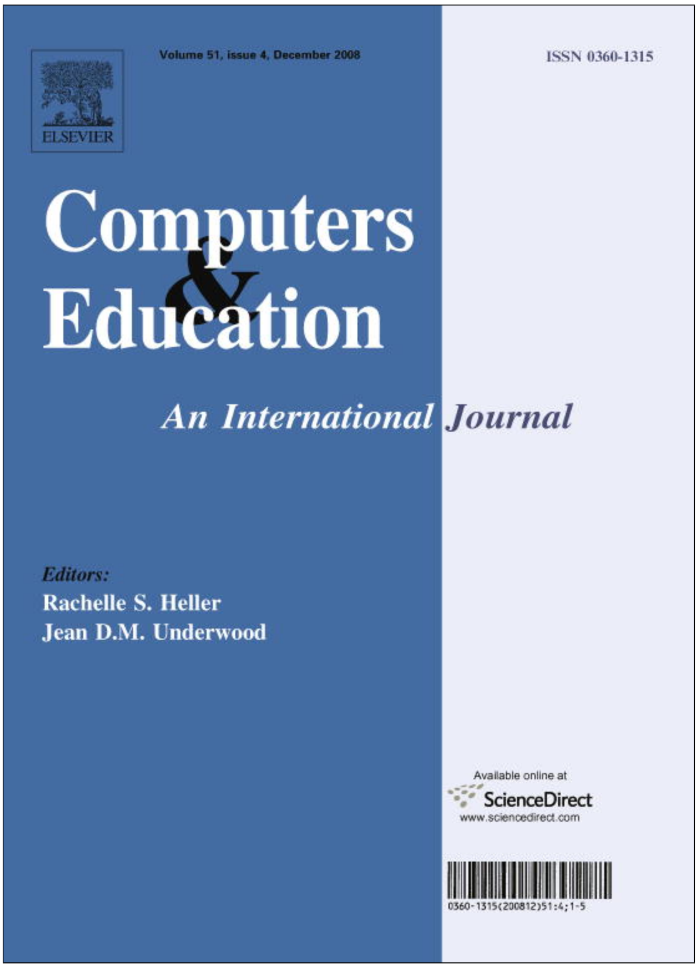
Volume 51, issue 4, December 2008
ISSN 0360-1315
ELSEVIER
Computers & Education
An International Journal
Editors:
Rachelle S. Heller
Jean D.M. Underwood
Available online at
ScienceDirect
www.sciencedirect.com

Computers & Education 51 (2008) 1718–1728

Contents lists available at ScienceDirect

Computers & Education

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

Breaking concept boundaries to enhance creative potential: Using integrated concept maps for conceptual self-awareness

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ARTICLE INFO

Article history:
Received 14 December 2007
Received in revised form 1 April 2008
Accepted 7 May 2008

Keywords:
Distributed learning environments
Evaluation of CAL systems
Learning communities
Pedagogical issues
Teaching/learning strategies

ABSTRACT

The authors address the role of computer support for building conceptual self-awareness—that is, enabling students to think outside of concept boundaries in hope of enhancing creative potential. Based on meta-cognition theory, we developed an integrated concept mapping system (ICMSys) to improve users' conceptual self-awareness in addition to applying concept mapping techniques in traditional learning scenarios. Since the ICMSys accommodates different perspectives, selected ideas made by peers are retained with the help of integrated concept map (ICMap) representations used as stimuli for reflective thinking. Results from a case study with 32 information management undergraduates indicate: (a) increased levels of conceptual self-awareness, (b) evidence of conceptual improvement in the students' redrawn concept maps, (c) that ICMap viewing frequency exerted a positive impact on level of conceptual self-awareness, and (d) a significant correlation between level of conceptual self-awareness in redrawn personal concept maps and actual conceptual changes as determined by three experts. We describe student perceptions of the ICMSys in terms of comprehension practicality and conceptual self-awareness, and give suggestions for future research.

1. Introduction

New ideas and applications must be expressed and externalized in order for social evaluation to occur (Fischer, Giaccardi, Eden, Sugimoto, & Ye, 2005). During the process of externalizing concepts, there is a need to let different voices be heard to prevent dominance, to accommodate representations of potentially valuable ideas, and to enable reflective thinking in a manner that allows for conceptual awareness. It is our belief that computer technology can be used as an auxiliary tool to externalize multiple viewpoints, facilitate individual awareness of concept boundaries (see Section 3.1), and enhance creative potential.

Concept mapping (Novak & Gowin, 1984), an approach to knowledge structure externalization, helps learners internally reconstruct their concepts and consider ways of visually representing their conceptual structures. Ausubel (1968) supported the ability of learners to actively link new knowledge to previously constructed concepts and propositions as a vital factor in meaningful learning. Malone and Dekkers (1984) describe concept mapping as a "window to the mind" because it allows for the observation of others as well as self-reflection. Fisher (1990) and Reader and Hammond (1994) are among researchers who have proposed various computer-assisted systems for facilitating concept map construction, whereas Chiu, Huang, and Chang (2000), Chung, O'Neil, Herl, and Dennis (1997), Okebukola and Jegede (1989), and Roth and Roychoudhury (1992) have focused on collaborative efforts to generate group concept maps. Group concept mapping (a text-based brainstorming

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doi:10.1016/j.compedu.2008.05.003

technique) is commonly used to achieve meaningful collaborative learning. While brainstorming is widely used to encourage individuals to contribute ideas and build creative thinking skills, its critics (e.g., Mullen, Johnson, & Salas, 1991) assert that brainstorming can create high levels of pressure in participants so as to stifle creativity. Group concept mapping has some of the same drawbacks as brainstorming, including hitchhiking and dominance tendencies (Lin, Sun, & Kao, 2002). In this paper we will look at the merits of concept mapping for concept externalization and meaningful learning by requiring all learners to visually express individual ideas in the form of concept maps as a means of encouraging them to express personal opinions.

Either consciously or unconsciously, learners tend to use habitual thinking patterns to solve problems (Finke, Ward, & Smith, 1992; Ford, 1996). This usually reduces the time required to develop solutions at the expense of experimenting with and testing alternatives. Asking learners to reflect on what they already do or do not know without external assistance may result in huge cognitive loads or cost too much in terms of mental effort. To take advantage of concept mapping to improve student engagement and creative potential, we believe an essential initial step is helping students become aware of what may be lacking in their existing conceptual structures. As Burleson (2005) observes, awareness and reflective technologies can be instrumental in developing meta-cognitive skills that enhance learning, expertise, creativity, and self-actualization. Since creativity involves a complex mix of factors, enhancing conceptual awareness alone may not result in more creative products, but instead serve as an initial step for achieving greater creative potential.

Human tendency is to think within concept boundaries constrained by personal backgrounds, educations, living environments, etc. Working with other individuals from diverse backgrounds can help ameliorate the effects of these constraints. Selker (2005) notes that sharing parts of tasks with others is useful for eliciting critiques and evaluations of creative possibilities. In practice, different designers working on the same problem often reach different solutions (Bisseret, Figeac-Letang, & Falzon, 1988). In our framework, personal concept maps that represent students' unique concept structures are viewed as sources of variation to be combined into integrated concept maps (ICMaps). The goal is to use various concepts or leads generated by peers to stimulate creative associations that individuals may not otherwise come up with because of their inflexibility in utilizing prior knowledge. The purpose of our integrated concept mapping system (ICMSys) is to assist learners in building *self-awareness of conceptual structures* (from this point forward we will use the term *conceptual self-awareness*) through a process of identifying knowledge structure insufficiencies, differences, and boundaries via comparisons with other learners' concept maps. In this manner we can reduce or eliminate the restrictive impact of habitual thinking on creative potential.

2. Background

2.1. Computer-assisted concept mapping system

Collaborative concept mapping is recognized as an effective means of promoting meaningful learning (Okebukola & Jegede, 1989), which explains in part the emphasis on collaborative concept map construction in Computer Supported Collaborative Learning (CSCL) environments. Examples include *Kmaps* (Gaines & Shaw, 1995), *KSIMapper* (Kremer, 1996), and *CmapTools* (Cañas et al., 2004). However, the approaches discussed so far tend to focus on reproducing face-to-face discussions on group concept map collaboration while neglecting the impacts of concept mapping on changes in individual conceptual structures and the preservation of ideas offered by individuals. One result is that existing collaborative concept mapping systems are not appropriate for research on conceptual self-awareness.

Chang, Sung, and Lee (2003) emphasize the value of searching for better ways of creating group products that preserve individual uniqueness. For this reason, we deemphasized the collaborative aspect of concept mapping in favor of preserving individual ideas by requiring each learner to construct his or her own concept map and focusing on individual conceptual awareness as stimulated by variations in their peers' concept maps. Our ICMSys encourages students to adopt various viewpoints to address tasks and projects in hope of bending or breaking individual concept boundaries and sparking creative ideas. Our system allows learners to request various ICMaps for inspection, thus allowing them to make comparisons among concept maps without requiring detailed inspections. Again, the central goal of our system is to have students concentrate on conceptual self-awareness.

2.2. Meta-cognition

Meta-cognition is defined as the conscious inspection of one's own cognitive system (Bandura, 1986; Flavell, 1976). Coffey (2007) believes that the primary focus of meta-cognitive applications to date has been on helping students gain awareness of how they approach reading and writing. The goals of our learning system are to help students become aware of the boundaries of their prior knowledge or their habitual thinking habits and to encourage them to make conceptual changes in hope of enhancing creative potential. Garner and Alexander (1989) have proposed three approaches to measuring children's meta-cognition: (a) asking them, (b) having them think aloud while performing a task, and (c) asking them to teach a younger child a good solution for a problem. Fry and Lupart (1987) have established a "confidence rating method" for measuring meta-cognition levels in terms of performance prediction. Following an exam, they asked students to predict their performances before learning their results. They concluded that the closer a student's prediction was to the real score, the greater that student's meta-cognitive and monitoring abilities. We chose this method for measuring conceptual self-awareness levels among our student participants—that is, smaller differences between a student's self-assessment and an actual assessment made by a team of experts were viewed as indicators of greater self-awareness.

2.3. Self-awareness

Improvement is difficult for individuals who are not aware of their shortcomings, indicating a need for a conceptual self-awareness dimension. Duval and Wicklund (1972) define self-awareness as occurring whenever one's attention is directed toward oneself, while Brown (1987) describes self-awareness as a condition of self-understanding and introspection of one's own thoughts. In this study we assumed that self-awareness is promoted when individuals focus their attention on their minds and inspect their thoughts and consciousness.

However, Nisbett and Wilson (1977) found that self-observations are imprecise because of our tendency to find reasons (which may or may not be true) to interpret situations in a specific manner. Therefore, ideas, suggestions, feedback, and other resources provided by peers are essential stimuli for discovering what we will call the *unaware zone*. Michinov and Primois (2005) further note that the social comparison process has a positive impact on productivity and creativity. Accordingly, our system encourages conceptual self-awareness via introspection and social comparison (Suls & Fletcher, 1983). Our belief is that conflicts arising from comparisons of concept maps among peers promote learner self-awareness and therefore minimize the unaware zone. We also believe this process can encourage learners to reconsider concepts they may have overlooked or alternative approaches to task resolution in a manner that is beneficial to breaking concept boundaries for problem solving.

2.4. From self-awareness to creative potential

Conceptual awareness is central to bringing out creative potential. For many decades creativity has been viewed as a gift (Gardner, 1993)—that is, if you aren't born with knowledge of how to be creative, it is very difficult to learn. Thus, the goal of most school systems is to equip students with skills or domain knowledge only, which might eliminate individual potential for developing creativity. Knowledge is only one aspect of creativity; others include (but are not limited to) imagination, evaluation skills, and awareness (Feldhusen, 1995). Among students who have similar background knowledge, those who can bring other factors into play are more likely to reach their creative potential. However, the traditional approach involves teaching students to solve problems quickly within limited personal search spaces without considering more innovative possibilities. As Finke et al. (1992) observe, creativity is stifled when individuals become fixated on a single interpretation or approach. To overcome functional fixedness and related tendencies, they recommend creating an attitude of looking beyond conventional ideas—an attitude that we believe may benefit from promoting conceptual self-awareness.

Some researchers have recently suggested that individual creativity can be greatly enhanced by establishing supportive socio-technical settings (Fischer et al., 2005). This suggestion implies the feasibility of developing creativity and underscores the importance of providing applicable interfaces or environments to achieve that goal. Burleson (2005) adds that awareness and reflective technologies can be instrumental in developing meta-cognitive abilities that enhance creativity. Accordingly, we developed the ICMSys to bend or break concept boundaries and to enhance creative potential via self-awareness and social comparison processes. The goal is to help willing individuals think outside of concept boundaries and break habitual thinking whenever they find their personal ideas or solutions are not sufficient for the task at hand.

3. Study design

3.1. Concept boundaries

Concept boundaries are detectable when students become aware of conceptual differences between their own and integrated concept maps. Initial unaware zones are reduced while students' conceptual awareness levels are increased. With our ICMSys, similar concept propositions are integrated for better presentation in hope of facilitating a conceptual introspection process in learners. Using Fig. 1 as an example, after Alice externalizes her concepts or ideas on a personal concept map, she manipulates the ICMSys to compare her map with those created by her peers. We believe this process lessens the burden of identifying differences between Alice's map and her peers' maps. She may discover that her map lacks certain concepts or good examples, and therefore decide to add them to better express her ideas. She may also decide to delete some concept nodes she believes are inappropriate. A third possibility is that she may notice creative concept relationships or cross-links that she did not recognize before; both are viewed as beneficial for learning or triggering new ideas. Or, she may adjust the concept hierarchy to better categorize ideas or accommodate concept changes. In other words, the breaking down of concept boundaries is observable whenever students make improvements in any one of Novak and Gowin's (1984) assessment criteria: examples, relationships, hierarchies, and cross-links.

Since the ICMSys emphasizes user potential to break concept boundaries, it is very important to help users recognize existing boundaries and reflect on their conceptual differences in order to identify valuable ideas. This process assumes that users have contributed conceptually correct ideas from different viewpoints about the topic of interest. However, there is a concern that students may model or imitate erroneous maps based on their current knowledge limitations. We therefore trained our

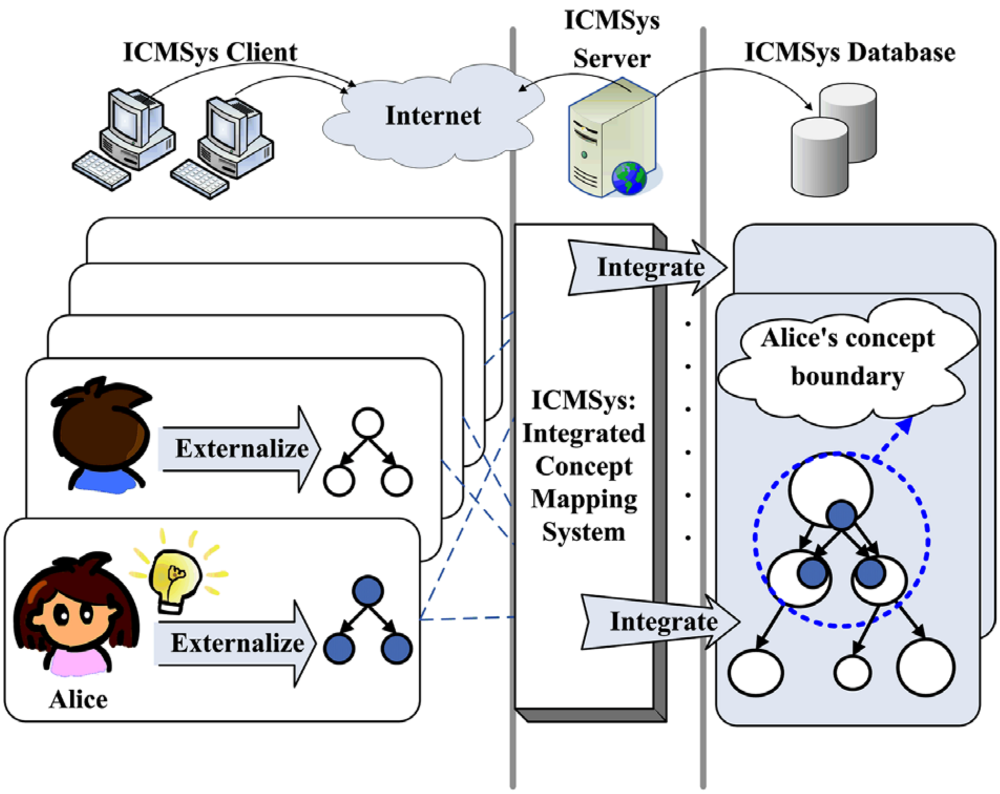

Fig. 1. Research focus and integrated concept map system architecture.

participants in concept mapping and peer assessment skills prior to our experiments. Realizing that some concept maps created by the participants might be inaccurate in some areas but valuable in others, we asked three experts to assess the quality of the students' redrawn maps to verify the benefits of modeling the first concept maps in the resource pool. In actual classroom situations, teachers will be responsible for correcting misconceptions or errors in revised concept maps.

3.2. Research questions and framework

Our research questions address four areas of concern:

- Q1. Can learner conceptual self-awareness be promoted using the ICMSys?
- Q2. Do revised concept maps contain evidence of conceptual improvements? Specific goals are to determine if students acknowledge insufficiencies and concept boundaries in their initial concept maps and construct extensions after viewing various ICMaps.
- Q3. Does ICMap viewing frequency affect the level of conceptual self-awareness?
- Q4. Do students with higher levels of conceptual self-awareness make better quality and larger numbers of improvements when redrawing their concept maps?

Our approach consists of three steps: constructing a personal concept map, observing various combinations of ICMaps, and redrawing the original personal concept map (Fig. 2). Map quality self-assessments and assessments by the three experts were collected twice for each student—once after the first maps were drawn and once after they were revised. The number of times that students viewed ICMaps was also recorded. As stated earlier, during the personal concept mapping process, students are encouraged to express ideas on which they can elaborate by comparing those ideas with their peers'. This allows for different voices to be heard without any single voice becoming dominant. After being instructed to share their individual concept maps, students are introduced to the ICMSys and begin reflective thinking based on ideas and concepts garnered from peer maps. Once their conceptual self-awareness is improved and concept boundaries are established, students are asked to consider how they can extend or elaborate their thinking in revised maps by incorporating new ideas or finding new relationships between concepts.

4. The integrated concept map system (ICMSys)

Based on Selker's (2005) suggestion that productive and non-intrusive interfaces allow individuals to focus on creative tasks, we set out to develop an integrated concept mapping system (ICMSys) for a distributed networking environment.

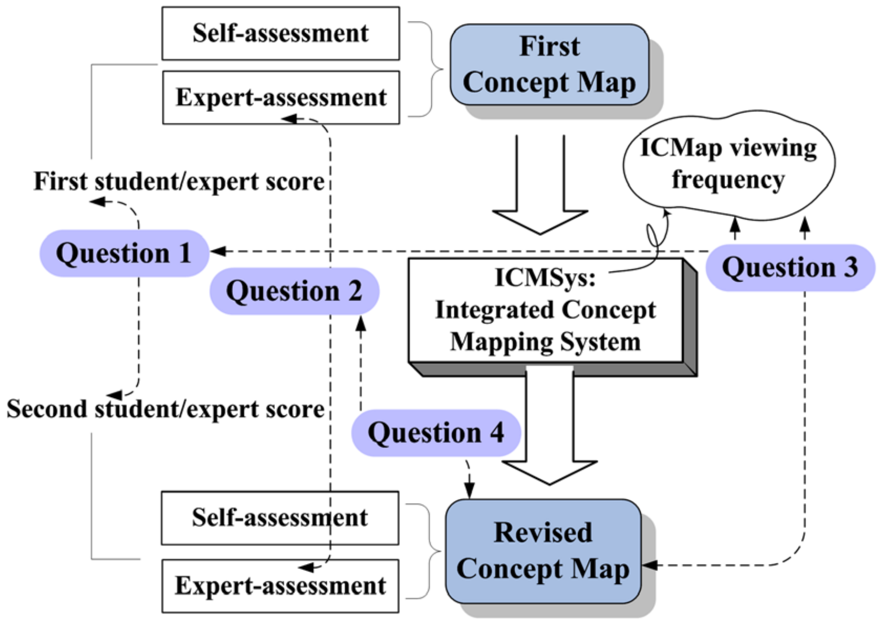

Fig. 2. Main research framework and questions.

As shown in Fig. 1, our ICMSys goals are to externalize each learner's ideas, integrate them into a representation that accommodates different viewpoints, and provide a convenient interface to help learners become aware of their concept boundaries. Our four main ICMSys design principles were:

1. Students occasionally come up with different concept words that have the same meaning. To reduce redundancy, we purposefully placed certain concept words into the ICMSys that the participants could use when constructing concept maps—for instance, "memory unit" and "CPU" within the "computer hardware" topic. Concept word lists are expanded each time a student-created concept is entered into the ICMSys database. Learners can therefore use the list to choose words they find to be most appropriate, or create a new concept node to better describe their ideas.
2. To assist with concept map integration, a lexical database for the targeted learning material (in this case, "computer hardware") must be generated in advance. To address the redundancy issue in principle number 1, the ICMSys takes synonyms into account when integrating similar terms. Kornilakis, Grigoriadou, Papanikolaou, and Gouli (2004) suggest using *Wordnet* (an electronic database) to support comparisons of concept words between student and expert concept maps. However, *Wordnet* is in English, meaning that a complete Chinese-language database of technology vocabulary needs to be constructed.
3. To promote self-awareness of concept boundaries, our ICMSys designates each individual's work as a default setting for concept map integration. Each ICMap consists of the learner's own map and learner-selected peer maps. Students can quickly move to the main task of making comparisons and finding differences between their own and their peers' maps.
4. Proposition integration categories include: (a) two propositions (each consisting of two concept words and one linking word) are completely identical, (b) the two concept words in each proposition are identical but the linking word is not, or (c) only one concept word in each proposition is identical (Fig. 3). In case (a), the two propositions are integrated into one. In (b), the two linking words are retained to preserve the uniqueness of each student's proposition, since a different linking word can change a proposition's meaning (Fig. 3a). In (c), even though the linking word "needs" is identical, only partial integration (i.e., branching) occurs because the phrases "leaf needs oxygen" and "leaf needs water" have different meanings (Fig. 3b).
5. Numbers in parentheses next to concept words indicate how many times the concept is mentioned in his/her and selected peers' concept maps (Fig. 3).

4.1. ICMSys interface

To create a Web-based distributed learning system, we used a combination of Java and JDBC to design our ICMSys interface (Fig. 4). In the "Personal concept mapping" section, students can use the form-based interface to externalize their ideas (i.e., map construction and connecting concept nodes with links). Concept nodes and linking words are not fixed, giving students greater flexibility for concept expression. As with many good tools, the learning system's main strength is its simplicity. Based on the above-mentioned design principles, our ICMSys accommodates ideas contributed by different peers and offers a convenient interface for making comparisons so as to lower the cognitive load of learners (i.e., there is no need to

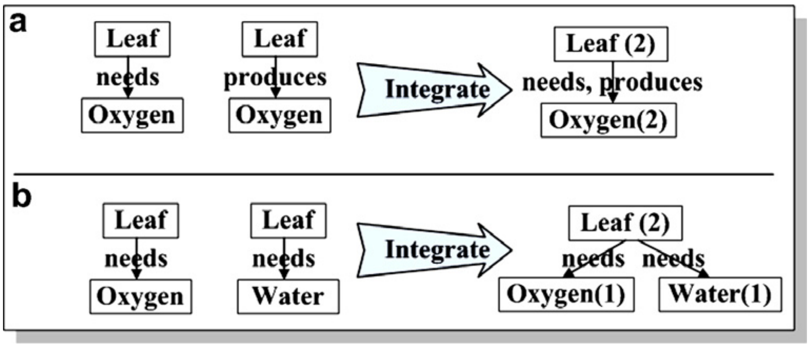

Fig. 3. Two proposition integration patterns.

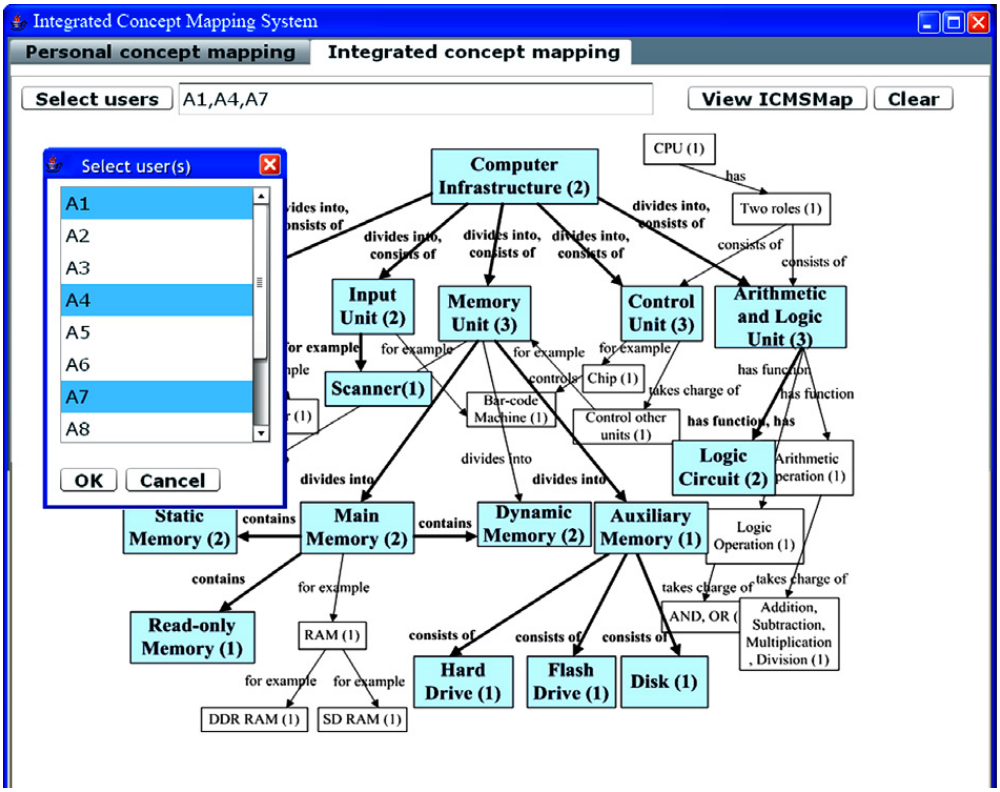

Fig. 4. Integrated concept map system user interface and an integrated concept map with student A1's map highlighted (translated into English for demonstration purposes).

intensively study individual concept maps and memorize every difference in detail). In the "Integrated concept mapping" section, students select some of their peers' aliases from a popup window, and then press the "OK" button for the content of an integrated map to be shown. This process can be repeated as many times as desired, which allows students to view various combinations of ICMaps to discover what is lacking or at fault in their own concept maps.

Identical concepts are marked with numbers in parentheses, indicating how many times the concept is mentioned in a student's and selected peers' concept maps. This makes the integrated maps more concise and easier to analyze in terms of similarities. Students can then decide to adopt some of their peers' ideas to address the task at hand, or those ideas may stimulate reflection that allows students to see creative connections they had previously overlooked. An example of an integrated concept map (translated into English) is presented as part of Fig. 4.

5. Case study

5.1. Participants and materials

Study participants were 32 information management freshmen enrolled in a computer hardware course offered by a Taiwanese technology institute. Course content focused on (but was not limited to) basic computer infrastructure, PC components, and storage processes. The ICMSys can be used in combination with any subject, whose domain knowledge can be expressed in concept map format to assist students in elaborating concepts, engaging in reflective thinking, or breaking concept boundaries.

5.2. Procedure

The study procedure is shown in Fig. 2. At some time during the first two weeks of the class, the instructor explained to students the concept mapping technique, concept map assessment criteria, and how to use the ICMSys. The three experts were also given training in concept mapping and assessment skills during this period. The training was based on Novak & Gowin's (1984) suggestions for concept map quality. For example, a linking word should describe a precise and meaningful relationship between two concept words, upper-level concept words should be more abstract, and general and lower-level concept words should be more detailed and concrete. At the end of week 2, students were given the learning material and task. In week 3, the participants constructed personal concept maps and made self-assessments of map quality; separate assessments were made by the three experts. In week 4, students were asked to assemble ICMaps for establishing personal concept boundary awareness via the peer map modeling process. In week 5, students redrew their personal concept maps and made self-assessments of revised concept map quality; again, separate assessments were made by the three experts. At the end of week 5, participants were asked to complete a questionnaire designed to measure their perceptions of the ICMSys (Table 1). After the activity, the instructor could use a combination of the revised concept maps and reflective writing by the students to correct misconceptions.

5.3. Conceptual self-awareness rating method

Pre- and post-tests are commonly used to measure variation in learning achievement across individual students (Wallace & Mintzes, 1990). In this study, pre- and post-tests consisted of self-assessments of personal maps by individual students and separate assessments of the same maps by three experts in computer science and information management. A 5-point Likert scale (1 = *strongly disagree*, 5 = *strongly agree*) was constructed to assess concept map quality in terms of four criteria: examples, relationships, hierarchies, and cross-links (Novak & Gowin, 1984) (Table 2).

According to Fry and Lupart's (1987) confidence rating method, the difference between self- and expert-assessment (what we call "student/expert score") is an indicator of self-monitoring and comprehension ability. In the present study, the difference represents the level of conceptual self-awareness: the smaller the difference between self- and expert-assessment scores, the greater the student's conceptual self-awareness. We refer to this approach as a "conceptual self-awareness rating

Table 1
Questionnaire to measure student perceptions of the ICMSys

Item content	Percentages of responses				
	Strongly disagree		Strongly agree		
	1	2	3	4	5
1. The ICMSys helped me discover major concept words	3.13	6.25	12.50	68.75	9.38
2. The ICMSys helped me quickly comprehend a large number of others' concept maps	0	3.13	6.25	84.28	6.25
3. The ICMSys facilitated my understanding of the learning material	3.13	6.25	25.00	59.38	3.13
4. The ICMSys facilitated comparisons of my own and others' concept maps	0	3.13	12.50	68.75	15.63
5. I found insufficiencies in my concept boundaries after viewing ICMaps	3.13	6.25	3.13	71.88	15.63
6. The ICMSys helped me find mistakes in my concept map	3.13	21.88	50.00	25.00	0
7. The ICMSys made it easier for me to make concept map extensions and revisions	0	3.13	6.25	81.25	9.38
8. The ICMSys interface is easy to use	3.13	9.38	15.63	68.75	3.13
9. I would like to use a similar concept mapping system for learning in the future	3.13	12.50	37.50	46.88	0
10. Did you revise your own concept map after using the ICMSys? Why or why not?					

Table 2
Concept map scoring

In the concept map...
1. Are all concept words correct and representative?
2. Does the constructed linking word describe a precise and meaningful relationship between the two concept words?
3. Are the concept and linking words (propositions) detailed and plentiful?
4. Are the characteristics of concept map hierarchies presented correctly? (e.g., are upper-level concept words more abstract and general and lower-level concept words more detailed and concrete?)
5. Are hierarchies and branches detailed and plentiful?
6. Are meaningful cross-links constructed to link concept words that belong to different branches?
7. Are there detailed and plentiful examples?
8. Are specific and representative examples outside of the learning material cited?

method." To determine if the gap between student and expert assessments decreased or increased during the study period, those assessments were performed twice—once for the initial map and once for the revised map. Differences between the first and second student/expert scores represent change in the level of conceptual self-awareness. A change greater than zero indicates a reduction in the gap between student and expert assessments and an improvement in student conceptual self-awareness. Expressed as equations:

1. Level of conceptual self-awareness (student/expert score) = student's self-assessment – expert's assessment.
2. Change in level of conceptual self-awareness = $\text{student/expert}_{\text{first}} - \text{student/expert}_{\text{second}}$.

6. Results and discussion

6.1. Does the ICMSys promote conceptual self-awareness?

As shown in Table 3, the first student/expert score ($M = 5.84$, SD = 3.61) represents the level of conceptual self-awareness for the first concept map, and the second ($M = 4.38$, SD = 2.96) represents the level for the revised map. Results from a paired *t*-test using the two scores indicate a statistically significant improvement in conceptual self-awareness ($t = 2.31$, $p < 0.05$), suggesting that the students were more capable of assessing their map quality without overestimation. Results from paired-sample *t*-tests for measuring improvement in conceptual self-awareness in specific concept map criteria are presented in Table 4. They indicate statistically significant improvements in examples ($t = 2.52$, $p < 0.05$) and relationships ($t = 2.18$, $p < 0.05$) but not in hierarchies ($t = 1.05$, *ns*) or cross-links ($t = 1.67$, *ns*). A possible explanation is that the students found it easy to identify differences in the first two areas using the ICMSys, but the above-mentioned hierarchy issue made it more difficult for students to find differences in the hierarchy criterion. These results find support in Novak and Gowin's (1984) observation that students find it difficult to construct and understand the real meaning of cross-links.

6.2. Is the ICMSys help learners locate insufficiencies and break boundaries in their concept maps, leading to conceptual improvement in their revised maps?

At issue here is the possibility that students could make negative conceptual changes even though their conceptual self-awareness had improved. To address this question, the experts examined the revised maps in terms of quality. A Kendall's coefficient of concordance was performed to measure inter-rater reliability. Agreement rates for both original and revised maps were statistically significant ($W = 0.82$, $p < 0.01$ and $W = 0.73$, $p < 0.01$, respectively). We therefore combined and averaged the ratings to provide a composite expert assessment figure for each concept map; *t*-tests were used to determine improvement in the quality of student concept maps as judged by the three experts as well as improvements in specific criteria. As shown in Table 5, the students made statistically significant improvements in examples ($t = 3.22$, $p < 0.01$), relationships ($t = 2.35$, $p < 0.05$), and cross-links ($t = 2.10$, $p < 0.05$). In other words, they regularly assimilated propositions, cross-links, or new concepts that they found to be meaningful into their conceptual structures with a few changes in existing hierarchies. This suggests that the study participants made significant and positive conceptual changes by breaking conceptual boundaries while their conceptual self-awareness levels improved.

Table 3
Statistics for the student, expert, and student/expert conceptual structure scores

Assessment source	First map		Revised map		*t*	Significance
	M	SD	*M*	SD		
Student	28.72	3.26	29.69	3.11		
Expert	22.88	4.65	25.31	4.90		
Student/expert	5.84	3.61	4.38	2.96	2.31	$p < 0.05$

Table 4
Improvement in conceptual self-awareness in terms of the four criteria

Criterion	Student/expert score				*t*	Significance
	First map		Revised map			
	M	SD	*M*	SD		
Examples	1.84	1.42	1.18	1.03	2.52	$p < 0.05$
Relationships	1.87	1.64	1.37	0.97	2.18	$p < 0.05$
Hierarchies	1.53	0.80	1.31	0.98	1.05	*ns*
Cross-links	0.60	0.53	0.52	0.31	1.67	*ns*

Table 5
Concept map quality as assessed by experts in terms of the four criteria

Criterion	Experts (average from three)				t	Significance
	First map		Revised map			
	M	SD	M	SD		
Examples	5.50	1.40	6.41	1.63	3.22	$p < 0.01$
Relationships	9.53	2.05	10.48	2.20	2.35	$p < 0.05$
Hierarchies	6.64	1.43	6.95	1.50	1.47	*ns*
Cross-links	1.23	0.62	1.45	0.76	2.10	$p < 0.05$

Even though the increase in the hierarchy scale was not statistically significant, increased scores were observed (from $M = 6.64$, SD = 1.43 to $M = 6.95$, SD = 1.50) (Table 5). This suggests that the participants made the necessary adjustments to concept hierarchies to better organize their ideas whenever they found major mistakes in their concept maps or irreconcilable differences between their maps and those of other students. One possible explanation for their limited improvement in the hierarchy scale may be the nature of the concept mapping technique—that is, more general concepts are situated in higher map positions and more specific concepts in lower positions. Some students adhered to this model while others did not, causing inconsistency in their hierarchy presentations. To encourage greater flexibility in hierarchy integration, our ICMSys allows students to manually adjust ICMap hierarchies.

6.3. Does ICMap viewing frequency affect conceptual self-awareness level?

According to the three experts, the participating students tended to select complete concept maps with lots of examples during the viewing process, perhaps because they felt they could make more worthwhile extensions and revisions based on those maps.

We divided the participants into two groups of 16 students each according to ICMap viewing frequency (group 1 = high and group 2 = low). The t-test results shown in Table 6 indicate a statistically significant difference between the first ($M = 5.31$, SD = 3.07) and second ($M = 3.13$, SD = 2.45) student/expert scores for group 1 ($t = 2.95$, $p < 0.05$) but not for group 2, meaning that group 1 students made a larger contribution to the overall improvement in conceptual self-awareness. The Table 6 data also indicate a significantly smaller ($t = -2.52$, $p < 0.05$) student/expert score for revised maps among group 1 students ($M = 3.13$, SD = 2.45) compared to group 2 students (M = 5.63, SD = 3.12), suggesting that group 1 students had better conceptual self-awareness than group 2 students, as reflected in the revised concept maps.

6.4. Is there a correlation between conceptual self-awareness level in the revised map and conceptual changes/improvements as assessed by the three experts?

A significant Pearson correlation was found between level of student conceptual self-awareness in revised concept maps and actual conceptual changes as measured by the three experts ($r = 0.38$, $p < 0.05$). Specifically, the students did not overestimate or underestimate their concept maps after viewing many of their peers' maps. They used other maps as models, located their concept boundaries, understood the relative quality of their own concept maps, and were more self-aware of those boundaries when revising their maps. Furthermore, the students' concept maps significantly improved in terms of overall quality. Again, a possible explanation is that the social comparison process helped students learn previously unknown concepts and incorporate them into their revised maps.

6.5. Questionnaire responses

Data on student perceptions of the ICMSys are shown in Table 1. In the "practicality for comprehension" category, the responses indicate that the majority of students found the ICMSys to be a convenient method for helping them observe (item 1, 78%) and comprehend (item 2, 91%) major concepts and to understand the target material (item 3, 63%). This suggests that

Table 6
Data for integrated concept map (ICMap) viewing frequency

Student/expert score	Group 1 ($N = 16$)		Group 2 ($N = 16$)		t	Significance
	M	SD	M	SD		
First map	5.31	3.07	6.38	4.11	−0.83	*ns*
Revised map	3.13	2.45	5.63	3.12	−2.52	$p < 0.05$
t	2.95		0.70			
Significance	$p < 0.05$		*ns*			

Group 1 = high, group 2 = low.

the students' ideas are not only externalized, but can also be selectively accommodated in representations considered practical for concept comprehension. Under "capability for conceptual awareness," the majority of students found the ICMSys to be helpful in terms of comparing their maps with their peers' maps (item 4, 84%), and therefore helpful in terms of finding concept boundaries (item 5, 88%) and adding extensions or making revisions to their own maps (item 7, 91%). These responses suggest that the ICMSys can assist students in conceptual reflective thinking, as well as in identifying and perhaps breaking through their existing concept boundaries.

Only 25% agreed that the ICMSys helped them find conceptual faults (item 6). The students admitted their limitations in presenting thorough/comprehensive concept maps, yet they asserted that the ideas they presented in their maps were almost correct. A possible explanation is that the students could not recognize their faults; this can be addressed by including expert concept maps as comparison sources or asking teachers to help correct misconceptions in the revised maps. Next, 72% felt that the ICMSys interface was easy to use (item 8), but only 47% stated an interest in using similar systems in the future (item 9). The vast majority of participants made changes to their original concept maps (item 10, 94%). When asked to identify factors that encouraged them to make revisions, they replied (a) some extensions could be added to make their concept maps more complete and thorough, (b) some previously unknown concepts were essential for inclusion in their revisions, or (c) their concept maps were inferior to their peers'.

7. Conclusions

We believe the introspective and comparative features of integrated concept maps can promote conceptual self-awareness, and that conceptual self-awareness can lead to personal conceptual change. Sometimes students are just a step away from coming up with their own comprehensive solutions or new ideas, and cannot utilize their prior knowledge flexibly due to their tendencies to frame their thinking within habitual concept boundaries. Thus, their attention is aimed at specific points or details to such a degree that they lack awareness of other possible solutions—what we call the "unaware zone." A review of concepts generated by peers may help students consider ideas they could not identify on their own.

Case study results show improvement in the students' conceptual self-awareness and evidence of their breaking concept boundaries due to their ability to use others' ideas to create quality revised maps. In other words, it is possible to design a learning system as an auxiliary tool to encourage conceptual self-awareness as a step toward breaking concept boundaries and making conceptual changes. Most existing e-learning systems aim at boosting learning performance, with little effort made to promote self-awareness in terms of meta-cognition. Our concept mapping system differs in that it does not take the traditional approach to using concept mapping in collaborative meaningful learning. Using meta-cognition theory and the concept mapping technique, we developed a system that allows students to break through concept boundaries by improving conceptual self-awareness. Promoting self-awareness may not directly result in greater creativity, but it can be an important step toward overcoming personal barriers to creativity. We believe such experiences can exert lifelong impacts on learners: appreciating others' viewpoints, recognizing their own thinking habits, and encouraging creative mindsets.

The topic used in the case study, computer hardware structure, may not be appropriate for encouraging the full use of creative potential. We therefore suggest that future researchers take care in selecting more suitable subject domains for creative thinking. The ICMSys can be used in combination with any subject, whose domain knowledge can be expressed in concept map format to assist students in elaborating concepts, engaging in reflective thinking, or breaking concept boundaries. For conceptual courses, the ICMSys can help students expand or elaborate their knowledge for better conceptual understanding. For example, teachers in introductory biology, psychology, or physics classes can use the ICMSys to make students aware of what they already know or don't know; students can consequently determine what concepts need to be incorporated into their cognitive systems and what links need to be created or deleted. Furthermore, they can consider how to restructure their concept maps to make them more meaningful. For design courses (e.g., industrial design or management), the ICMSys can assist students in creative thinking or innovative problem solving for assigned case studies or product design assignments. Instructors may also be interested in asking students to write reflective essays to demonstrate their creative ideas and conceptual change outcomes in addition to having them construct revised concept maps. The strength of the ICMSys software is that it provides opportunities for students to take responsibility for reflecting on what they did, what others did, and what improvements might be made by choosing and viewing, making comparisons, and engaging with their peers' maps.

In this study, the ICMSys was used as a personal conceptual self-awareness tool for emphasizing the importance of breaking concept boundaries via the modeling of peer concept maps. It can also be used as a good model for distributed learning or as a basis for collaboration and debate. Finally, when utilizing the ICMSys or a similar system, teacher expectations and other sources of motivation need to be considered to determine how and why students break through concept boundaries and generate creative ideas.

References

Ausubel, D. P. (1968). *Educational psychology: A cognitive view*. New York: Holt, Rinehart & Winston.

Bandura, A. (1986). *Social foundations of thought and action: A Social cognitive theory*. Englewood Cliffs, NJ: Prentice Hall.

Bisseret, A., Figeac-Letang, C., & Falzon, P. (1988). Modelling opportunistic reasonings: The cognitive activity of traffic signal setting technicians. INRIA Technical Report No. 893. Rocquencourt: INRIA.

Brown, A. L. (1987). Metacognition, executive control, self-regulation, and other more mysterious mechanisms. In F. E. Weinert & R. H. Kluwe (Eds.), *Metacognition, motivation, and understanding* (pp. 65–116). Hillsdale, NJ: Lawrence Erlbaum.

Burleson, W. (2005). Developing creativity, motivation, and self-actualization with learning systems. *International Journal of Human–Computer Studies, 63*, 436–451.
Cañas, A. J., Hill, G., Carff, R., Suri, N., Lott, J., Eskridge, T., et al. (2004). CmapTools: A knowledge modeling and sharing environment. In *Proceedings of the first international conference on concept mapping* (pp. 125–133). Pamplona, Spain.
Chang, K. E., Sung, Y. T., & Lee, C. L. (2003). Web-based collaborative inquiry learning. *Journal of Computer Assisted Learning, 19*, 56–69.
Chiu, C. H., Huang, C. C., & Chang, W. T. (2000). The evaluation and influence of interaction in network supported collaborative concept mapping. *Computers and Education, 34*(1), 17–25.
Chung, W. K., O'Neil, F., Herl, E., & Dennis, A. (1997). Use of the networked collaborative concept mapping to measure team processes and team outcomes. Paper presented at the annual meeting of the American Educational Research Association. Chicago, IL.
Coffey, J. W. (2007). A meta-cognitive tool for courseware development, maintenance, and reuse. *Computers and Education, 48*(4), 548–566.
Duval, S., & Wicklund, R. A. (1972). *A theory of objective self-awareness*. New York: Academic Press.
Feldhusen, J. F. (1995). Creativity: A knowledge base, metacognitive skills, and personality factors. *Journal of Creative Behavior, 29*(4), 265–268.
Finke, R. A., Ward, T. M., & Smith, S. M. (1992). *Creative cognition: Theory, research, and applications*. Cambridge, MA: MIT Press.
Fisher, K. M. (1990). Semantic-networking: The new-kid on the block. *Journal of Research in Science Teaching, 27*, 1001–1018.
Fischer, G., Giaccardi, E., Eden, H., Sugimoto, M., & Ye, Y. (2005). Beyond binary choices: Integrating individual and social creativity. *International Journal of Human–Computer Studies, 63*, 482–512.
Flavell, J. H. (1976). Metacognition aspects of problem-solving. In L. B. Resnick (Ed.), *The nature of intelligence* (pp. 231–235). Hillsdale, NJ: Lawrence Erlbaum.
Ford, C. M. (1996). A theory of individual creative action in multiple social domains. *Academy of Management Review, 21*(4), 1112–1142.
Fry, P. S., & Lupart, J. L. (1987). *Cognitive processes in children's learning*. Springfield, MA: Charles C. Thomas.
Gaines, B. R., & Shaw, M. L. G. (1995). Concept maps as hypermedia components. *International Journal of Human–Computer Studies, 43*(3), 323–361.
Gardner, H. (1993). *Creating minds: An anatomy of creativity seen through the lives of Freud, Einstein, Picasso, Stravinsky, Eliot, Graham, and Gandhi*. New York: Basic Books.
Garner, R., & Alexander, P. A. (1989). Metacognition: Answered and unanswered questions. *Educational Psychologist, 24*(2), 143–158.
Kornilakis, H., Grigoriadou, M., Papanikolaou, K. A., & Gouli, E. (2004). Using WordNet to support interactive concept map construction. In *Proceedings of the fourth IEEE international conference on advanced learning technologies*. Joensuu, Finland.
Kremer, R. (1996). Toward a multi-user, programmable web concept mapping "Shell" to handle multiple formalisms. In *Proceedings of the tenth Banff knowledge acquisition workshop*. Banff, Alberta, Canada.
Lin, S. S. J., Sun, C. T., & Kao, G. Y. M. (2002). Designing a networked-sharing construction environment. *British Journal of Educational Technology, 33*(4), 489–492.
Malone, J., & Dekkers, J. (1984). The concept map as an aid to information in science and mathematics. *School Science and Mathematics, 84*(3), 220–231.
Michinov, N., & Primois, C. (2005). Improving productivity and creativity in online groups through a social comparison process: New evidence for asynchronous electronic brainstorming. *Computers in Human Behavior, 21*(1), 11–28.
Mullen, B., Johnson, C., & Salas, E. (1991). Productivity loss in brainstorming groups: A meta-analytic integration. *Basic and Applied Social Psychology, 12*, 3–23.
Nisbett, R. E., & Wilson, T. D. (1977). Telling more than we can know: Verbal reports on mental processes. *Psychological Review, 84*(3), 231–259.
Novak, J. D., & Gowin, D. B. (1984). *Learning how to learn*. Cambridge, UK: Cambridge University Press.
Okebukola, P. A., & Jegede, O. J. (1989). Cognitive preference and learning model as determinates of meaningful learning through concept mapping. *Science Education, 71*, 232–241.
Reader, W., & Hammond, N. (1994). Computer-based tools to support learning from hypertext: Concept mapping tools and beyond. *Computers and Education, 22*, 99–106.
Roth, W. M., & Roychoudhury, A. (1992). The social construction of scientific concepts or the concept map as conscription device and tool for social thinking in high school science. *Science Education, 76*, 531–557.
Selker, T. (2005). Fostering motivation and creativity for computer users. *International Journal of Human–Computer Studies, 63*, 410–421.
Suls, J., & Fletcher, B. (1983). Social comparison in the social and physical sciences: An archival study. *Journal of Personality and Social Psychology, 44*, 575–580.
Wallace, J. D., & Mintzes, J. J. (1990). The concept map as a research tool: Exploring conceptual change in biology. *Journal of Research in Science Teaching, 27*(10), 1033–1052.