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ABSTRACT

This paper discusses what metacognitive and cognitive actions elementary students make when they tackle mathematics problems. Findings are presented from the first 30 multimethod interviews conducted with Australian elementary mathematics students. Students used a set of specially designed metacognitive and cognitive action cards to stimulate responses about their thinking during problem solving. Their attempts to solve the problems were videotaped, and they were allowed to see the video after attempting to solve the problem. While watching the video, researchers had the students discuss their thinking and behavior during different moments of the problem solving process, focusing on three metacognitive functions: awareness (what they knew and had done before), evaluation (judgements regarding their thinking or strategy choices), and regulation (changes in the way they were working or plans to work the problem out). Students reported diverse metacognitive transitions and sequences when they tackled different types of problems. Most of the 30 students reported starting with the awareness function and ending with the evaluation function, which was the most frequently used function. Within the evaluation category, the most frequently reported action statement was, "I checked my answer as I was working." Most of the transitions were from regulation to evaluation. (Contains 22 references.) (SM)

The Nature of Metacognition:
What do primary school problem solvers do?

Paper presented at the National AREA conference, Melbourne University, June 29th-30th 1998.

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Introduction

The link between successful problems solvers and metacognitive thinking has often been made (Biggs, 1987, Birenbaum, 1996, Goos, 1993 and 1995, Goos, Schoenfeld, 1987 and 1990, Venezky and Bregar, 1988, Wilson and Wing Jan, in press). Stacey claims that: 'Good problem solvers tend to show more meta-cognitive knowledge.'(1990:6) Research in the field of mathematics and metacognition has reported that students having difficulties in mathematics do not use a range of cognitive or metacognitive strategies (Munro, 1993a).

Despite the acknowledged importance of metacognition for student learning the term metacognition is mysterious to many practicing teachers and remains ill-defined amongst researchers (Brown, 1987; Munro, 1993b, Wilson, 1998). The confusion over the definition is often traced to the dual aspects of metacognition. These are usually referred to as the knowledge of thinking and the control or regulation of thinking (Brown, 1987, Brown, Bransford, Ferrara & Campione, 1983, Garofalo & Lester, 1984, Schoenfeld, 1990, and Schraw & Dennison, 1994).

The postulated dual nature of metacognition provides only a superficial model of metacognition. It does little to explain the use of metacognition by students. A number of important questions remain unanswered about what metacognitive and cognitive actions students actually make when they tackle mathematics problems. Only with a much more detailed model of metacognition can we seek to answer questions such as: In what ways do successful and less successful problem solvers behave metacognitively? More specific information about what primary school problem solvers do could assist practicing teachers to improve the teaching and learning of metacognition and consequently to enhance student problem solving.

This paper reports on findings of the first 30 multi-method interviews conducted as a part of a PhD research project with upper primary students in the curriculum domain of mathematics. Students used a set of especially designed metacognitive and cognitive action cards to stimulate responses about their thinking during problem solving. They reported a diversity of metacognitive transitions and sequences when they tackled different types of mathematics problems. The model presented on figure 1 forms the basis of data analysis. The study highlights key aspects of the nature of students' metacognitive thinking and raises important teaching implications.

Purposes of the Research

The focus of the study is on the assessment of metacognition within mathematical problem solving. Three sub questions have been used to focus the study:

1. Which strategies are most effective for the assessment of metacognition?
2. What do these assessment strategies reveal about the nature of metacognition?
3. What is the relationship between metacognition and task type?

Findings related to the second sub questions have been presented in this paper.

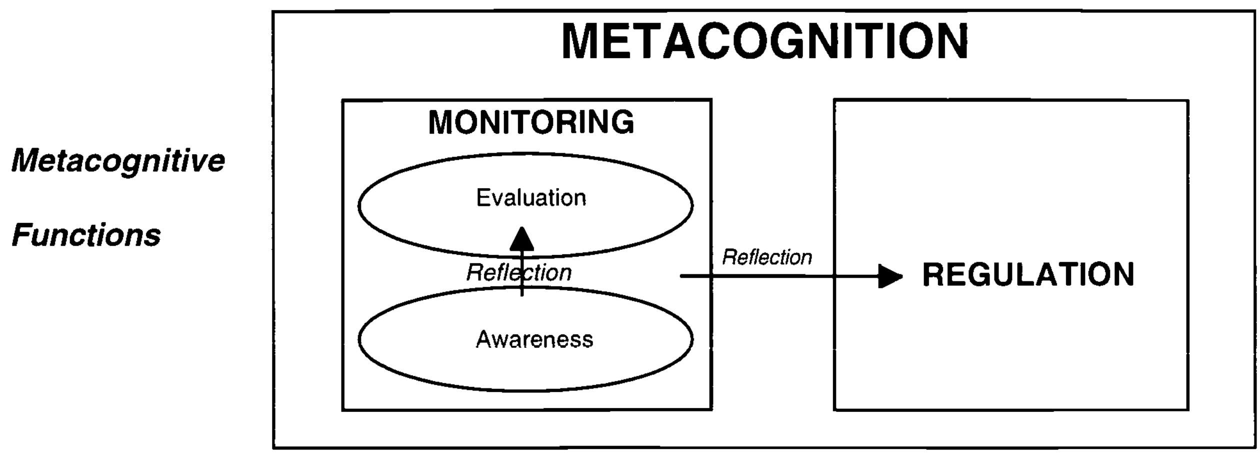
Defining the Terms

Metacognition

In this paper metacognition refers to the *awareness individuals have of their own thinking and their ability to evaluate and regulate their own thinking.*

Figure 1 diagrammatically represents this definition of metacognition. It is used as a framework to show the three functions of metacognition and their relationship to each other. The functions include: Awareness, Evaluation and Regulation of one's own thinking. Awareness and Evaluation are components of the thinking activity classified as Monitoring. Reflection is the mediating process whereby Awareness may become Evaluation and Evaluation may be transformed into Regulation of the thinking processes.

Figure 1. Model of Metacognition



The three functions of metacognition are defined as:

1. *Metacognitive Awareness* relates to an individual's awareness of where they are in the learning process, of their content specific knowledge, of their knowledge about their personal learning strategies, and what needs to be done in particular problem solving situations.

2. *Metacognitive Evaluation* refers to judgements made regarding one's thinking capacities and limitations as these are employed in a particular situation or as self-attributes. For example, individuals could be making a judgement regarding their effectiveness of their thinking and/or strategy choice.

3. *Metacognitive Regulation* occurs when individuals make use of their metacognitive skills to control their knowledge and thinking. They reflect on their knowledge about self and strategies (including how and why they may use particular strategies). Metacognitive Regulation may include the ability to plan, self-correct, set goals and optimise the use of one's own cognitive resources.

Metacognition can be studied in relation to problem solving and/or learning. Although learning may occur as a result of problem solving involvement, students often perceive problem solving as a task to solve and not as learning. In this research the use of metacognition is studied specifically in relation to mathematical problem solving.

Transitions and Sequences

Transition refers to ordered pairs of metacognitive functions, for example: Awareness followed by Evaluation. For the purposes of this study, a *sequence* refers to a list of metacognitive and cognitive actions and associated transitions within the context of one problem solving task.

It is possible that some students employ sequences of metacognitive actions that are structurally consistent. Such a repeated pattern could be termed the student's *'metacognitive style'*. This notion is raised later in the paper.

Action Statements

Learning is an active process where students may choose to act or not act. Thinking is considered to be a legitimate act. The methodology in this study makes use of *'action statements'* which describe cognitive or metacognitive actions, for example: *'I made a plan to work it out'*. Action statements are listed individually on cards. They relate to one of the metacognitive functions (Awareness, Evaluation or Regulation identified in figure 1). These cards are used during the multi-method interviews as described below.

Methodology

There are many difficulties associated with researching and assessing metacognition. For example, because metacognition remains ill-defined the phenomenon is hard to research. Researchers of metacognition often rely on self-reporting. The validity of self-reporting is often challenged (Nisbett & Wilson, 1977, Nuthall & Alton-Lee, 1995).

A New Multi-Method Approach

A new approach which is based upon the strengths of many commonly used assessment strategies has been designed as a result of this pilot study and in response to published criticisms of previous metacognitive research. The new approach used in this research has been given the title 'multi-method interview'. Within the framework of a clinical interview, this approach integrates: oral Likert-type responses, self-assessment, observation and think aloud technique (where chosen by the participant). All interviews are video and audio recorded. This approach could be adapted and applied to other mathematics contexts and to a range of educational settings.

The approach makes use of revised Likert scale items related to metacognitive and cognitive action used in the pilot study. But the procedure is implemented in a more 'hands on' way. Students are asked to have a go at solving a mathematics problem. The procedure is video taped. Instead of ticking along a line to indicate how they worked, metacognitive behaviors are listed individually as action statements on a playing cards (Clarke, 1989) for students to sort and sequence according to how they solved the problem. Cards which do not apply are discarded. Cards listing cognitive behaviors and blank cards are also provided and used to sequence what students do and think while trying to solve the mathematics problems.

After the students have placed the cards in order, the video of their problem solving attempt is replayed. While watching the video, students are asked to point to the particular card which represents their thinking and behavior at each moment in the problem solving process. If they wish to, they can change the cards by discarding, adding to or changing the sequence.

It is recognised that no one can ever say with total confidence that they know what another person is thinking. Indeed, individuals may not be able to reconstruct and communicate their own thinking processes. The 'multi-method approach' was designed to provide a more reliable account of student metacognitive thinking. The findings in this study can be stated with greater confidence than studies based only on self-report questionnaire responses because they draw upon several pieces of data.

Action Statements

The Action Statements were constructed after a thorough examination of the literature and relate specifically to the model (figure 1) and the associated definition. This research approach has similarities with inventories and rating scales often used in the study of metacognition (Fortunato, Hecht, Kehr, Tittle & Alvarez, 1991, Stacey, 1990, Grubaugh & Speaker, 1991-2). Using inventories and rating scales, students are asked whether they always, never or sometimes engage in particular activities. In this study, students are asked to sort the action statements on cards to indicate whether they used the particular actions while solving specific mathematics tasks. Most inventories have been used for assessing the metacognition of students at tertiary or secondary levels, therefore the language had to be adapted for the cards used with children at the grade six level.

The *Action Statements in this study included:*

a. I thought about what I already know (awareness)
b. I thought about something I had done another time that had been helpful (awareness)
c. I tried to remember if I had ever done a problem like this before (awareness)
d. I thought about how I was going (evaluation)
e. I thought about whether what I was doing was working (evaluation)
f. I checked my answer as I was working (evaluation)
g. I thought about what to do next (regulation)
h. I made a plan to work it out (regulation)
i. I thought about a different way to solve the problem (regulation)
j. I changed the way I was working (regulation)

Types of Mathematics Tasks

Three mathematics problems were used as a basis for students' reflections on their metacognitive thinking. The problems were non-routine and challenging because it is recognised that many classroom mathematics problems require little student reflection (Fortunato et al., 1991). Some mathematics tasks do not demand the use of metacognitive functions therefore careful selection was required. The tasks needed to provide an effective basis for reflection at the card sorting stage. Further discussion about the connection between various mathematics task types and metacognition is within the parameters of the study but beyond the scope of this paper.

Findings

The findings reported in this paper focus on aspects of primary student metacognitive transitions and sequences used during problem solving in mathematics.

Starting Points

Out of 30 interviews most students reported that they started with the awareness function (21 times). Regulation was reported as a starting point 5 times, of which on student reported starting at Regulation twice. Evaluation was the reported starting point three times.

Ending Points

Students reported that they ended with Evaluation 23 times. On 6 occasions the Regulation function was reported as used at the end of the problem. One student who solved the problem very quickly reported using only the Awareness function.

Frequency of Use of the Functions

Evaluation was reported as the most used function. It was reported as being used 3 times as a starting point, 23 times as a finishing point and most commonly during the problem solving processes. During 30 interviews, the use of the metacognitive actions associated with the Awareness function was reported 45 times, the Evaluation function 82 times and the Regulation function 64 times.

Most to Least Used Action Statements

Within the evaluation category, the most frequently reported action statement was *'I checked my answer as I was working'*(Reported as used 30 times). Note that while this figure is equivalent to the total number of interviews, not all students reported this action. Some students reported this action more than once during a task (7 times) and some students reported not using the action at all (9 times not used).

In the other two categories: the most frequently reported Awareness action statement was *'I thought about what I already know.'* (18 times) and the most regularly reported Regulation action statement was *'I thought about what I'd do next.'* (22 times)

The least reported action statement was: 'I *made a plan to work it out'* (Regulation, 6 times). The least reported Evaluation action statement was *'I thought about whether what I was doing was working.'* (10 times) The least reported Awareness action statement was *'I thought about what I had done another time that had been helpful.''* (10 times)

Transitions and Sequences

Most of the transitions reported were from Regulation followed by Evaluation (occuring a total number of 38 times). The next most reported transition was from Evaluation followed by Evaluation (35 times).

The least reported transition was Evaluation followed by Awareness (2 times). The transition of Regulation to Awareness was only reported 6 times. Evaluation was only reported as being used directly after Awareness 7 times.

Students tended to report a similar number of metacognitive acts in each of the tasks. For example, one student, Fleur, reported the use of 7 metacognitive acts on the logic task, 7 on the tangram task and 6 on the number task. Tony reported 3 metacognitive acts on the logic task, 3 on the tangram task and 4 on the number task. Sequences of metacognitive acts tended to be longer on tasks which were not completed successfully.

Individual Students

Analysis of responses of individual students has not been completed. More interviews are needed to interpret the preliminary data. Two different examples have been included here to illustrate the type of findings emerging, not for the purposes of generalisation.

Some students have used a similar sequence of metacognitive functions for the three different tasks. For example, Jennifer reported starting with the Awareness function on all three tasks, this was always followed by the use of Regulation. The use of Evaluation follows Regulation on all tasks. Unlike most students she used Awareness during the sequence after Regulation on task 1. Where the tasks took longer Jennifer has used Regulation and then the Evaluation functions again. It is noted that although Jennifer completed two of the three tasks, none were completed successfully.

Jennifer's Metacognitive Sequences:
Task 1: Awareness, Awareness, Regulation, Awareness, Awareness, Regulation, Evaluation, Regulation, Evaluation, Evaluation.
Task 2: Awareness, Awareness, Awareness, Regulation, Evaluation, Evaluation, Regulation, Evaluation.
Task 3: Awareness, Regulation, Regulation, Regulation, Evaluation, Evaluation.

Tony completed all tasks in a short amount of time and did not report the use of many functions. He successfully completed the last two tasks. His sequence does not demonstrate a clear and consistent pattern. The only similarity is that he started task 1 &3 at the Awareness function and ended both in Regulation.

Tony's Metacognitive Sequences:
Task 1: Awareness, Awareness, Regulation.
Task 2: Evaluation, Regulation, Evaluation.
Task 3: Awareness, Evaluation, Evaluation, Regulation.

These findings should be considered preliminary as only one third of the intended data (from one school) has been collected so far. Patterns and trends reported here may be challenged, refuted or confirmed when the total data is collected from twenty other students from two other schools.

Discussion and Implications

This paper has documented the characteristics of some sequences and transitions used by year 6 students as they accessed and manipulated their thinking processes during mathematical problem solving.

It seems logical that when students encounter a problem they would try to make links to what they know and have done before (Awareness). They might have a go at answering the problem, monitor what they are doing and realise that they are not travelling a successful route (Evaluation) change the way they are working or make a plan to work it out (Regulation). This hypothesised sequence is consistent with the model as proposed in this paper but preliminary research findings demonstrate that student sequences vary notably. Many do not work in this manner. Most start with a Monitoring action and then proceed to Regulation. The transitions and sequences which follow depend on many factors. What then do the actual transitions and sequences tell us about the nature of metacognition and student problem solving?

1. There are some transitions which are rarely used, for example, Evaluation followed by Awareness (used only twice) It is conceivable that a student, having evaluated their progress might reflect on alternate strategies. Why transitions like this occur, or do not occur, is worthy of further study.

2. The use of Evaluation is often reported. Students appear to regularly evaluate their progress. Further analysis will address the effectiveness of the use of this metacognitive function and the consequences of these evaluations.

3. Awareness is rarely used except at the beginning of the sequence. This is discussed below.

The link between successful problem solving and particular metacognitive transitions or sequences would be worthwhile identifying. It may be that the awareness function could be more frequently accessed by students. Teachers might more explicitly encourage the use of several 'Awareness acts' particularly when students' problem solving acts are unsuccessful, when students perceive the tasks to be less routine or difficult. For example, if students attempts are unsuccessful they might be encouraged to make links to something they have done before that has been helpful. While it seems that students identify the need to use their Awareness of known strategies at the beginning of tasks, they may not recognise the need/usefulness of this function during a task.

Evaluation is reported as being used far more than other functions. It may be more productive for students to intersperse the use of awareness and regulation more often during the problem solving task rather than repeatedly using Evaluation.

If further analysis reveals that students demonstrate metacognitive styles, an awareness of this by teachers would be helpful. For example, modelling of metacognitive language of different functions could be included in the teaching program. At a practical level, some students may need to make better connections to what they have done before (Awareness), taught to self-assess (Evaluation) or to make a plan of action (Regulation).

Conclusion and Further Study

The findings in this study provide interesting starting points for discussion about the use of metacognition in mathematical problem solving and have implications for teaching practice at other levels and in other curriculum domains. Some questions which remain to be explored during this study are:

- What do these metacognitive transitions and sequences tell us about students as problem solvers?

- Are there some transitions and sequences which always lead to success and are there some transitions and sequences that are unfruitful?

- Are there productive and non-productive 'metacognitive styles'?

- Do transitions and sequences vary between tasks according to the level of difficulty or as a consequence of other factors?

It is intended that the completion of the 90 multi-method interviews by the end of this year will provide data to be used to respond to these questions about task type, the nature of metacognition and the assessment of metacognition.

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