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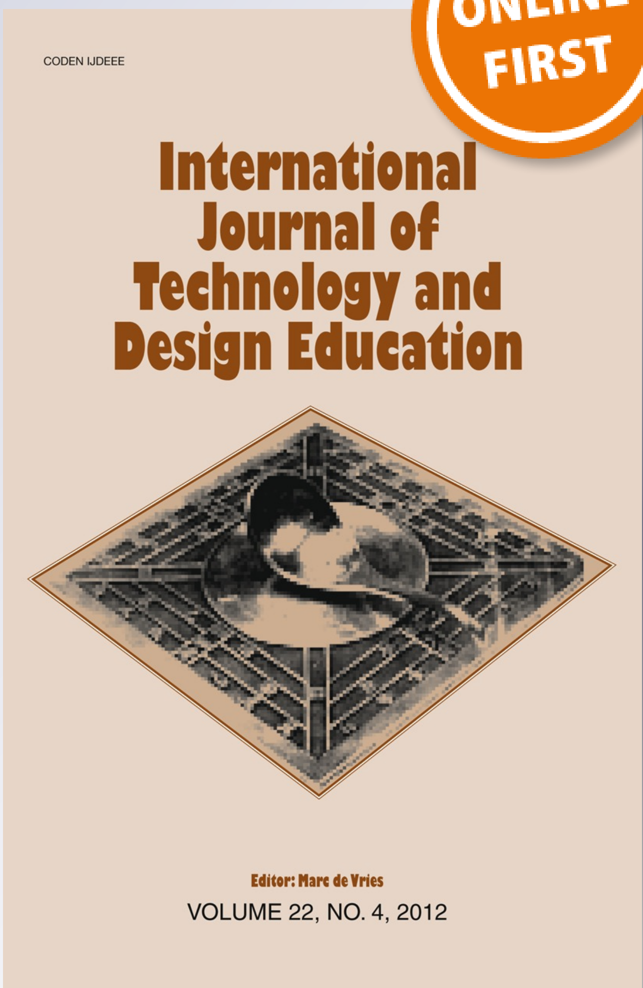

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Using creative problem solving to promote students' performance of concept mapping

Kuo-Hung Tseng · Chi-Cheng Chang · Shi-Jer Lou · Pi-Shan Hsu

Abstract The purpose of the study was to explore that using creative problem solving can promote students' performance of concept mapping (CMPING). Students were encouraged to use creative problem solving (CPS) in constructing nanometer knowledge structure, and then to promote the performance of CMPING. The knowledge structure was visualized through CMPING which helps students to improve their performance. The participants were 42 college juniors who selected the course "Nano-environmental Engineering Technology". Four instruments were used to classify student learning performance (meaningful learning, rote learning and non-learning). This study included three main issues: (1) Student learning quality was determined by the change in concept map construction. (2) In-depth interviews were applied to understand student's CPS process. (3) Student interaction quality in a discussion board on a web-platform was evaluated. The results showed that meaningful high-level learners successfully applied CPS in constructing concept maps and they presented better performance of CMPING. Rote learners' results were in the second place, and non-learners achieved the worse outcomes. It is

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suggested that a future teaching study can use creative problem solving to promote students' performance of CMPING in other courses.

Keywords Concept mapping · Creative problem solving · e-Learning

Introduction

In science education, it is crucial to foster students' problem solving ability in order to solve real world problems. Independent thinking and problem solving abilities are thus essential for students to develop their mapping potential. Concept mapping (CMPING) has been proven to be an effective instructional tool for problem solving (Stoyanova and Kommers 2008). Creative problem solving (CPS) is an effective strategy in solving real problems and overcoming challenges by using creativity (Treffinger et al. 2005). CMPING and CPS are two learning strategies which emphasis the thinking procedures of learners. Through visualization, CMPING helps to understand the learners' thinking procedures. CPS encourages students to solve problems with good thinking abilities (including creative thinking and critical thinking). The purpose of the study was to promote students' performance of CMPING. Students were encouraged to use CPS in constructing nanometer knowledge structure through good thinking behavior. CMPING was adopted afterwards for students to present their knowledge structure through visualization.

Literature review

Concept map and creativity

The term of creativity is a broad field and difficult to define. It can be seen as a product of enlightenment for individual to solve unknown problems. This enlightenment provides various alternations for problems, creating new ideas, and discovering relationships between old concepts with new ideas (Riza 2002). In recent research, it has argued that creativity is assessable for very individual definition (Sternberg and Lubart 1992) and with great potential to be trained and taught (Ma 2006; Scott et al. 2004). The effectiveness of creativity training has been concluded to result in significant consequences in learning achievement (Russell and Meikamp 1994). In Cropley and Cropley's (2000) study, they attempted to foster engineering undergraduates' creativity through creativity training, and concluded a positive outcome due to the increase of innovative ideas. As a result, creativity support tools are required (Selker 2005). Then Shneiderman (2007) mentioned that the creativity support tool is available to "extend users' capability to make discoveries or inventions from gathering information, hypothesis generation, and initial production, through the later stages of refinement, validation and dissemination" (p. 22), concept mapping can be seen as a useful creativity support tool due to the fact that it can put these functions into practice. The result reveals the existence of high-level interrelationship between concept mapping and creativity (Novak and Cañas 2007).

According to Novak and Cañas (2007) (Fig. 1), high learning performance takes place through learning in meaningful ways. While CMPING aimed to achieve meaningful learning, the requirements of explicit knowledge structure and successful integration of new and prior knowledge are essential. Thus, the competence of creative thinking and knowledge creation were required to facilitate acquiring innovation knowledge (Torrance

1993) and reinforce mapping performance. Additionally, creativity can be seen as a "process" resulting in innovative and useful products (Burleson 2005). This makes the concept mapping construction process to be seen as a creative thinking process. As a result, CMPING is a creative process and a creativity support tool to stimulate creativity. In addition, constructing concept maps in a creative way facilitates high-level meaningful performance. Therefore, concept mapping in this study is a powerful creativity support tool and creativity thinking process to enhance creativity outcomes.

Web-based collaborative concept mapping

Concept Mapping (CMPING) (Novak and Gowin 1984) is a graphic learning strategy and visual representation presenting the change of individual knowledge structures. It also helps learners to organize and integrate their understanding of prior knowledge and newly learned knowledge and aims to result in a more meaningful learning outcome (Novak 1990). Novak and Gowin (1984) mentioned that various components were essential for constructing successful concept maps. Firstly, concepts are the priority elements of concept mapping. They are presented from general to specific and from macro to micro to form a hierarchical structure. The linking labels form propositions to present the inter relationships of the concepts. The appropriately use of linking labels helps learners to identify good cross-links, another important element of concept mapping, which are powerful connections to form a "web" (Heinze-Fry and Novak 1990, p. 463) within vary clusters. The quality of the use of cross-links is essential due to it may be seen as a foundation for evaluating learner understanding and misunderstanding of the concepts. According to Novak and Cañas (2007), they argued that "cross-links often represent creative leaps on the part of the knowledge producer" (p. 2). They also claimed the competence to create new cross-links is one of the important features of concept mapping. We may thus further presume that cross-links play an important role in the facilitation of the production of meaningful learning. On the other hand, CMPING is used not only as an instruction tool, but also an evaluation tool (Edmondson 2000). In recent research, Hay, Kinchin and their colleagues (ex: Hay 2007; Hay and Kinchin 2008; Hay et al. 2007) evaluated student

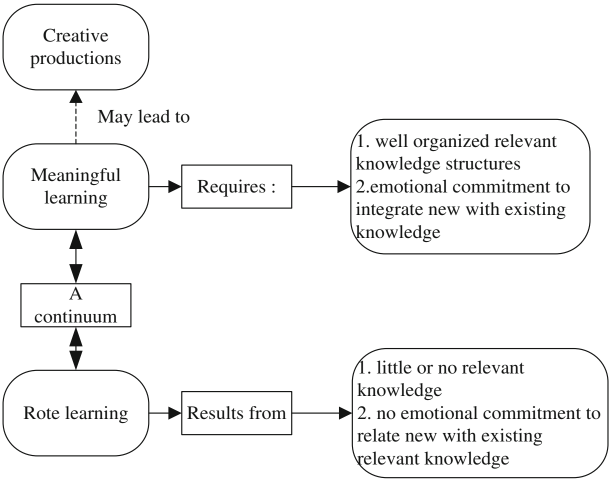

Fig. 1 Learning can vary from highly rote to highly meaningful. Creativity results from very high levels of meaningful learning (Novak and Cañas 2007)

learning quality through analyzing students' concept maps. The present research adopted concept mapping analysis to evaluate the change of students' knowledge structure, and further determine their learning quality.

Collaborative learning facilitates learners to assess into a more flexible cognitive pattern and stimulates critical thinking (Stoyanova and Kommers 2002). It also enables learners to share and negotiate personal ideas and inspires knowledge exchange through group brainstorming and discussion. Michinow and Primois (2005) argued that creativity measured the quantity of ideas generated by participants at least during the asynchronous electronic brainstorming. It is indicated that the group brainstorming activity inspires new ideas. Also, through group discussion during collaborative learning, learners are able to generate members' ideas, and increase members' interaction and positive contributions (Sizmur and Osborne 1997). Communication and interaction among participants thus occurs in a collaborative learning context and leads to knowledge construction and deep understanding (Komis et al. 2002). As a result, collaborative learning provides an appropriate atmosphere for CMPING learning, because it stimulates different kinds of knowledge growth (Fu et al. 2009).

Furthermore, according to Webb (1982), student interaction and achievement are closely related to each other. In distance education or web-based learning environment, in particular, interaction between individual involved in learning may decrease the negative influences on communication (Thorpe 2008). Due to this reason, asynchronous and synchronous communication seem to be influential communication tools to engage in critical thinking (Jamaludin and Lang 2006; Klisc et al. 2009), and to enhance group interaction (Cheong and Cheung 2008; Yukselturk and Yildirim 2008). In the research of Stoyanova and Kommers (2002), they reported better learning effectiveness and group creativity through intensive learner interaction in collaborative concept mapping. Additionally, the use of a web-based instrument yields meaningful learning due to the fact that it offers larger knowledge acquisition potential (Hron and Friedrich 2003), and allows learners to assess information seeking, analyzing and synthesizing strategies (MacGregor and Lou 2006). In the study by Jong et al. (2005), the web-based collaborative concept mapping was adopted. They indicated a close relationship between collaborative learning and concept mapping outcomes, and concluded that there was a better learning outcome with intense interaction. As a result, web-based collaborative concept mapping, as a communication tool, may encourage group interaction and further improve learning achievement. This research proposes that collaborative learning increases interaction and creativity.

Creative problem solving and concept map

CMPING has long been developed for students' learning. However, most studies emphasized the influence of concept mapping on problem solving performance (ex: Lee and Nelson 2005; Hollenbeck et al. 2006; Stoyanova and Kommers 2008). Few have investigated the interrelationship between creative problem solving (CPS) and CMPING. CPS is an effective strategy for solving real problems and overcoming challenges by using creativity (Treffinger et al. 2008). The CPS framework was originally developed by Alex Osborn, and has been modified by Treffinger, Isaksen with their team to version 6.1. According to Isaksen and Treffinger (2004), the CPS version 6.1 included four elements: understanding the challenge, generating ideas, preparing for action and planning your approach; and eight stages: constructing opportunities, exploring data, framing problems, generating ideas, developing solutions, building acceptance, designing processes and appraising tasks. The major purpose of the process is to clarify leaner understanding of problems, generating ideas, and planning for action (Treffinger 1995) through creative ways. Brophy (1998) mentioned that the complete application of the CPS process is not essential. It can be seen as a standard for solving a particular problem, and can allow the problem solver to determine and choose required scopes. The CPS process thus provides a great range of flexibility for problem solvers.

In the CPS process, continuous thinking is crucial for every problem solver. While solving problems with creativity is the major goal of the CPS process, it requires learners to think creatively of innovative ideas. More important, it requires learners to think critically to reflect on problem solutions. The development of critical thinking skills is essential because students with critical thinking skills can analyze and compare obtained knowledge, and revise knowledge from various perspectives (MacKnight 2000). Besides, critical thinking is a reflective tool to reflect and evaluate important information and classify possible solutions (Dabbagh 2001). Additionally, Wang et al. (2009) claimed that there is a close interrelationship between critical thinking and knowledge construction. CMPING, as a knowledge changing tool (Stoyanova and Kommers 2008), thus requires critical thinking skills to reflect on mapping solutions and knowledge examinations. Consequently, it can be claimed that the CPS process is an influential feature in concept mapping performance. It may further facilitate the classification of learners' knowledge structure in regard to continuous high-order thinking. In addition, the increase of a reflective ability may also be revealed in a concept map outcome which was appropriately adopted through the CPS process.

As a result, through appropriate use of CPS, a better mapping performance can be achieved. Also, solving mapping problems in creative and critical way may result in a high-level learning performance. In conclusion, we believe that the combination of CPS and concept mapping is beneficial for students to learn creatively. This is why this study adopted CPS to support concept mapping in the Nanotechnology course that requires extensive information and greater cognitive workload.

Social comparison and self-assessment

Social Comparison Theory assumes that all human beings have the ability to evaluate their own opinions (Festinger 1954). Various studies have found that social comparison process stimulates self-improvement (Michinov and Primois 2005; Helgeson and Mickelson 1995; Wood 1989). In the research of Fry and Lupart (1987), they adopted social comparison to measure self-monitoring and comprehension ability that can be revealed by the difference between self-assessment and expert-assessment. In more recent research, Kao et al. (2008) utilized social comparison (student self-assessment and expert-assessment) to improve the student self-awareness. They indicated that the creativity potential can be stimulated through the comparison process. Further, the study of Michinov and Primois (2005) also found a positive influence of social comparison process on productivity.

Self-assessment can be seen as a reflective tool (Mok et al. 2006) that develops learner's self-reflection ability. Self-reflection skill is cssrucial in knowledge learning, due to the fact that it improves conceptual understanding (May and Etkina 2002), and allows individuals to consider and judge self prior experience (Kong et al. 2009). Further, Burleson (2005) suggests that creativity can be inspired through the development of meta-cognitive ability with reflective tools. This implies that learners with better self-reflection ability have a potential to produce mapping performance. Consequently, this research argues that self-assessment is a powerful reflective tool that improves learners' self-reflection ability through the use of social comparison (self-assessment and expert-assessment). A complete concept map usually requires continuous revision, which provides learners with an opportunity to reflect on their previous work. We believe that using the social comparison process in concept mapping education encourages learners to review conceptual knowledge, and reflect on problem solving solutions.

Methodology

How to examine students' performance of CMPING?

In this study, we used the followings to examine students' performance of CMPING: (1). thinking abilities, (2). self-assessment and social comparison, (3). self-reflection, (4). group interaction, (5). link quality (6). creativity. Furthermore, thinking abilities included creative thinking and critical thinking. And the standard of creativity used was revised from the work of Novak and Cañas (2007) who mentioned related theories. This study further developed three assessment criteria to measure the creativity performance of concept maps: (1) conceptual richness or the effective integration of new with existing knowledge, (2) the quality and quantity of meaningful cross-links or evidence of understanding, (3) a well organized hierarchical structure.

Sample

All of undergraduate samples are major in the department of chemical engineering and material engineering in a national university in Taiwan. They were enrolled in the "Nano-environmental Engineering Technology". Most of them obtained knowledge of chemistry and material characteristics related subjects, due to they had taken related coursework such as chemistry, physics, chemical and physical sciences, engineering mathematics, thermodynamics, and mechanics of materials as essential courses.

Forty-two-third year undergraduates participated (33 males and 9 females) in this study, Eleven groups were divided depending on year performance (year record) of the required course "chemical and physical sciences," which is prior knowledge of the course"Nano-environmental Engineering Technology", in the last academic year. In other words, there is heterogeneity of year record within each group and homogeneity of year record among different groups.

In addition, the other three groups of the sample in this study: meaningful, rote learning, and non-learning, would be discussed at the last paragraph in the part of "Procedure."

Course contents

The course was mainly taught via multi-media and facilitated by concept maps of each unit. This was aimed to help students to be more familiar with concept mapping from this concept mapping learning context. During the course, the teacher firstly introduced the basic characteristics of the course theme, "Nano Photocatalyst". The principle and practical examples and issues were then illustrated for students to further gain a deep understanding of the topic.

Procedure

In this course, a 15-week (3 h per week) experiment was designed and conducted to practice the concept mapping technique. During the experiment, since the procedures or workflow for both individual and group students were all the same, we proposed the procedure as below: (1) the students in each group were provided an interactive web-platform for extracurricular, learning group interaction and group discussions. The website contained teaching videos of CMPING, a CPS learning area, a course introduction, hyperlinks to Nanometer-related websites, discussion boards and an assignment zone. (2) An online teaching assistant (TA) was assigned to each group. The TA's role was to guide students to plan CPS procedures and utilize mapping skills. (3) The CPS procedures play an important role in this activity as it facilitates group students to extend unknown concepts through continuous searching, analyzing and generating information of the theme in order to develop feasibility mapping plan. (4) Group students may be able to create creative concepts, examples and successful cross-links through brainstorming and continuous reflective thinking during the process. Before the activity formally began, the students were taught the rules and techniques of concept mapping. In addition, they were instructed how to use CPS in planning the mapping procedure. (5) Each group was required to construct two concept maps (pre-test and post test) on the theme of "Nano Photocatalyst". An example map (post test) chosen from eleven groups of maps was shown in Fig. 2. The quality of the students' mapping performance was evaluated by three experts. (6) To encourage group students' reflection, the students were also required to evaluate their own concept maps and their assessment was compared with the experts'. (7) To classify three groups of the sample: meaningful, rote learning, and non-learning, which will be discussed in detail in the next paragraph. (8) In-depth interviews were adopted to understand how group students' creative thinking was employed through using CPS to learn concept mapping of Nanometer knowledge. (9) To send feedback of analysis of the collected data and the results to the teacher and group students.

Three groups of the sample: meaningful, rote learning, and non-learning, were selected by three experts who examined the students' maps to determine their learning quality. In other words, three experts used the following criteria of students' learning quality to classify three groups mentioned above. We adapted Hay et al. (2007)'s works and proposed: (1) Meaningful learning involved a great amount of conceptual knowledge change, and a deeply significant understanding of the theme topic revealed by the integration of prior and new knowledge as well as superior outcomes in regard to self-assessment competence and social comparison in constructing concept maps. (2) Rote learning was indicated by an increase in new knowledge. However, the integration of prior and new knowledge was insufficient in constructing concept maps led to the ineffective use of partial creative problem solving. (3) Non-learning is illustrated by a concept structure that was simply formed by prior knowledge, and by a lack of knowledge increase in the second concept map showing the relationships among concepts. Moreover, the integration of prior and a great amount of new knowledge were not successful in constructing concept maps.

Instrument and data analysis

The analysis of concept mapping

This study required each group to construct one concept map before and after learning, in order to determine the change in their concept map structure. Afterwards, three experts examined the students' maps to determine their learning quality or mapping performance.

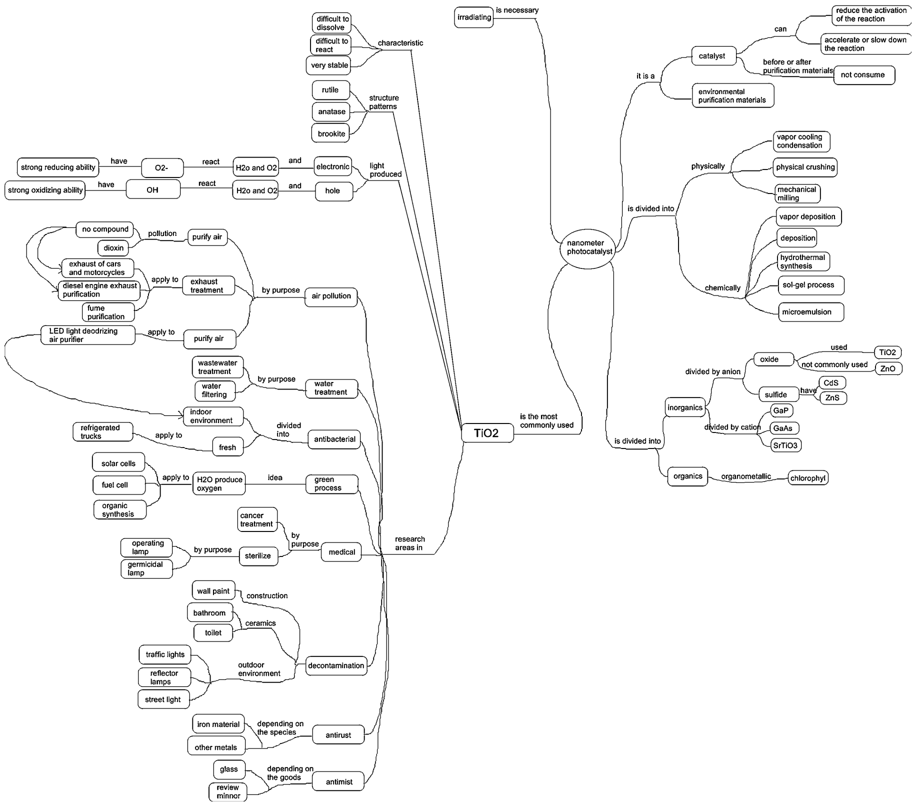

Fig. 2 An example map (post-test)

In-depth interview

The in-depth interview was conducted to further explore how the students solved problems with creative thinking during concept map construction. It also aimed to understand how students' interact with their peers and TAs through the web platform. In regard to the interviewees, six groups were selected according to their CM performance. Six interviewees were randomly chosen from each of the six groups. In other words, we selected two interviewees randomly from high level of CM performance groups, two randomly from middle level of CM performance groups and two randomly from low level of CM performance groups. A semi-structured interview technique was used and both open-ended and closed questions were asked. Sixteen questions were devised according to the research purpose, such as "How do you feel about the concept mapping process from the first time to the second?", "After the first concept mapping, do you think that collaborative learning is helpful and is able to inspire mapping creativity for the second concept mapping?", and "Can you mark your second concept map, and provide some comments? Furthermore, the questions were confirmed by five experts in the area in order to establish content validity.

The data analysis adopted grounded theory to analysis interview content through line by line analysis. Then, category and semi-category were divided for Axial coding and Selective coding. The standard for coding were "the attitude of students toward concept mapping", "the nine stages of CPS", "the opinions and interaction of students toward the web platform", and "students' self-assessment of concept mapping". The reliability analysis of interview texts was completed by two coders. The coding reliability was built up with an analyst triangulation method which was to ask two coders to analyze interview texts independently and then to compare the similarities and differences between them. At last, Holsti's formula (1969) produced a reliability coefficient of 0.891 across all categories between two coders.

Self-reflective rating method

In the study of Kao et al. (2008) conceptual self-awareness rating method was adopted to determine the differences of student self-assessment and expert-assessment from the pre-test to post-test. The self-awareness and social comparison process was mainly applied to improve student potential. Accordingly, this study utilized the paired-samples *t* test to compare the cognitive variation between student self-assessment and expert-assessment. The variation represents the students' self-reflection ability. That is, a lower difference represents better self-reflection of the student. The difference between first and second student/expert-assessment indicates the change of student self-reflection. When the gap of the second student/expert score is smaller than the gap of the first student/expert score, it indicates students have gained an improvement in self-reflection ability.

The measurements of students' and experts' pre-test and post-test were "student self-assessment questionnaire" and "expert-assessment questionnaire". The purpose of the self-assessment questionnaire was for students to reflect on their concept maps. Three experts rated students' concept maps with the expert-assessment questionnaire. The three experts were devoted to the field of Nanotechnology and Microsystems Engineering, Research of Material equipment of Nanometer powder, and Knowledge Transfer respectively. It assesses concept maps in 20 questions from four dimensions: conceptual richness (ex: I (student) have integrate my prior knowledge and new-learned knowledge in meaningful way), link quality (ex: The linking words that I used can clearly explain the relationships between concepts), evidence of understanding (ex: The cross-links that I used can prove my further understanding of the concept knowledge), and hierarchy and structure (I have re-organized the conceptual construction) (Hay et al. 2007). With minor revisions, under each dimension, there are 4 to 6 items in five-point Likert scale modes (from strongly agree to strongly disagree).

The revision was made in accordance to the comments of five experts in order to establish content validity. The entire reliability of the scale is 0.864. The reliability of each of the dimensions is: 0.789 for conceptual richness, 0.713 for link quality, 0.801 for evidence of understanding, and 0.604 for hierarchy and structure. In addition, Kendall's Coefficient of Concordance (W) was used to assess rater reliability. The result reveals a good inter-rater reliability because both χ^2 (28.797) and W (0.959) have reached a significance level.

Evaluation of student interaction and creativity in a web-platform discussion board

The study categorized the effective interaction (number of logs) and creativity (originality of ideas) from the log files of each group in the web-platform discussion board. The measurement of interaction was obtained by calculating the number of effective log files of a student in the discussion board (meaningless log files were deleted from the calculation). As mentioned by Michinow and Primos (2005), creativity can be measured by the quality of ideas generated by participants during asynchronous electronic brainstorming. Accordingly, the measurement of creativity performance in this study was to calculate the number of stimulated creative ideas during group interactive discussion from the effective log files. Two coders analyzed and classified the content of interactive conversation. The coding reliability of 0.953 indicates a sound reliability. Finally, the variation of the effective interaction and the creativity of students among the three learning quality groups was analyzed with ANOVA.

Results

After students evaluated their own performance of concept maps, their assessment was compared with three experts, and students' learning quality was based on the rules of Hay et al. (2007)'s dividing into three groups of learning, which included meaningful learning, rote learning, and non-learner. And since the results for both of individual and group students are all the same, so we proposed the same results as below. As well, all the individuals in each group discussed how to construct CPS and CMPING and solved problems till the map finished so that all the individuals had much contribution or influence on completing the map.

The results of quantitative data

Meaningful and rote learning students have significantly better self-reflection competence and improvement

In Table 1, the student/expert scores in the "first map" column indicates the level of self-reflection before learning concept mapping, and the student/expert scores in the "second

Table 1 The difference between the student self-assessment and expert-assessment

Assessment source	First map M (SD)	Second map M (SD)	t	Significance
Overall				
Student	3.68 (0.24)	3.84 (0.24)		
Expert	1.79 (0.47)	3.13 (0.68)		
Student/expert	1.89 (0.57)	0.71 (0.78)	6.59	0.000
Meaningful learner				
Student	3.57 (0.31)	3.79 (0.10)		
Expert	2.05 (0.69)	3.84 (0.56)		
Student/expert	1.52 (0.96)	−0.05 (0.65)	6.69	0.022
Rote learner				
Student	3.72 (0.18)	3.78 (0.16)		
Expert	1.84 (0.38)	3.31 (0.17)		
Student/expert	1.88 (0.47)	0.47 (0.10)	6.54	0.007
Non-learner				
Student	3.71 (0.29)	3.93 (0.38)		
Expert	1.53 (0.33)	2.41 (0.24)		
Student/expert	2.18 (0.11)	1.52 (0.47)	2.45	0.092

map" column suggest the level of self-reflection after learning concept mapping. The paired-samples *t* test was used to examine the difference of two scores. The results indicated a significant improvement in self-reflection of all the students ($t = 6.59$, $p < 0.001$). Deeper examination explored the change of student self-reflection in different groups with three different learning qualities. The results revealed that there was no major improvement in the self-reflection ability of students with non-learning ($t = 2.45$, $p > 0.05$). The results are caused of the overestimate of students' first self-assessment. At the first self-assessment, students were unfamiliar with topic knowledge, and presented an overestimate of their competence compare with the first expert-assessment. At the second self-assessment, students obtained better understanding of the topic knowledge and applied CPS process as a reflective tool for learning. They thus estimated their ability more carefully. In contrast, both rote learning and meaningful learning students obtained a significant improvement in self-reflection ability ($t = 6.54$, $p < 0.01$, and $t = 6.69$, $p < 0.05$ respectively). The implied conclusion is that meaningful learning and rote learning students were more able to successfully evaluate their concept maps. Also, better self-reflection ability was revealed from these students due to the inexistence of exaggeration in the quality of their concept mapping.

Higher frequency of interaction helped students to create creative ideas with better quality, and it reinforced Meaningful learning to produce high quality concept maps

This study used one-way analysis of variance to compare the variation of the number of effective interaction and creative ideas in the web-platform discussion board of students with different learning quality. The Scheffe's method was conducted to make a post hoc comparison. The results (Table 2) illustrated that meaningful learning students had the greatest frequency of effective interaction. Rote learning students had the next and non-learning students had the fewest. Moreover, meaningful learning students also produced the most creative ideas with higher quality than rote learning students and non-learning students. In the study of Chiu et al. (2000), they found that a higher frequency of group online interaction was associated with better concept mapping performance. Stoyanova and Kommers (2002) argued that collaborative learning reinforces interaction and further enhances creative thinking and critical thinking. Accordingly, the study suggests that meaningful learning students achieved better critical thinking and creative thinking due to their better group interaction and brainstorming during the online collaboration process. The consequence resulted in more creative ideas, and led to high-level concept mapping performance. In regard to rote learning and non-learning students, their inferior concept

Table 2 ANOVA of interaction and creativity among three learning quality groups

Learning effect	ML[a] (N = 11) Mean (SD)	RL[b] (N = 16) Mean (SD)	NL[c] (N = 15) Mean (SD)	F	Scheffe
Interaction (number of logs)	60.33 (10.41)	21.00 (12.02)	15.25 (7.59)	19.20**	ML > NL ML > RL RL > NL
Creativity (originality of ideas)	39 (9.85)	13.25 (9.22)	7.25 (4.11)	15.02**	ML > NL ML > RL RL > NL

* $p < .05$, ** $p < .01$, *** $p < .001$; [a] Meaningful learning; [b] Rote learning; [c] Non learning

mapping performance resulted from a lower frequency of interaction, which has negative influence on creative production.

The results of qualitative data

The groups that obtained meaningful learning used CPS effectively to facilitate concept mapping and to enhance learning quality

Three groups achieved meaningful learning, and their maps displayed high creativity. These groups' concept maps presented complete integration of new and prior concept knowledge and excluded incorrect and irrelevant concepts. Obviously, these students applied CPS to develop knowledge, and re-organized the concepts through critical thinking. Moreover, their maps demonstrated meaningful cross links, which is an indication of innovation, comprehension, reorganization and deliberation of concept-map structure.

According to the interview data, students in these groups are active learners. They fully adopted creative thinking and critical thinking to solve mapping problems. They learn through meaningful ways, and effectively applied CPS to facilitate concept mapping construction. They work hard and have positive learning attitudes. They "actively search new knowledge related to concept mapping, and appropriately use the newly acquired knowledge (D026)". They "utilized group brainstorming to inspire new ideas for constructing concept maps, and used group discussions to select suitable concepts (D188, H205)". During the mapping process, "problems such as cross links and linking words were effectively solved (D192, 279, H361)" through "more extensive search of information, group discussions, and consultation of teachers and online TAs (D, H)".

The study proved that students who learn through meaningful ways produce knowledge creation in their final concept maps. Meaningful learners fully adopted creative thinking and critical thinking to construct concept maps. They actively discover and solve problems during the mapping process. Also, they inspired new ideas through group discussions and continuous reflection in order to complete the final maps. Their maps show that they effectively integrate their prior knowledge and new learned knowledge, and thus worked creatively. Russell and Meikamp (1994) indicated that creativity can be recognized in learning performance. Moreover, Novak and Cañas (2007) also mentioned that creative thinking and knowledge creation can be found in the ultimate learning outcome of meaningful learners.

Rote learning students utilized critical thinking unsuccessfully

The maps of four rote learning groups showed the integration of prior knowledge and new knowledge. The incorrect concepts were deleted and modified, and the cross links were increased. However, the maps' quality was not as good as those of the meaningful learning groups. Generally speaking, only part of their concept maps were re-organized even though the evidence of creativity was shown.

The interview of the students from these groups revealed that they felt positively about concept mapping, and have good learning attitudes. However, they mentioned that the quality of their concept maps was impaired "due to the misunderstanding of concepts (F006), and not incorporating important concepts from the class (K084)". Only a medium level of mapping performance was achieved because the students were "unfamiliar with the rules of cross links, which reduced the quality of cross links (K142, F037)." They also indicated that during constructing concept maps "linking words (K104, K108) and cross links are the most difficult parts (K296, F041)". Despite several opportunities for modification, problems were only partially solved in the final maps and therefore negatively influenced the learning performance.

Rote learning students continually learned with traditional methods. As mentioned above, although they altered linking words and increased cross links, the quality of the maps was not good enough. In addition, the structure of their concept maps was impaired because of the misunderstanding of concepts. This indicates that the lack of effective use of critical thinking in problem solving is the crucial reason for inadequate performance. This also suggests that students' insufficient creative thinking led to their failure of critical thinking. As Dabbagh (2001) argued that critical thinking can be used to identify and verify the quality of concept map, critical thinking assists learners to improve their maps. As a result, rote learning students failed to use critical thinking to examine their own thinking, which negatively influenced their mapping performance.

Non-learning students displayed no indication of creativity in their concept maps

The concept maps of four non-learning groups failed to integrate prior knowledge and new knowledge, to illustrate the assigned theme topic adequately, and to delete the incorrect concepts indicating no concept convergence. This led to inappropriate cross links and interrelationships between concepts. Therefore, the concept structures were not reorganized and had low creativity. In conclusion, the non-learning students failed to utilize creative thinking and critical thinking to construct concept maps and presented low level of mapping performance.

In the interview, non-learning students displayed a bad learning attitude. All of them "were rushed into map construction when the deadline approached (A028, E129)"and did not "put enough effort in learning concept mapping (A112, E309)". In regard to innovation, problems that occurred during mapping failed to be solved due to "little peer interaction (A031, E130), rarely logging into the platform, and little interaction with TA (A167, E271)." Furthermore, they mentioned that "the appropriate use of cross links and linking words are the greatest difficulty in the whole process (A213, I264, and E242)", but this problem was not at all solved. The major reasons were "inappropriate time management in construction of maps which led them to give up revision (A104, E222)", and "being unfamiliar with the rules of cross links and linking words (A213, E253)". These problems obstructed the development of innovation in concept maps, and have a significant negative impact on the quality of concept maps.

Non-learning students were unable to use critical thinking and creative thinking. In addition, they had poor peer interaction and low self-monitoring competence; they didn't know how to use cross links and linking words in their concept maps: and they achieved poor learning quality in concept mapping.

Discussion and conclusion

CM is an effective tool for creating new knowledge (Novak and Cañas 2007). CMPING is an effective tool for organizing concepts, and for developing both individual and group creativity (Stoyanova and Kommers 2002). According to Scott et al. (2004), individual creativity potential is accessible to be trained and taught, and has a positive influence in enhancing innovation ideas. In the study of Cropley and Cropley (2000), they found that positive outcomes can be obtained by increasing innovative ideas through conducting creativity training to foster students' creativity. Accordingly, this study adopted CPS in a concept mapping learning activity in order to train students to create better concept maps. Also, two learning methods were applied to facilitate mapping performance. First, the social comparison process was used to increase student self-reflection ability. Moreover, the use of group brainstorming helped students to create innovative ideas. We believe that the utilization of these two methods during concept mapping process provides students with better opportunities to create concept maps with high quality.

This study applied the CPS strategy into the concept mapping learning activity to train and foster students' mapping performance. Through group discussion in a collaborative learning environment, brainstorming was used to inspire new ideas followed by the use of critical thinking to generate ideas. The major purposes of self-assessment are to self-examine through critical thinking, and to facilitate students to improve thinking awareness and comprehension. Social comparison (students/experts) was utilized to help students to be aware of self-cognition, and obtained further improvement in learning in order to stimulate mapping potential.

In this study, meaningful learners are active learners who are highly positive in learning with CMPING. They effectively applied CPS and used creative thinking and critical thinking to facilitate map construction. They also gained superior outcomes in regard to group interaction, creativity, self-assessment competence and social comparison, which led to high-level concept mapping performance by meaningful learners. Russell and Meikamp (1994) mentioned that learner creativity can be revealed from students' learning performance. The same arguments are also mentioned by Novak and Cañas (2007) who suggests creative production can be obtained through very high-level meaningful learning. The argument was consistent with the results of this study. It further proved that the meaningful learning students achieved very high-level concept mapping performance due to the existence of creativity productions in their concept maps.

Rote learning students made great effort and significant improvement of self-reflection ability. However, they were passive in acquiring new knowledge, which led to a negative influence on learning quality and creativity. They failed to solve problems in terms of linking words and cross-linking. The development of their creativity was thus limited. Novak and Cañas (2004) argued that students usually mentioned that cross-linking is the most difficult part in concept mapping due to the fact that they poorly understand the meaning and relationships among the concepts. This also suggests that the rote learning students in this study had only achieved surface understanding of the relationships among the concepts. On the other hand, Novak and Cañas (2007) further argued rote learning is often unsuccessful at achieving creative thinking or novel problem solving, because of the limited advantage that it brings to enriching a knowledge structure. The argument implied that the rote-learning students in this study were lacking deep critical thinking that could add to the enrichment of new knowledge in order to construct their concept maps. Also, the insufficiency of knowledge led to the ineffective use of critical thinking and partial problem solving.

Non-learning students were passive learners, whose learning attitude was negative. Although they completed every task in the concept mapping activity, the non-learning quality was presented. From the in-depth interview, rote learning students were subjective learners and preferred to continue previous learning pattern. They had not yet accepted the new learning model nor had they adapted to the newly established learning environment. The interview data also suggest that non-learning students had low participation, and kept an attitude as observers in the activity. Moreover, they failed to integrate a great amount of new knowledge in constructing concept maps because they had not yet accepted the new learning method. Their concept maps showed a poor learning quality.

The contribution of this study is to integrate the merits of CPS and CMPING in order to inspire performance in students' learning outcomes. Through adopting the learning strategies which are offered by this study, learners are able to train their self-reflection competence with reinforcement. We concluded that the CPS is a student-centered learning method and teacher is just a learning facilitator.

In this research, we put emphasis not only on applying CPS and CPMING, but also included the design of the materials, the assistance of teaching assistant (TA), and the expertise provided from experts. Therefore, we integrated all external resources as possible to enhance the effectiveness of teaching and learning. In addition, although student-centered learning was administrated to fit students' needs, not all the students presented their good performance. From this fact, we infer that some of the students had not yet accepted the new learning method, or the learning motivation had not yet been completely stimulated. According to Novak and Cañas (2007), it is difficult to change the learning behavior of individuals within a short period of time. It implied that students continue to use their old learning model in the CMPING learning activity, which could not have a good impact in their learning outcome.

The limitations of this study are provided as below. First, in this condition, such as: special nanotechnology courses, limited students attending this study and limited groups chosen for interview with related chemical and physical prior knowledge, we applied special teaching methods and tools to strengthen the capacity to do the conceptual breakthrough. Therefore, there are limited inferences and conclusion and the results of this study can not be generalized to the general teaching subjects. So we need more student samples or groups and experimental teaching data to validate this study in order to be generalized to more undergraduate student population and general teaching courses. Second, in this study we have ignored some issues, such as: the composition of the group members with no equal numbers of the male and female student because of limited female students and with no equal level of educational background, and no equal support or guidance for each group provided from teachers or TA. These factors might have some hidden effects on teaching and learning. Therefore, these issues or relationships are worthy of being explored in the further study. Third, the quality of communication and interaction among group members, and how the members within each group interacted with each other were not investigated in this study so that we will explore these worthwhile works in the following study.

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