

YOUNG PUPILS' METACOGNITIVE ABILITY IN MATHEMATICS

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ABSTRACT

It is important for pupils to be aware of their strengths and limitations as learners. Last years metacognition has been receiving increased attention in cognitive psychology. Special attention has been focused on metacognition as the interface between cognition and affect and its essential role in self-regulation in achievement settings. The present study, represents the initial phase of instrument development for the measurement of metacognition in mathematics learning appropriate for young children. Almost all items of the inventory loaded as expected. Four factors contained items about metacognitive knowledge and five factors contained items about regulation of cognition. There were high correlations between the nine factors, reflecting the high correlation between the two metacognitive aspects of metacognition. Results of pupils' attempt to solve a non-routine problem indicated that they had a very poor knowledge about their cognitive abilities.

METACOGNITIVE KNOWLEDGE AND REGULATION OF COGNITION

There is a growing evidence that metacognition is an important component of intelligence and cognition as well as a major influence on academic success. "Metacognition refers loosely to one's knowledge and control of his/her cognitive system" (Brown, 1987, p.66). There are many different kinds of knowledge and processes subsumed under the term metacognition; this term "has been used by different authors to mean different things" (Campione, 1987, p. 119). Actually, in modern psychological literature, the term "metacognition" has been used to refer to two distinct areas of research: knowledge about cognition and regulation of cognition.

Flavell (1976) was the first who introduced the term "metamemory" into the literature after his study of metamemorial processes in children, referring to the knowledge that individuals have about their memory processes. The term "meta" refers to second order knowledge or function. Then the term "metacognition" was used and Flavell (1979) expanded the concept to include the metacognitive knowledge and regulation of cognition. He suggested a model of metacognition and cognitive monitoring in describing the actions of and interactions among four classes

of phenomena: metacognitive knowledge, metacognitive experience, goals or tasks and actions or strategies.

Metacognitive knowledge is “knowledge or beliefs about what factors or variables act and interact in what ways to affect the course and outcome of cognitive enterprises” (Flavell, 1999, p.4). The major categories of these factors or variables are person, task and strategy. The person category encompasses everything that a person believes about the nature of him/herself and other people as cognitive processors. It refers to the kind of acquired knowledge and beliefs that concern what human beings are like to cognitive organisms. The task category concerns the information about the object available to a person during a cognitive enterprise. Thinkers must recognize that different tasks entail different mental operations (Demetriou, 2000). The strategy category includes a great deal of knowledge that can be acquired concerning what strategies are likely to be effective in achieving what goals and in what sort of cognitive undertakings. Actually, metacognitive knowledge is knowledge that people have about their cognitive abilities (I have a bad memory), about cognitive strategies (to remember a phone number I should rehearse it) and about tasks (categorized items are easier to recall).

Whereas Flavell uses the person-task-strategy taxonomy to define metacognitive knowledge, Brown (1987) has categorized metacognitive knowledge based on a person’s awareness of his/her metacognitive knowledge: declarative, procedural and conditional. Declarative knowledge is propositional knowledge which refers to “knowing what”, procedural knowledge refers to “knowing how” and conditional knowledge refers to “knowing why and when”.

The second dimension of metacognition, metacognitive regulation refers to processes that coordinate cognition. According to De Corte, Verschaffel and Op’t Eynde (2000) self-regulation constitutes a feature of effective learning and problem solving. It is the ability to use metacognitive knowledge strategically to achieve cognitive goals. In the last decade it has become clear that one of the key issues in self-regulated learning is the students’ ability to select, combine and coordinate strategies in an affective way (Boekaerts, 1999). It is essential to the development of students’ ability to learn cognitive strategies, such as self-questioning, widen the application of these strategies and gain conscious control over them. Self-regulation strategies play an important role on the learning process. Successful learners are able to swiftly transfer the knowledge and strategies acquired in one situation to new situations, modifying and extending these strategies on the way. Self-regulatory behaviors in mathematics include clarifying problem goals, understanding concepts, applying knowledge to each goal and monitoring progress toward a solution.

Metacognitive regulation and metacognitive knowledge are interdependent. For example knowing that you are not very good at a certain task would lead you to monitor your process more carefully. On the other hand, if you monitor and detect a lot of errors, you may conclude that the task is difficult or that you are not very good at it.

Recent research has focused on the phenomenon of metacognition and its role in learning, mathematical performance and especially problem solving. Problem solving ability is recognized as a complex interplay between cognition and metacognition. A primary source of difficulty in problem solving may lie in pupils' inabilities to actively monitor and subsequently regulate the cognitive processes engaged in during problem solving (Artzt & Armour-Thomas, 1992). For the successful solution of any complex problem-solving task a variety of metacognitive processes is necessary. It is known that individuals with higher levels of metacognitive ability perform better in problem solving tasks. They take great care to understand the relationships among the facts in a problem. They check themselves for accuracy, they break complex problems down into simpler steps, they self-question and answer to clarify their thoughts.

A variety of programs are used to teach the metacognitive skills needed to work efficiently with the givens goals and obstacles find in the problem solving. Some of the programs cover a wide range of processes and some others focus on only one of them. Improving either metacognitive knowledge or metacognitive control appears to improve learning. Schoenfeld (1992) describes ways that students can be taught to monitor and evaluate their performance on math problems. For example, students are required to pause frequently during problem solving and ask themselves questions such as "What am I doing right now?" According to Flavell (1979) metacognition undoubtedly improves with practice. One way to become better at metacognition is to practice it.

The development of metacognition occurs in the same manner as intelligence with children learning more about themselves, strategies and tasks, as they get older. It is not an automatic process but it is a result of long-term development of the cognitive system and it is both a product and producer of cognitive development. Although we know that as children get older they gradually develop more metacognitive knowledge, we know little about how this knowledge is acquired. Metacognitive theory has not focused on how metacognitive processes develop with age (Carr, 1998), because of methodological problems researchers encounter in their attempt to measure the development of metacognition.

THE MEASUREMENT OF METACOGNITION

One of the basic problems of the study on the field of metacognition is to develop and use valid tasks in order to measure metacognitive ability. Brown (1987) believes that using the term metacognition to refer to two distinct areas of research makes the research procedure more difficult and creates confusion clouding interpretation of research findings. Although several methods of measuring metacognition have been implemented each method has advantages and disadvantages. For example, one of the most popular approaches for assessing both

metacognitive knowledge and control is to ask students directly about what they know or what they do. For assessing metacognitive control participants may be asked to think aloud about what they are doing and thinking as they solve a problem. Nevertheless verbal reports are subject to many constraints and limitations (Baker & Cerro, 2000). Asking children, particularly young children about their cognitive processing pose some special problems. Answers may reflect not what the child respondents know or do not know, but rather what he/she can or cannot tell to the interviewer. On the other hand, metacognition is cognitive in nature rather than behavioural and consequently, self-report inventories are, in some ways, the least problematic technique to measure metacognitive ability (Sperling, Howard, Miller & Murphy, 2002).

We present three of the inventories that have been used for the measurement of metacognition. Fortunato, Hecht, Tittle and Alvarez (1991) asked seventh-grade students to work on a non-routine problem and then respond to twenty-one statements about what they were thinking while solving a problem, in order to measure their metacognitive abilities in relation to their performance on solving mathematical problems. Schraw and Sperling-Denisson (1994) developed a 52-item Likert scale self-report inventory for adults (MAI), which measured both knowledge of cognition and regulation of cognition. They set out to confirm the existence of eight factors, from which three related to knowledge of cognition and five related to regulation of cognition. The final factor structure was best represented by two main factors. Post-hoc content analysis confirmed that these factors were ended knowledge of cognition and regulation of cognition. Sperling et al. (2002) used the idea of the MAI inventory and developed two inventories for the use with younger learners, the Jr MAI, version A and B.

The major purpose of the present study was to develop an inventory based on the idea of MAI (1994), Jr MAI (2002) and the questionnaire of Fortunato et al. (1991), for the measurement of young pupils' metacognitive ability in mathematics. The second aim of the study was to develop and apply a strategy for assessing metacognition within the context of problem solving.

The sample: Participants included all 246 children from 8 to 11 years old of an elementary school (74 were 4th graders, 81 were 5th graders and 91 were 6th graders).

Procedure: The questionnaire was consisted of two basic parts. At the first part which was about their metacognitive abilities in mathematics (see Appendix) pupils were instructed to read 30 items and for each item circle the answer that best described their thoughts when solve a problem they might see in a math class (1=never, 2= seldom, 3=sometimes, 4=often, 5=always). At the second part, which was about their cognitive ability in problem solving, they had to read a non-routine problem and without solving it they should read six items and for each item circle the answer that best described their thoughts when trying to think the solution of the problem (e.g. "I've tried to rewrite the problem in my own words"). After they solved the problem they had to answer six more questions about their thoughts while

solving the problem (e.g. “I checked the operations I used”). In all classes the questionnaire was administered as part of normal class procedure. The problem was: “Mr John wants to buy digit-cards in order to use them for the numbers on the doors of 100 houses of a camp. On each card there is only a digit-number (from 0 to 9). How many different cards he has to buy?”

RESULTS

We present first the results of the first part of the inventory. The 30 items were checked to assure no items were non-normal given skewness or kurtosis. All items were within criteria for meeting normality. We conducted an exploratory factor analysis and we utilized an extraction method using varimax factor rotation. Initial results revealed a ten-factor solution ($KMO=0,785$, $p=0,000$) with eigenvalues 1,023 and above, which accounted for 58,805% of the sample variance. The overall inventory demonstrated a reliability of alpha 0,8298 while the reliability for each factor ranged from 0,8174 to 0,8374. Three of the factors were consisted of only one item each, so we eliminated the respective items (A13, A20 and A27) which appeared to have the lowest correlations with the other items. The factor analysis was conducted again ($KMO=0,807$, $p=0,000$) and the resulting solution revealed nine factors accounting for 58,964% of the sample variance. The reliability of the inventory was 0,7686 and the reliability for each factor ranged from $\alpha=0,7361$ to $\alpha=0,7722$.

Four factors were represented by regulation items, three factors were represented by knowledge of cognition items and two factors (factors 6 and 8) split and contained items from both the knowledge of cognition and the regulation of cognition. This finding is likely to due to the high correlation between knowledge and regulation of cognition. Items A16 and A17 were dropped so that four factors were represented knowledge of cognition and five factors were represented regulation of cognition. After a content analysis of the 25 items, the following definitions were given for each factor:

Knowledge of congition:

Factor 2: awareness of personal success (items 1,5,26)

Factor 3: beliefs for factors that influence academic performance in mathematics (items 2,28,29)

Factor 6: knowledge of ways for effective learning (items 3,4,17)

Factor 9: knowledge of strategies that should be used (items 6,18)

Metacognitive regulation:

Factor 1: self-control of problem solving ability (items 10,11,24,25)

Factor 4: self-regulation on the overall behavior of the person (items 12,15)

Factor 5: ways of self-regulated behavior in order to encounter a situation (items 7,8,9,21)

Factor 7: self-regulation of problem solving (items 14,19,30)

Factor 8: overcoming the difficulties while solving a problem (items 16,22,23)

The nine factors solution was further examined to assess the relationships among factors. As expected, there were significant high correlations between almost all the factors. A one-way anova was conducted to assess differences between overall responses by grade level but no significant difference was indicated.

The analysis of pupils' answers at the second part of the inventory investigated their metacognitive behavior while they tried to solve a non-routine mathematical problem. The difference between pupils' beliefs about their abilities before they solved the problem and after that indicated their metacognitive knowledge about their abilities. Additionally few items were about their attempts to overcome difficulties they encountered indicating their metacognitive regulation.

A one-way anova was conducted to assess differences on the success of the solution of problem and there was no significant difference ($p=0,038$). The frequencies of the correctness of the problem solving are presented in Table 1.

Table 1: Frequencies (%) of the correct problem's solution

| Class | Correct solution | Solution with some faults | Wrong solution |
|-----------------|------------------|---------------------------|----------------|
| 4 th | 64,9 | 16,2 | 18,9 |
| 5 th | 58 | 28,4 | 13,6 |
| 6 th | 49,5 | 18,7 | 31,9 |

From the crosstabs analysis of pupil's answers, before their attempt to solve the problem and their performance on the solution of the problem, it is interesting that only 35,2% of the pupils who solved it correctly claimed that they realized that they had the ability to solve it. Even after the solution of the problem only 42,6% of the pupils who solved it correctly claimed that they knew that their solution was correct. The equivalent percent of those who solved it incorrectly and claimed that they knew what was their performance on the solving of the specific problem was only 29,3%. As it was expected 59,7% of the pupils who claimed that they were confused and they could not regulate their behavior, solved the problem incorrectly. There was significant difference between pupils' answers before the solution of the problem and after that on the items that expressed their knowledge about their abilities to solve the specific problem ($\bar{X}_{\text{before}}=2,32$, $\bar{X}_{\text{after}}=1,91$, $p=0,001$). This result indicates that pupils did not have a rich metacognitive knowledge of their abilities and they overestimated their abilities.

DISCUSSION

This study represents a part of a pilot study on the development of pupils' metacognitive ability in mathematics. Actually this part represents the initial phase of an instrument development for the measurement of metacognition in mathematics education appropriate for pupils in primary education. Undoubtedly it is not easy for young pupils to express their thoughts about their cognitive system and their cognitive abilities. We believe that it is possible in an attempt to measure metacognitive abilities to interfere to the metacognitive processes while pupils are obliged to think about their cognitive system. Those thoughts are metacognitive by their own nature.

The factor analysis of the data of the present inventory indicated that almost all items loaded as expected. Two factors contained items from both the knowledge of cognition and regulation of cognition and there were high correlations between almost all the factors because of the high correlation between the two basic dimensions of metacognition: knowledge of cognition and regulation of cognition. These findings are consistent with the work with the MAI (Schraw & Sperling - Dennison, 1994) and Jr MAI (Sperling et al, 2002). We believe that the inventory has been constructed can be used for the measurement of young pupils' metacognition after maybe few changes are made especially at the second part. Part A could be actually consisted of the 25 items while at part B pupils could answer the six questions before the solution of the problem and only after two or three days could solve it and answer the questions about their solution in order to avoid the possibility that pupils repeat the same answers in their attempt to be consistent in their behavior.

Although the current research sought to add to the knowledge base regarding the measurement of metacognitive skills, we believe that a second study could examine the instrument the present study developed for the measurement of young pupils' metacognitive ability in mathematics, through a validity investigation.

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APPENDIX: The questionnaire

1. I know how well I have understood a subject I have studied.
2. My performance depends on my will and my effort.
3. I try to use ways of studying that had been proved to be successful.

4. I can learn more about a subject on which I have previous knowledge.
5. I can learn more about a subject on which I have special interest.
6. I understand something better if I use pictures or diagrams.
7. I define specific goals before my attempt to learn something.
8. I examine my own performance while I am studying a new subject.
9. After I finish my work I wonder whether I have learned new important things.
10. After I finish my work I wonder whether there was an easier way to do it.
11. After I finish my work I repeat the most important points in order to be sure I have learned them.
12. I use different ways to learn something according to the subject.
13. When I do not understand something I ask for the help of others.
14. For the better understanding of a subject I use my own examples.
15. I know ways to remember knowledge I have learned in Mathematics.
16. When I read a problem I know whether I can solve it.
17. I concentrate my attention on the data of a problem.
18. I understand a problem better if I write down its data.
19. In order to solve a problem I try to remember the solution of similar problems.
20. While I am solving a problem I try to realize which are its aspects that I cannot understand.
21. When I try to solve a problem I pose questions to myself in order to concentrate my attention on it.
22. When I encounter a difficulty on problem solving I reread the problem.
23. When I encounter a difficulty that confuse me in my attempt to solve a problem I try to resolve it.
24. While I am solving a problem I wonder whether I answer its major question.
25. Before I present the final solution of a problem I try to find some other solutions as well.
26. After I finish my work I know how well I performed on it.
27. I believe that some mathematical concepts are more difficult than others.
28. When I cannot solve a problem, I know the factors of the difficulty.
29. I believe that some problem solving strategies are easier than others.
30. When I encounter a difficulty in problem solving I am looking for teacher's help.