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Training On Concept Mapping Skills in Geometry

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Concept maps have not been extensively used in China and Singapore schools for the teaching of mathematics. This lack of exposure suggests that students must be properly trained before they can construct meaningful concept maps. This paper reports on several ways to train secondary students to construct concept maps about elementary geometry. Different training methods were tried and a revised training scheme with high demand on detailed linking phrases was proposed and then carried out with a Grade 8 class in Nanjing, China. With extended training, most of the students were able to construct meaningful concept maps, as assessed by a specially designed Concept-Mapping-Skill Test.

Key Words: assessment, concept map, concept mapping skill, geometry, secondary students

Introduction

Concept maps are one of many forms of graphic tools that have been used extensively to detect how people organize their thoughts and experiences about certain phenomena. They are generally defined as two-dimensional maps consisting of nodes denoting concepts and labeled lines representing the relations between pairs of nodes (Baroody & Bartels, 2000; Novak & Gowin, 1984). Over the last three decades, concept maps have been used extensively to assess conceptual understanding, especially in science education, through student-constructed concept maps (Novak, 1998; Ruiz-Primo, 2004).

Since concept maps have not been extensively used in some schools, it is necessary to train students on concept mapping techniques before they can construct meaningful concept maps. Researchers have expended different efforts to such training and the effects vary considerably (Afamasaga-Fuata'I, 2006; Edwards & Fraser, 1983; Wallace & Mintzes, 1990; Williams, 1998). Researchers such as Ruiz-Primo (2004) suggest that students can be trained to construct concept maps in short periods of time with limited practice. Edwards and Fraser (1983) also provided only a brief introduction (around 30 minutes) on how to construct concept maps and almost immediately asked students to construct concept maps about a list of mathematics concepts. However, Wang and Dwyer (2006) claimed that short training on concept mapping such as a 50-minute workshop was not sufficient to prepare students with adequate mapping skills to express their knowledge. Their argument is consistent with claims made by Novak and Gowin (1984), Schau and Mattern (1997), and others that concept mapping imposes a high cognitive demand on students by requiring them to identify important concepts, relationships, and structure within a specified domain of knowledge. Thus, extended training is needed.

Despite the unequal effort devoted for training in different studies, little attention has been paid to students' ability to construct concept maps after training. After reviewing the literature, we found only one study, Ruiz-Primo, Schultz, Li, and Shavelson (2001) that reported the effectiveness of a 50-minute training program. The first part of the paper addresses how much training effort should be devoted and which issues about concept mapping should be emphasized in the training. This is important because no consistent answer has been found due to the limited research available. The rest of the paper reports on several training techniques attempted with secondary school students about elementary geometry concepts. The findings will help to determine the quality of effective training in order to ascertain the validity of concept map as an assessment tool.

Method

This study has two parts: Part I and Part II. Part I involved 10 Singapore students, who were trained in English since English is the language used for teaching in Singapore schools. It was designed to compare different training methods on concept mapping so as to provide the researchers with a better understanding of how concept mapping should be introduced to secondary school students. A revised version of the training was then proposed. In Part II, this revised method was implemented for 36 Grade 8 students in Nanjing, China, and was conducted in Chinese.

Comparison of Training Methods on Concept Mapping

Participants

A convenient sample was taken from a government secondary school in Singapore. Eight students were selected by their mathematics teacher because they were relatively articulate and willing to participate in this study. Two of the students (one male student A and one female student B) were from Grade 7 (G7) and the other six (all male students, C, D, E, F, G, and H) were from Grade 8 (G8). In addition to these eight students, students I and J were also involved in this study. Student I was a G7 male student. He had some difficulty in learning mathematics and knew little about concept map before this study. Student J was a Grade 9 (G9) female student. She was a top student in her class and had used concept maps for her own study since Grade 4 when she was first introduced to this technique by her science teacher.

Training methods and students' mapping performance

All the participants in Part I study, with the exception of Student J, were not familiar with concept maps. Even though some of them had heard about it or had seen similar maps (e.g., mind maps), they admitted that they did not know how to use and construct concept maps.

Group 1: Simple training for students A and B. For the first group, the training began with a 10-minute explanation of Novak's (1998) definition of concept maps. It focused on the three features: nodes representing concepts, arrowed links showing directional connections, and linking phrases describing the relationships between linked concepts. This was followed by a 5-minute demonstration of how to construct a concept map with eight concepts about *numbers*. After this, the two students were given a piece of paper with five concepts about *triangles* and asked to construct a concept map individually. Their maps met the standards for effective training proposed by Ruiz-Primo et al. (2001), specifically, *use of given concepts, use of labelled links,* and *accuracy of the propositions*. However, most of the linking phrases were very general. When prompted, both of them could add more links and detailed information to the linking phrases. For example, student B initially constructed a proposition which in written form was "isosceles triangle is a kind of triangle". When asked to explain what he meant by "a kind of", student B said that "isosceles triangle is a triangle with 2 equal sides; thus, it is a kind of triangle". This shows that the students knew more than what was shown in their concept maps. The brief training had not prepared them well enough to construct concept maps that reflect their full knowledge of the concepts.

Group 2: Accuracy of linking phrases for Students C and D. In the second attempt, the first researcher stressed the accuracy of linking phrases, and encouraged the students to add as many connections and as much detail as they could. This training took about 15 minutes of explanation and demonstration (as before) and another 15 minutes for students' practice using the same concept list about *triangle* as Group 1. After that, the two students were provided with 12 concepts about *quadrilaterals* and asked to construct a concept map individually. They took about 25 minutes to finish the mapping. Figure 1 is the concept map constructed by Student D and re-drawn by the first author for clarity.

This map shows that Student D had captured the essential aspects of a concept map: connections, linking phrases, and general hierarchy. However, the linking phrases were still quite brief without detailed information. Once again, when prompted, Student D could describe more about the relations among *rectangle, square, parallelogram, rhombus*, and *trapezium*. This finding revealed that the student's map had not included all the information that he actually knew. A possible reason is that the students simply treated concept mapping as a drawing task instead of a test of their knowledge. Hence, the training needs to specify the purpose of concept mapping tasks and to help students better understand what they are expected to show.

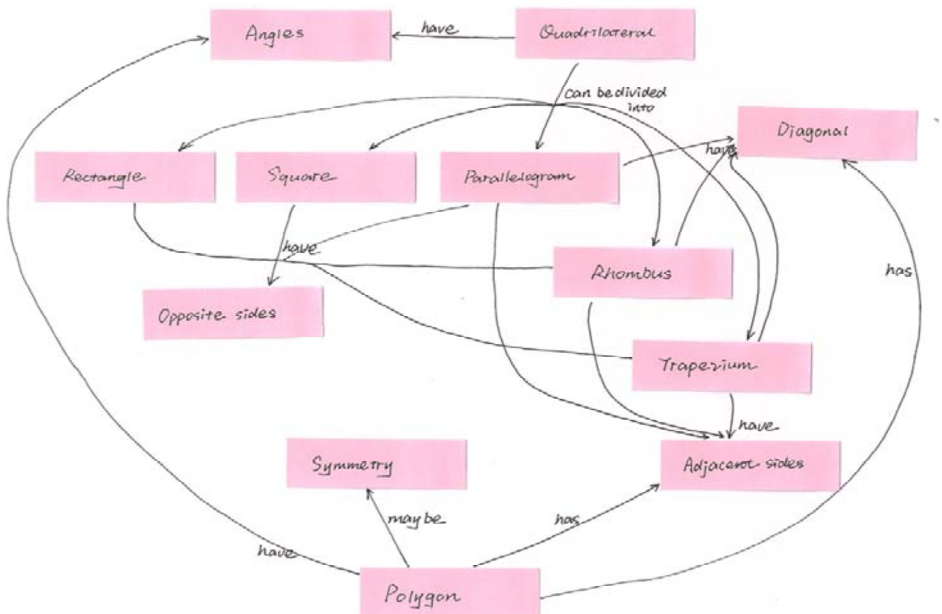

Figure 1. **Student D's concept map on quadrilateral (re-drawn for clarity).**

Group 3: Extended training for Students E, F, G, and H. For the third group, the first researcher planned a more extended training. The training took around 50 minutes. In addition to the explanation and demonstration as given to Group 2, it covered the purpose of concept mapping tasks and added examples of good and poor concept maps, as well as opportunities for practice and discussion. After the training, the students were given the concept list on *quadrilateral* and asked to construct a concept map individually. Student E spent less than 15 minutes on his mapping; F and G spent around 20 minutes, while H spent nearly 40 minutes. More information could be drawn from their concept maps than those constructed by Group 2. Figure 2 and 3 are the maps constructed by Student F and H respectively.

In these two maps, the concepts were generally divided into three layers. The most inclusive concept *quadrilateral* was placed at the top, the five particular quadrilaterals were at the intermediate level, and the remaining four property-related concepts were arranged at the lowest level.

Most of the connections in Student F's map were between the particular quadrilaterals and the property-related concepts. Student F had used detailed linking phrases to label the connections. For example, he linked *rhombus* and *adjacent sides* with "has equal" instead of "has." With detailed labels, more information about student's conceptual understanding can be detected. Such information is of value for teachers and educators to better understand students' learning difficulty and to improve their teaching.

Student H constructed many connections among the given concepts. He carefully checked the possible links between each pair of concepts. When he found that there was no space for him to neatly add more propositions, he turned to the first researcher for help. The researcher suggested that he mark the links and write his explanations below the map. This map provides much information about the students' understanding about the concepts. Misconceptions were also easily detected.

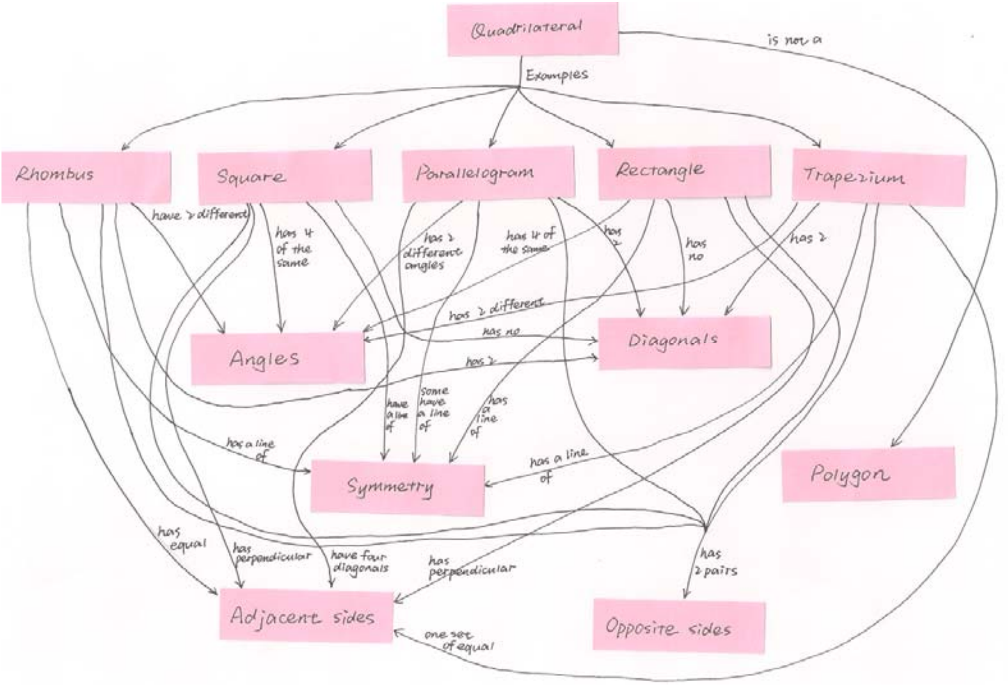

Figure 2. **Student F's concept map on quadrilateral (re-drawn for clarity).**

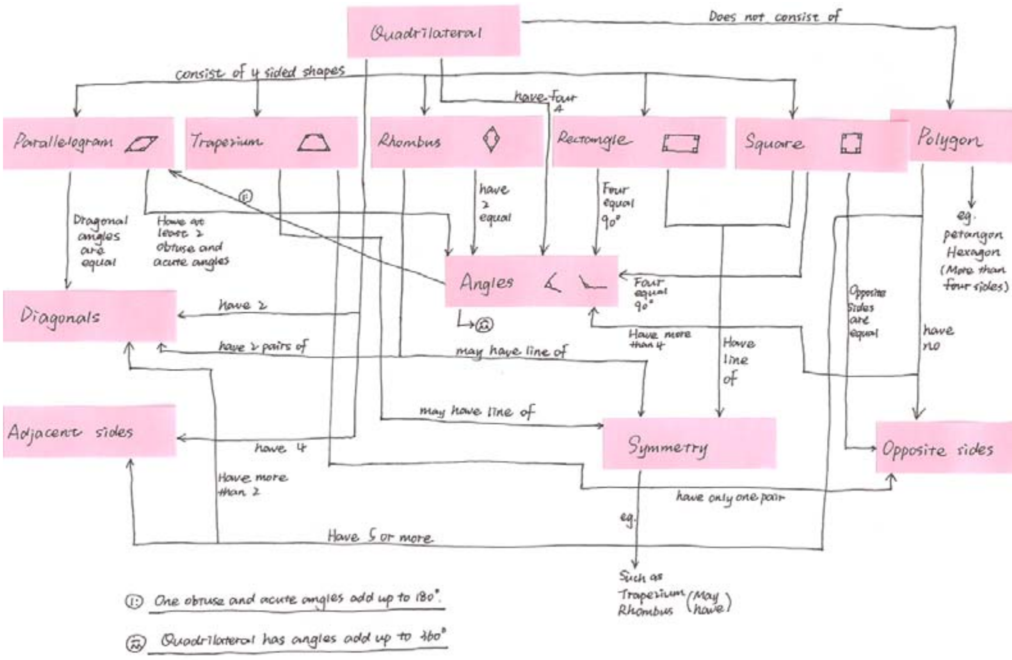

Figure 3. **Student H's concept map on quadrilateral**

(re-drawn for clarity).

Extensive training for Student I. The first researcher worked with Student I individually. He was trained in the same way as Group 3 students. But during the mapping practice, he tried to copy the structure of and linking phrases from the researcher's example though the example and the practice task were about two different sets of concepts. Given 10 minutes, he built only three links by himself, two of which were wrong. His performance indicates that he did not capture the purpose and requirements of concept mapping. The training was not adequate for this student to acquire the mapping ideas.

Brief training for Student J. Student J had used graphic tools similar to concept maps very often for her own study. However, she mentioned that the nodes in her graphic tools were not necessarily concepts. They could be phrases or even sentences. And the links were not necessarily labeled. Based on her description, the training focused on making clear the differences between the concept maps defined in this study and the graphic tools she had used. The researcher briefly explained the same construction procedure described for Group 3. This training took 10 minutes. It was followed by Student J's practice on a concept list with 11 concepts about *triangles*.

The concept list on quadrilaterals provided to Student J was different from for Groups 2 and 3. She was given a list of 9 concepts rather than 12 concepts since the experience with Group 3 suggested that 12 concepts may be too many for secondary students to express their ideas on one piece of paper. Her final map was shown in Figure 4. As a whole, this map indicated a very comprehensive understanding of the nine concepts. Altogether, this mapping task took Student J about 15 minutes to complete.

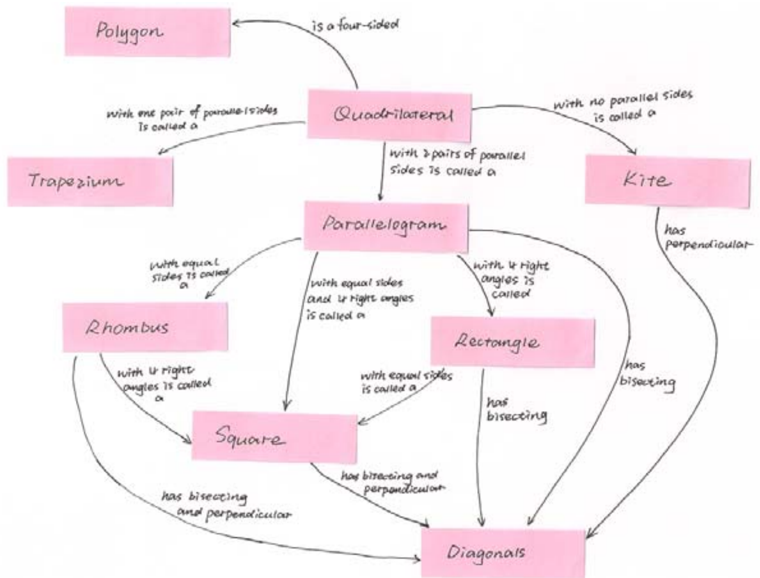

Figure 4. **Student J's concept map on quadrilateral (re-drawn for clarity).**

Summary for Part I: The above training experience indicates that different training methods have different effects on students' concept mapping. Even with the same training provided, students' mapping skills may be different. Part I suggests that a 45-minute training might not be sufficient for secondary students. They could not fully express in their concept maps what they knew about the concepts and connections. More practice is needed for the students to become competent in concept mapping.

2.2 Concept Mapping Skill

The definition of concept mapping skill (CMS) is derived from the training experience in Part I, together with other training considerations mentioned in the literature (e.g., Ruiz-Primo & Shavelson, 1996; Williams, 1998). Three key mapping skills are drawn:

The first skill is *statement transformation.* It refers to the ability to transform a given statement to a diagrammatical proposition. It requires the meaning of the proposition to be consistent with the meaning of the given statement. Students need to first identify key concepts from the statement, capture their relations, and then express the relations through linking phrases. See the examples in Figure 5.

Statement 1：Zero is an even number.
Key concepts：zero, even number.
Proposition：

Statement 2：A rectangle is a quadrilateral with four right angle.
Key concepts：rectangle,quadrilateral.angles
Propocition：

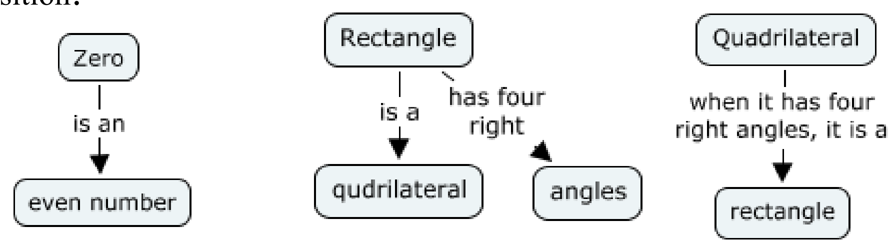

Figure 5. **Examples for the first CMS - *statement transformation.***

Statement 1 is quite straightforward. However, Statement 2 can be mapped differently, as illustrated by the two examples, one with three nodes and the other with two nodes. As long as the meaning of the given statement has not been changed, it does not matter how many concepts are used as nodes. Students are *not* expected to express their own ideas at this stage.

The second skill is called *simple free-association*. Students are given two to four concepts. Compared to *statement transformation, free-association* emphasizes self- generated connections and detailed linking phrases. It requires students to fully express what they know about the connections between the concepts. No concept should be left isolated unless it has not been taught. Since different students may have different ways of connecting same concepts, these free-associated propositions will expose students' understanding of the concepts. Consider the examples in Figure 6.

Key concepts given: quadrilateral, rectangle.
Propositions:

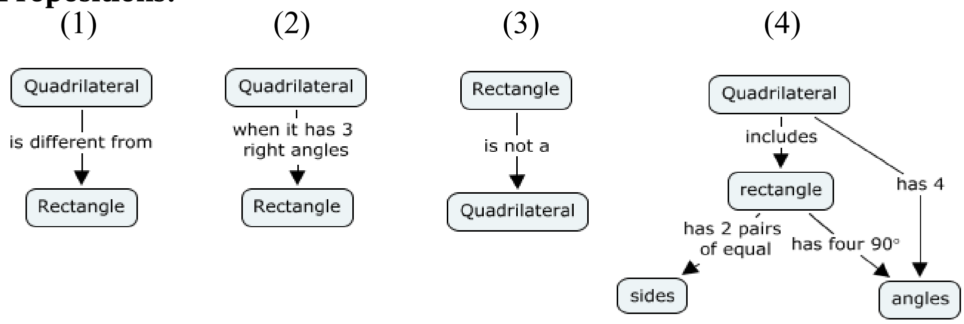

Figure 6. **Examples for the second CMS - simple free-association.**

Proposition 1 does not describe how a quadrilateral is different from a rectangle. Compared to it, Proposition 2 shows a better understanding about the connection between the two given concepts while Proposition 3 indicates a misconception. Finally, Proposition 4 shows comprehensive understanding. Two extra but related concepts were added. This addition is accepted as long as the connections between the given concepts are indicated with correct phrases.

The third skill is *extended free-association.* It is built on *simple free-association.* It involves more than four concepts and requires attention to the organization of the propositions and the structure of the entire map. The criterion map in the Appendix is an example of extended free-association. In the literature, this skill is required for the construction of concept maps.

A Revised Training Method

On the basis of Part I training experience and the above definition of CMS, the training for concept mapping was revised to cover the following five aspects:

(1)Introduction: Introduce what a concept map is, what it is used for, and what its attributes are, i.e., nodes, arrowed links, and linking phrases.

(2)Statement transformation: Use examples to explain how to convert statements into propositions without changing the meaning of given statements followed by practice and comments.

(3)Simple free-association: Use examples to show how to construct propositions with two to four given concepts followed by practice and comments.

(4)Extended free-association: Use examples to show how to construct a concept map with more than four given concepts. Be attentive to the organization of the entire map, redrawing it if necessary. Follow by practice and comments.

(5)Discussion: Summarize students' common problems that appear in their practice; stress the accuracy of linking phrases; encourage students to include as much information as they know about the relations between the concepts.

Part II: Implementation of the Revised Training Method

Part II aims to investigate the effectiveness of the revised training method through a specially designed Concept Mapping Skill (CMS)-test.

Participants

The participants in Part II were a class of Grade 8 students (n = 36) in a junior middle school in Nanjing, China. The students indicated that they did not know about concept maps before this study and had not attempted similar mapping tasks.

Training

The class received three 40-minute training sessions on concept mapping over two weeks. The training procedure followed the revised training method given in Section 2.3. The first session was about *introduction* and *statement transformation*. Practice and comments were given in the class. At the end of this session, transformation exercises were assigned as homework. The homework was collected one day before the second session and the students' mistakes in the homework were discussed at the beginning of the second session. After that is the training on *simple* and *extended free-association*. Since *extended free-association* is the most complicated among the three CMS, it was again covered in the first half of the third session. The second half was discussion and summary of the key ideas about concept mapping.

All the practice and exercises used in the training sessions were different from the topics on the CMS-test so that the students could not just recall from what they had learned. The training and CMS-test was in Chinese.

Concept-Mapping-Skill-Test (CMS-test)

The CMS-test was specially designed to assess how well the students had mastered the CMS after training. The statements and concepts in the test were taken from the school mathematics textbooks and they covered topics that the students had already learned.

Concept Mapping Skill Test

Introduction:

- The purpose of this test is to measure your concept mapping skills.
- This test has NOTHING to do with your school performance and your understanding of the concepts involved.
- Please attempt all of them as best as you can, according to the requirements specified in the training session.

2. Statement Transformation
   (5) A triangle has three median lines.
   (6) Two plane figures are called congruent figures if they can coincide exactly with each other.
   (7) Two lines in a plane are either parallel lines or intersecting lines.
   (8) Two numbers with different symbols but same absolute value are called opposite numbers.

2. Simple Free Association
   (1) Scalene triangle, triangle
   (2) Linear inequality with one unknown, unknown
   (3) Even numbers, odd numbers, prime numbers
   (4) Square root, rational number, irrational number

3. Extended Free Association: construct a concept map using the given concepts.
   Parallel lines, intersecting lines, perpendicular lines, perpendicular bisector, equidistance,
   middle point

Note: please check your concept map: (1) whether it includes all the given concepts, (2) whether all the links are directional, (3) whether you have added as many meaningful links as you can, and (4) whether the linking words are completed and accurate.

Figure 7. **The concept mapping skill test (CMS-test).**

The CMS-test was administrated two days after the last training session. Students were given 40 minutes to complete the test. Their answers were then recorded in a checklist. The checklist examined four aspects, i.e., *concepts, links, linking phrases* of propositions, and *organization* of the propositions. Under *concept*, it checked whether the concepts were correctly extracted from the given statements or whether the students had included all the given concepts. Although the students were allowed to add extra concepts which they thought were related to the given ones, these additional concepts were not counted in the checklist. For *link*, the checklist considered the number of links constructed and whether the links were arrowed correctly so that the connections could be read easily without confusion. Under *linking phrase*, the checklist examined the number of labeled links and how many of the labels were detailed. In regard to the *organization*, the checklist examines the structure of the student-constructed maps against a criterion map (see Appendix), which was constructed by the first researcher.

Results of CMS-Test

The focus of the skill *statement transformation* was not to change the idea of the given statements. For Statement 1 (SM1) and Statement 2 (SM2) in the CMS-test, 31 out of the 36 students were able to convey the statements into propositions. The remaining 5 students tried to relate the given ideas to what they had known. They included additional information but the given ideas were not clearly stated. Nevertheless, none of these five students got both SM1 and SM2 wrong. Compared with SM1 and SM2, the students' performance on Statement 3 (SM3) was much better. Despite the format of propositions, 35 students correctly expressed the idea of SM3. For Statement 4 (SM4), however, only 27 students answered correctly. The students seemed to find SM4 more difficult than the other three statements since SM4 involved four concepts: *number*, *symbol, absolute value*, and *opposite numbers*. Difficulty arose when the students attempted to extract all the four concepts as nodes and combine them into a single proposition. The training did not address statements like SM4. Further training needs to deal with statements involving more than three concepts.

There are four *simple free-association* (SFA) tasks. Almost all the students correctly included the given concepts as nodes in propositions for the first three SFA tasks. Only 1 student missed out the concept *unknown* in the second SFA task. For the fourth SFA task, 5 students left out the concept "square root". Their mathematics teacher noted that "square root" was not a familiar concept to the students. Thus, this omission of "square root" may be due to their poor conceptual understanding rather than lack of concept mapping skill. With regard to the links constructed, 81% of the links had correct directions. The remaining either did not show direction or were bi-directional (i.e., ↔). About 95% of the links constructed were labelled. Among the labelled links, 67% were labelled with detailed linking phrases. Linking words like "include", "is", "has" and "may be" were considered to be not detailed. Among the 36 students, only two did not use any detailed linking phrase throughout the four simple free-association tasks. This finding indicates that most of the students were able to provide detailed linking phrases.

The third task *extended free-association* involved six given concepts. One student did not attempt this task. Among the remaining 35 students, 31 of them included all the six given concepts in their maps. The other four students left out "equidistance". Among the links constructed, 86% had correct directions and 96% were labelled. Nearly 75% of the labels were detailed ones. Only 2 students did not use any detailed linking phrase throughout their maps. In regard to the *organization,* nearly 80% of the students paid attention to the hierarchy of the concepts and the sequences were easy to follow.

In summary, the training in Part II succeeded in helping many students master relevant concept mapping skills. The students could use links to show connections and add linking phrases to indicate relationships. They were aware that the links should be unidirectional and the linking phrases should be detailed. More in-depth practice may be needed for more complex *statement transformation* tasks. Moreover, the percentages of detailed linking phrases could be further raised (67% for *simple free-association* and 75% for *extended free-association*) by addressing some of the factors mentioned above.

Conclusion

This paper deals with several training methods to help secondary school students develop concept mapping skills. The first part of the study suggests that, for secondary students, a brief training with limited practice on concept mapping could not prepare them with sufficient mapping skills. Different students may acquire different proficiency with concept mapping under the same training. When the training became more extended as described in Part II, the students were able to construct propositions and concept maps that included detailed linking phrases. Studies are needed to further examine the training methods with students at different grade levels.

The training on concept mapping is time consuming. It is not "economical" to spend much time on introducing concept maps simply for assessment only, as its validity is still under discussion (e.g., Yin & Shavelson, 2008). On the other hand, many studies (see chapters in Afamasaga-Fuata'I, 2009) have provided evidence of the benefits of using concept maps as an instructional method and a learning strategy in mathematics. Once concept maps are used for learning purposes, the burden of training for assessment would be relieved since the students would have become familiar with concept mapping in the process of classroom teaching and learning. The challenge is to align teaching and learning with assessment in order to help students deepen their conceptual understanding through mind-mapping techniques such as concept mapping.

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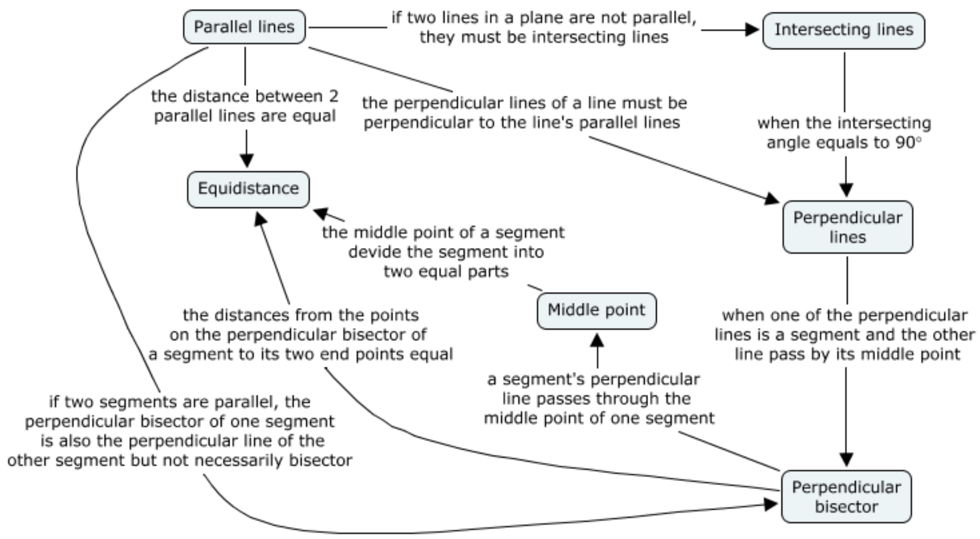
APPENDIX

A criterion map for the Extended Free Association task in the CMS-test:



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