The Development of Metacognitive Inventory to Measure Students' Metacognitive Knowledge Related to Chemical Bonding Conceptions

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Abstract

Since the mid-1970's metacognition has become one of the major fields of cognitive and educational psychology research. However, an assessment on metacognitive ability has been still problematic because it is difficult to distinguish between what is *meta* and what is *cognition,* and also assessments in classroom practice normally pay attention only to students' cognition. Numerous studies suggested that matacognition is important for students' learning because it affects how students apply what they had learnt to solve problems. Therefore, the purpose of this study is to develop metacognitive inventory in order to measure students' metacognitive ability. The metacognitive ability means the students' capable of explicitly thinking about their ideas or conceptions one holds. The inventory focused on metacognitive knowledge which included declarative, procedural, and conditional knowledge. The inventory consisted of 7 open-ended questions, and all of which contents related to the concepts of chemical bonding. The inventory was piloted with 68 students to improve language used and analyze the reliability of scoring criteria. Pearson's correlation of consistency among interraters was .79. Then, the inventory was administered to 62 tenth grade students who had already learnt those concepts. The results indicated that the discrimination of test items ranked from 0.31 to 0.94, Cronbach's alpha coefficient reliability was .80. The results of this study indicated that the inventory was qualified to be used as an instrument to measure students' metacognitive ability.

Keywords: metacognition, metacognitive knowledge, chemical bonding, open-ended question

Introduction

Metacognition has become one of the major fields of cognitive and educational psychology research since the mid-1970's. Research activity in metacognition was originally explored by John Flavell (Weiner & Kluwe, 1987; Wolters, 1987; Hartman, 1998; & Georghiades, 2004). Under the word of metacognition, several terms commonly associated with research on metacognition: metacognitive beliefs, metacognitive awareness, metacognitive experiences, metacognitive knowledge, feeling of knowing (FOK), judgment of learning (JOL), theory of mind, metamemory, metacognitive skills, executive skills, higher-order skills, metacomponents, comprehension monitoring, learning strategies, heuristic strategies, and self-regulation (Veenman, Van Hout-Wolters & Afflerbach, 2006). Numerous researchers specified the definition of metacognition and one's behavior related to it. For example, John Flavell (1976) refers to metacognition as one's knowledge concerning cognitive processes and products, and one's actively monitoring and regulating that cognitive process. Hennessey (1993, 2003) refers to metacognition as an inner awareness or process which is not an overt behavior. The inner awareness can be what one knows, one's learning process, or one's current cognitive state

(awareness of mental constructs). However, Wellman (1981) referred to metacognition or metamemory as a "fuzzy concept." At this point, Brown (1987) discussed two primary problems with the term metacognition. Firstly, it is difficult to distinguish between what is *meta* and what is *cognitive.* Secondly, in the psychological research, metacognition has been used to refer to knowledge of cognition and regulation of cognition; and, trying to separate them is oversimplification because the two forms of metacognition are closely related.

Even though there were attempts to develop the operational definition of metacognition, measuring students' metacognition was still difficult. According to Wolter (1987) "A central problem in the research area on metacognition is the adequacy of the assessment techniques designed to measure metacognition." Many methods for the assessment of metacognition have been being used such as questionnaires, interviews, analysis of thinking-aloud protocols, observations, raise-awareness tasks, diaries, or autobiographies. However, all of these instruments have both advantage and disadvantages. For example, using interviews and think-aloud techniques are not appropriate for students with inability to verbalize their answers or thinking patterns (Wolter, 1987). Using questionnaires is easier to administer with a large number of students but it may: (1) fail to provide an in-depth analysis of the beliefs held; (2) lack specificity and contextualization; and (3) contain problematic wording (Victori, 2004; Veenman; et.al, 2006). A diagnostic test for assessing cognitive skills related to metacognition (e.g., visualizing lecture information and interpreting diagrams) provides a limited number of skills related to metacognition (Garrett, Alman, Gardner & Born, 2007).

According to the literatures above, there is still the need to develop further more effective instrument for assessing metacognitive ability which is determined far more precisely. The fact that distinguishing metacognition from a cognitive perspective is difficult, because this process is internal and can be inferred from the basis of overt behavior (Rickey & Stacy, 2000). This research, therefore, intended to develop an effective instrument to measure student's metacognitive ability concerning the knowledge of cognition. Schraw (1998) described knowledge of cognition as what individuals know about their own cognition or about cognition in general and includes three different kinds of metacognitive awareness: declarative knowledge (knowledge about oneself as a learner and about what factors influence one's performance), procedural knowledge (knowledge about doing things which is represented as heuristics and strategies), and conditional knowledge (knowing when and why to use declarative and procedural knowledge). The following section introduced the process of the inventory development, its results, and its implication in learning and teaching chemistry.

Purpose of the study

The purpose of this study was to develop an instrument in a set of open-ended questions for assessing students' metacognitive ability concerning the knowledge of cognition in the scientific context.

Research Method

The metacognitive inventory consisted of seven open-ended questions in a written form which allowed the students to express what they know about their own ideas, cognitive strategy, when and why to use that strategy. The contents were related to the concepts of chemical

bonding aligned with the Thailand's Basic Education Curriculum B.E. 2551. The subjects were a group of 68 tenth grade students for a pilot study of which the purpose was to improve the inventory, and a group of 62 tenth grade students for a main study of which the purpose was to analyze the quality of the inventory. Those students included boys and girls who had studied the concepts of chemical bonding.

Procedures

The procedures of inventory development were as follow.

Step 1: the definition of metacognitive knowledge was determined. In this study, metacognition defined as an ability to explicitly think about conceptions concerning metacognitive knowledge. *Metacognitive knowledge* includes declarative, procedural and conditional knowledge. Details of the definition are presented in table 1.

Table1. Categories and definition for the metacognitive knowledge

Categories	Definition
Declarative knowledge	Refers to the knowledge that learners have about the information or resources needed for undertaking the given tasks e.g. knowledge about: (a) purpose of a task (What is the objective in performing a given task?); (b) about task demands (What resources and steps are necessary to solve the problem); (c) about the nature of the task (what kind of given task is related to?).
Procedural knowledge	Refers to knowledge or beliefs about oneself about the given task. An individual's self-perceptions of one's capacity of how to do something.
Conditional knowledge	Refers to knowledge concerning when and why to use strategies to solve problems. Knowledge of the situations in which students may use subject-specific skills, algorithms, techniques, and method.

Step 2: cognitive tasks, open-ended questions, and scoring criteria were developed. According to Gunstone (1994), assessment of metacognition required appropriate content contexts for the achievement of metacognitive purposes. The contexts should neither already understand nor totally unfamiliar. Therefore, in this study, items presented in the inventory were neither too easy nor too difficult to understand for the students. The tasks allowed student to see and be able to build on an existing conceptual understanding on chemical bonding. In the inventory, there are totally 2 tasks with 7 questions. In task I, students were asked to identify which pair of elements is less ionic when the table of electronegativity is given. Students who have high level of metacognitive ability were expected to clearly: (1) explain what the given task is related to, (2) provide specific method (strategy) for problem solving, and (3) explain when and why to use that strategy. For task II, a statement regarding to the bond length is given and the students are asked to decide whether they agree or disagree with the statement. Students who have high level of metacognitive ability were expected to clearly: (1) explain their thinking to support the answer, (2) describe the knowledge used for their responses, (3) explain when and why to use those thinking steps. Sample of questions are demonstrated as in Figure 1.

Electronagativity of Elements

Group							
1A	2A	3A	4A	5A	6A	7A	8A
H 2.20							He ---
Li 0.98	Be 1.57	B 2.04	C 2.55	N 3.04	O 3.44	F 3.98	Ne ---
Na 0.93	Mg 1.31	Al 1.61	Si 1.90	P 2.19	S 2.58	Cl 3.16	Ar ---

Instruction: use given information above to answer the question 1-4.

1.1 When the given two atoms chemical bond together, which pair of atoms is prone to be the least ionic bond?
   (mark X over the answer you select) (Cognition: Comprehension)
        a. Na and F   b. Li and O   c. C and Cl

1.2 To answer the question above, what the content knowledge related to? Explain (Declarative knowledge)

1.3 Display what your thought to obtain the answer for question 1 (Procedural knowledge)

1.4 Explain when and why you use such a thought process above to find the answer (Conditional knowledge)

Figure 1. **Example of questions**

Step 3, the face validity of the inventory was verified by three experts. Domain considerations of each item were: (1) the consistency between item objective and item question, (2) the correctness of clearly communicated language, (3) the correctness of ways to answer the question, and (4) the suitability of scoring criteria. Result of the expert's judgment was presented in term of the Item Objective Congruence (IOC). By doing so, each expert evaluated all of items and assigns a +1 if the item was appropriate, a 0 if the expert was uncertain, and a -1 if the item was not appropriate. The results of this rating were used to calculate the index value (Osterlind, 1998). The result of experts' judgment indicated that the IOC value ranked from 0.67 to 1.00.

Step 4, the inventory was piloted with 68 high school students to examine whether the language used was understandable for the students. Then, the inventory was revised in order to be understood. Also, some of students' responses were used to be the examples in the scoring criteria. In order to examine the reliability of scoring criteria, ten students' answer sheets were randomly selected and scored by two raters. Pearson's correlation of consistency among interraters was .79 which showed a high level of agreement; therefore, the scoring criterion was reliable. The overview of scoring criteria is presented in Table 2.

Table 2. Overview of scoring criteria

Score	Description		
	Declarative knowledge	**Procedural knowledge**	**Conditional knowledge**
0	Nothing relevant to the task. The student does not describe *what* the task related to.	Students do not describe which strategy they use to solve a problem, and *how* they solve that problem.	Students do not explain *when and why* to use strategies to solve problem.
1	Student writes nonspecific statements that are related to chemistry, but they are not related to the question.	Students seem to understand of the task purpose, but they make nonspecific statements that are not interrelated or connected between given information and the question.	Student lists general strategies used to solve problem, but they do not explain only *when or why* to use that strategies or nonspecific statement.
2	Student has a clear overview of what the task is related to.	Student has clearly defined which strategy they use. Students explicitly consider the implications between given information and the question.	The student generates clearly when and why to use strategies they use to solve problem. The overview of their strategy connects concretely to the given information and the question.

Step 5, the inventory was administered to a two class of 62 high school students. Results of students' responses were used to compute the discrimination of test items and the reliability of the inventory. The result indicated that the item discrimination ranked from 0.31 to 0.94, and Cronbach's alpha coefficient was .80.

Conclusion

This study aims to develop metacognitive inventory in order to measure students' metacognitive ability. The objectives of each item were established based on the definitions of metacognitive knowledge. Then, opened-questions and scoring criteria were developed and verified for the face validity. The inventory was piloted with 68 high school students to improve language used and analyze the reliability of scoring criteria. Then the inventory was administered with 62 high school students to analyze the discrimination of test items and the reliability of test scores. The results of this study indicated that the inventory was qualified to be used as an instrument to measure students' metacognitive ability.

For classroom practice, measuring students' metacognitive ability can help teachers to find out how well students learn science in order that the teachers are able to support students to improve their abilities. Several literatures reported the importance of metacognition in teaching and learning in that metacognition affects acquisition, comprehension, retention, and application of what is learned; it also affects learning efficiency, critical thinking, and problem solving (Hartman, 1998). In addition, this metacognitive ability can lead students to become more knowledgeable of their own cognition, make students think more about their own learning, and finally help students to taking responsibility for their own learning (Israel, 2007). Particularly in

science classroom, metacognition help students in their learning and developing scientific concepts (Hennessey, 1993, 2003).

This study was the first step of trying to understand students' metacognitive knowledge in chemistry classroom. Further research should extend to metacognitive control which focuses on how students regulate their own learning.

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