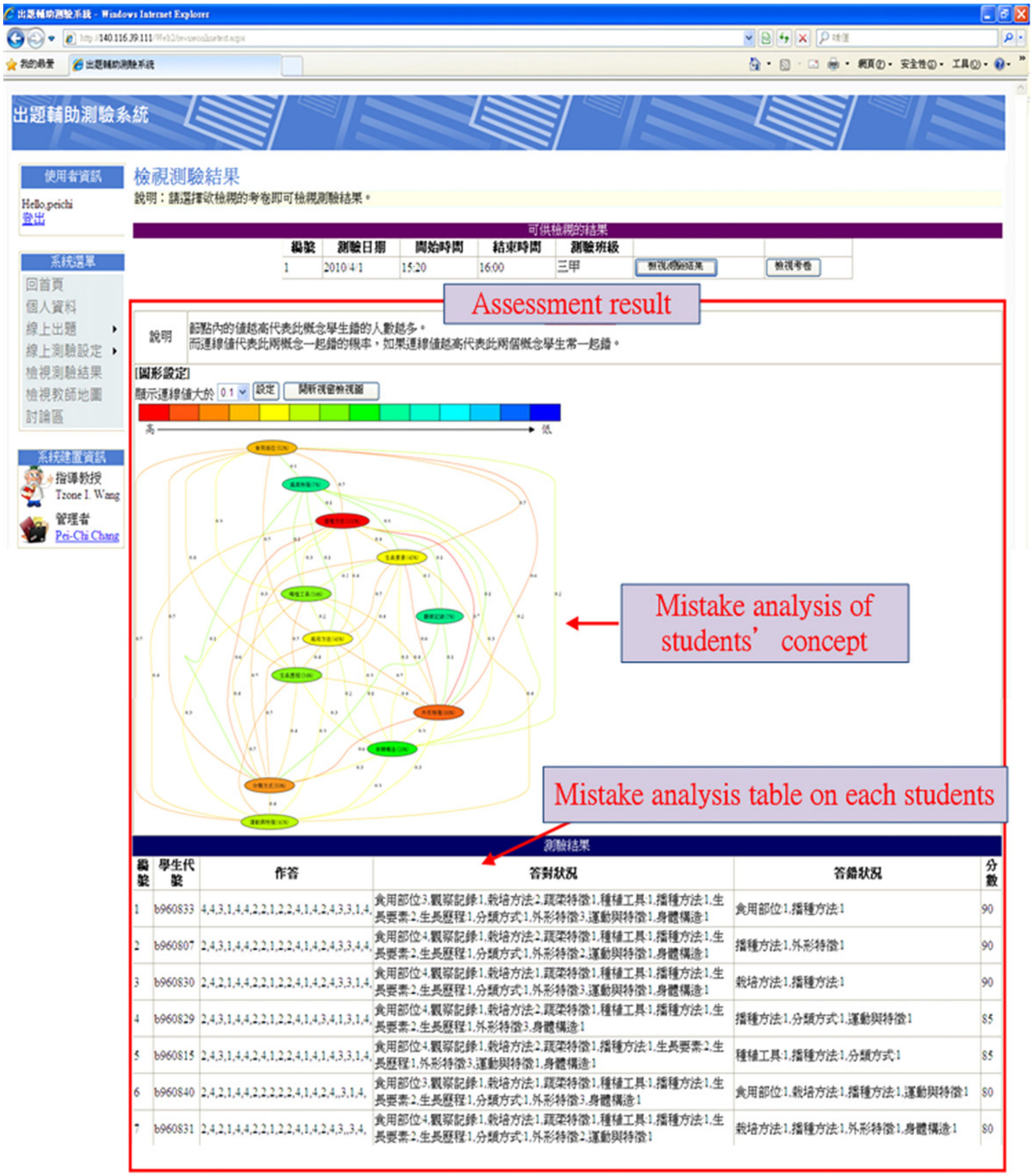


Fig. 6. A chart of students' mistake analysis.

teachers' experiences with assessment knowledge-sharing, their satisfaction and opinions about the system's functionalities, and more in-depth information on why teachers responded towards the IKMAAS as they did. The results provide evidence that supports the IKMAAS's potential for improving the assessment tasks of teachers in various domains.

An important phenomenon was observed by analysing usage records from the second stage: the more a teacher used the IKMAAS, the more he or she tended to adopt the suggested weights of concept distributions for test items on his or her assessments. Only a few teachers consistently ignored the suggestions from the IKMAAS and used their own concept weight proportions on test items in their assessments. However, the final proportions of concepts among test items on the assessments produced by these teachers were still quite similar to what the system suggested, as shown in Fig. 7. For the 1-st subject, the average proportion of all the assessments produced saw 83 percent similarity, which rises to 91 percent for the 4-th subject. This means, overall, teachers appeared willing to follow the suggestions pertaining to concept weights that were calculated using the accumulated assessment knowledge. Teachers also agreed that they became more aware of the need to change their assessment practices to avoid inappropriate concept-test item weights on future assessment compilations.

Thirty two items on the questionnaire, as shown in appendix A, covered nine different dimensions among: *usefulness*, *easiness*, *attitude*, *technological complexity*, *concentration*, *intentions*, *satisfaction*, *system stability* and *knowledge map presentation*. Responses were defined using a Likert-type scale radar chart, as shown in Fig. 8. As can be seen, every individual answer to all of questions were positive, although those related to *technological complexity*, *satisfaction*, and *system stability* were slightly lower than the others. These results suggest that the

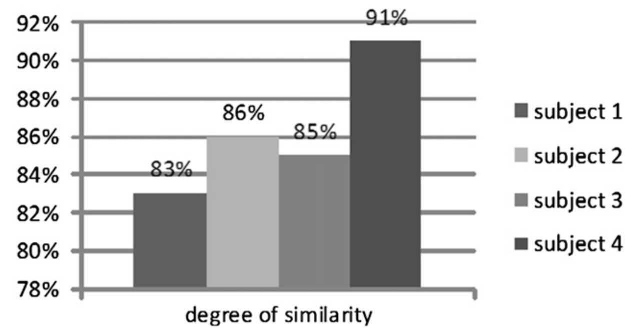


Fig. 7. The degree of similarity on concept weight proportions between system suggestions and teacher decisions.

IKMAAS would benefit from a friendlier user interface. However, the high score on *concentration* also confirms that the IKMAAS can indeed help teachers by providing a supportive overview of the relative importance of concepts and allowing them to concentrate on the distribution of concepts among the test items.

Some examples of the feedbacks from the interviews are listed as follows:

This system is amazing; it helps me see the proper concept distribution percentage by knowledge maps when compiling a test sheet. In addition, I can also refer to the maps of other teachers' assessment knowledge to help me determine… (teacher C).

I got some important assessment information easily from this system; it helps me to comprehend or regulate my ideas on the assessment work. It also solved some of my problems, for example, inadequate proportion of concepts in my assessment works…(teacher H).

It is convenient for me to review my faults in the previous assessment works and to understand the misconception distributions of students…. (teacher A).

In short, teachers believe that the primary benefits of the IKMAAS are as follows: (1) the knowledge map can clearly and visually identify key assessment knowledge (e.g., concept weights and item configuration) that is most strategic and critical to assessments; (2) the knowledge map can assist teachers in identifying the necessary knowledge easily and effectively; and (3) other teachers' assessment experiences and knowledge accumulated in the IKMAAS were easy to acquire and refer to using the knowledge maps. One piece of negative feedback is worth noting, and some teachers give an advice on increasing test items in the future. However. Some senior teachers and experts were not willing to share their knowledge and experiences due to security concerns about test items on the IKMAAS. Most teachers did find that the IKMAAS is a helpful platform for editing test items, managing assessment assignments, sharing assessment knowledge, and improving their assessment tasks.

The evaluations confirm that, by integrating knowledge maps and teachers' accumulated assessment knowledge, the IKMAAS is able to provide teachers with novel forms of assistance. All of the teachers' captured assessment knowledge could be summarised and concretised as knowledge maps that were useful to both veteran and novice teachers. Knowledge maps played such a significant role in knowledge management that they were also useful blueprints for implementing teachers' assessment knowledge management systems.

6. Conclusions and future work

Sharing teachers' assessment knowledge may be useful in convincing them to use assessment methods found to be effective in certain situations. The phrase, "accumulating assessment knowledge of teachers" as used in this study refers to the elicitation and accumulation of

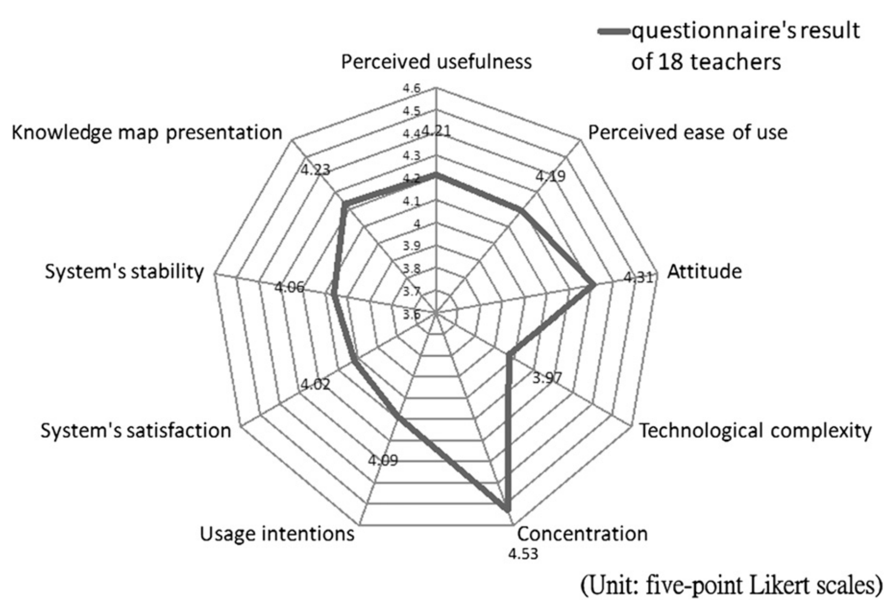


Fig. 8. Results of questionnaire responses.

teachers' assessment knowledge; it may or may not refer to a generic assessment theory that is prescriptive in nature. However, it is assumed that the sharing is focused on concept- and item weight-related issues only and that the sharing is done using the collected assessment information in the database. Knowledge management is effectively utilised during the construction stage of an assessment to enable teachers' assessment experience and knowledge to be captured and reused for similar assessment projects.

This study used collected assessments of teachers in a specific domain as the source of knowledge. This knowledge was then utilised to calculate the weights of concepts and their relationships. The operational IKMAAS uses knowledge maps to show these weights and to offer teachers comprehensive knowledge during the arrangement and construction phase of their assessment. Because of its power to collect teachers' assessment knowledge and concretise it as knowledge maps, the IKMAAS assists teachers in constructing assessments with great confidence. For veteran teachers, knowledge maps provide a visual overview of the distribution of concepts among the test items to help them avoid neglecting some important concepts on an assessment. For those teachers without much experience, knowledge maps and the accumulation of the experience and knowledge of veteran teachers helped them to realise the relative importance of concepts to be tested. Furthermore, it helped them to arrange test items with a proper ratio reflective of the relative importance of these concepts.

Although the present study used the IKMAAS to evaluate science and technology curricula found in elementary school in Taiwan, it is possible to use the system for other subjects and curricula without making any changes other than uploading different assessment files and test items. The IKMAAS uses only well-developed methodologies and technologies, which makes it domain-independent and highly flexible for transfer to other course domains. Ongoing improvements to the IKMAAS include providing suitable recommendations in compliance with teachers' personal needs, calculating an algorithm that can leverage the acceptance of recommendations, establishing incentive policies to encourage teachers to contribute their assessment experience and knowledge, and improving the design of the item repository and the recommendation engine to increase the desire to contribute.

Acknowledgments

This research was supported by the National Science Council, Taiwan, under Grant No. NSC 98-2511-S-006-001-MY3.

Appendix A

Items	Mean	
Usefulness		
1. Using the IKMAAS improves my educational assessment work performance.	4.18	4.21
2. Using the IKMAAS enhances my effectiveness in my assessment work.	4.29	
3. I find the IKMAAS to be useful in my assessment work.	4.24	
4. Using the IKMAAS would make my assessment work easier.	4.12	
Easiness		
5. It would be easy for me to become skillful at using the IKMAAS.	4.35	4.19
6. My interaction with the IKMAAS is clear and understandable.	4.12	
7. I believe that it is easy to get the IKMAAS to do what I want it to do.	4.06	
8. Interacting with the IKMAAS does not require a lot of my mental effort.	4.24	
Attitude		
9. I think that using the IKMAAS is beneficial.	4.35	4.31
10. I thank that the IKMAAS is worth to use.	4.35	
11. The attitude of using the IKMAAS is positive.	4.65	
12. I like to use the IKMAAS.	3.88	
Technological complexity		
13. Learning to use the IKMAAS takes up too much of my time.	2.00	3.97
14. Using the IKMAAS involves too much time.	2.06	
Concentration		
15. I was absorbed intensely in the educational assessment activity.	4.59	4.53
16. My attention was focused on the educational assessment activity.	4.47	
Intentions		
17. Assuming I have access to the IKMAAS, I intend to use it.	4.12	4.09
18. I intend to increase my use of the IKMAAS in the future.	4.06	
System satisfaction		
19. The interface of IKMAAS is easy to use.	4.18	4.02
20. The text style and forms are suitable.	4.00	
21. Operating Instructions and tips are clearly and I can understand easily.	4.06	
22. Making assessment by IKMAAS's interface is very convenient.	4.18	
23. The IKMAAS meets my needs.	3.71	
System stability		
24. The IKMAAS is stability for me.	4.06	4.06
25. The functions of the IKMAAS are faultless.	3.59	
26. The IKMAAS infrequently happened error.	4.18	
Knowledge map presentation		
27. Teachers' assessment knowledge can be sharing effectively by the IKMAAS.	4.24	4.23
28. Sharing teachers' assessment knowledge is useful for me.	4.24	
29. Teachers' assessment knowledge can be presented appropriately by Knowledge map.	4.18	
30. The colour of the node in knowledge map helps me discriminating the importance of concept.	4.29	
31. The assessment suggestion proposed by the IKMAAS presented the accumulating and visualizing tacit knowledge of teachers properly.	4.24	
32. The assessment suggestion proposed by the IKMAAS is beneficial to me.	4.18	

References

Abel, R., & Kulhavy, R. (1986). Maps, mode of text presentation, and children's prose learning. *American Educational Research Journal, 23*(2), 263–274.

Arkoudis, S., & O'Loughlin, K. (2004). Tensions between validity and outcomes: teacher assessment of written work of recently arrived immigrant ESL students. *Language Testing, 21*(3), 284–304.

Cañas, A., Coffey, J., Carnot, M., Feltovich, P., Hoffman, R., Feltovich, J., et al. (2003). *A summary of literature pertaining to the use of concept mapping techniques and technologies for education and performance support*. Final report to CNET. (Retrieved).

Carroll, T., & Moody, L. (2006). Teacher-made tests. *Science Scope*, 66–67.

Cizek, G., Fitzgerald, S., & Rachor, R. (1995). Teachers' assessment practices: preparation, isolation, and the kitchen sink. *Educational Assessment, 3*(2), 159–179.

Davenport, T., & Prusak, L. (2000). *Working knowledge: how organizations manage what they know*. Boston, Massachusetts: Harvard Business School Press.

Davison, C. (2004). The contradictory culture of teacher-based assessment: ESL teacher assessment practices in Australian and Hong Kong secondary schools. *Language Testing, 21*(3), 305–334.

Frey, B., Petersen, S., Edwards, L., Pedrotti, J., & Peyton, V. (2005). Item-writing rules: collective wisdom. *Teaching and Teacher Education, 21*(4), 357–364.

Gaines, B. R., & Shaw, M. L. G. (1995). Concept maps as hypermedia components. *International Journal Human-Computer Studies, 43*(3), 323–361.

Kuwata, Y., & Yatsu, M. (March 24–26, 1997). Managing knowledge using a semantic-network. In *Proceedings of the AAAI spring symposium on artificial intelligence in knowledge management* (pp. 94–98). Stanford University.

Kveton, P., Jelinek, M., Voboril, D., & Klimusova, H. (2007). Computer-based tests: the impact of test design and problem of equivalency. *Computers in Human Behavior, 23*(1), 32–51.

Larkin, J., & Simon, H. (1987). Why a diagram is (sometimes) worth ten thousand words. *Cognitive Science, 11*(1), 65–100.

Lin, Y.-C., Wang, L.-C., & Tserng, H. P. (2006). Enhancing knowledge exchange through web map-based knowledge management system in construction: lessons learned in Taiwan. *Automation in Construction, 15*(6), 693–705.

Liu, L., Li, J., & Lv, C. (2009). A method for enterprise knowledge map construction based on social classification. *Systems Research and Behavioral Science, 26*, 143–153.

Meng, A., Ye, L., Roy, D., & Padilla, P. (2007). Genetic algorithm based multi-agent system applied to test generation. *Computers & Education, 49*(4), 1205–1223.

Mertins, K., Heisig, P., & Vorbeck, J. (2003). *Knowledge management: concepts and best practices*. Springer Verlag.

Mitri, M. (2003). Applying tacit knowledge management techniques for performance assessment. *Computers & Education, 41*(2), 173–189.

Nesbit, J. C., & Adesope, O. O. (2006). Learning with concept and knowledge maps: a meta-analysis. *Review of Educational Research, 76*(3), 413–448.

Nevin, A., Thousand, J., & Villa, R. (2009). Collaborative teaching for teacher educators–What does the research say? *Teaching and Teacher Education, 25*(4), 569–574.

O'Donnell, A., Dansereau, D., & Hall, R. (2002). Knowledge maps as scaffolds for cognitive processing. *Educational Psychology Review, 14*(1), 71–86.

O'Leary, D., & Selfridge, P. (1999). Knowledge management for best practices. *Intelligence, 10*(4), 12–24.

Panjaburee, P., Hwang, G., Triampo, W., & Shih, B. (2010). A multi-expert approach for developing testing and diagnostic systems based on the concept effect model. *Computers & Education, 55*(2), 527–540.

Polanyi, M., & Sen, A. (2009). *The tacit dimension*. University of Chicago Press.

Shaw, R.-S. (2010). A study of learning performance of e-learning materials design with knowledge maps. *Computers & Education, 54*(1), 253–264.

Shepard, L. (2000). The role of assessment in a learning culture. *Educational Researcher, 29*(7), 4–14.

So, W. W.-m., Pow, J. W.-c., & Hung, V. H.-k (2009). The interactive use of a video database in teacher education: creating a knowledge base for teaching through a learning community. *Computers & Education, 53*(3), 775–786.

Su, C. Y., & Wang, T. I. (2010). Construction and analysis of educational assessments using knowledge maps with weight appraisal of concepts. *Computers & Education, 55*(3), 1300–1311.

Tseng, Y.-H., Chang, C.-Y., Rundgren, S.-N. C., & Rundgren, C.-J. (2010). Mining concept maps from news stories for measuring civic scientific literacy in media. *Computers & Education, 55*(1), 165–177.

Verdi, M., & Kulhavy, R. (2002). Learning with maps and texts: an overview. *Educational Psychology Review, 14*(1), 27–46.

Wang, K. C. (2000). The research of teachers' teaching believes and teaching practice. *Educational Research & Information, 8*(2), 84–98.

Xu, Y., & Liu, Y. (2009). Teacher assessment knowledge and practice: a narrative inquiry of a chinese college EFL teacher's experience. *TESOL Quarterly, 43*(3), 493–513.

Yang, J.-B. (2007). Developing a knowledge map for construction scheduling using a novel approach. *Automation in Construction, 16*(6), 806–815.

Yang, Y., & Chan, C. (2008). Comprehensive evaluation criteria for english learning websites using expert validity surveys. *Computers & Education, 51*(1), 403–422.

Yin, P., Chang, K., Hwang, G., Hwang, G., & Chan, Y. (2006). A particle swarm optimization approach to composing serial test sheets for multiple assessment criteria. *Educational Technology and Society, 9*(3), 3–15.

Zhao, J. (2010). School knowledge management framework and strategies: the new perspective on teacher professional development. *Computers in Human Behavior, 26*, 168–175.