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MATHEMATICS EDUCATION AND USE OF MATHEMATICAL LANGUAGE IN ENHANCING UNDERSTANDING OF MATHEMATICS IN SECONDARY SCHOOLS

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Abstract:

There are many factors attributed to the poor performance of mathematics at high school level, for example, students' attitude to mathematics, low cognitive abilities, poor teacher- student relationships, poor study environments, poor usage of mathematical language as a tool for communication among others. This paper sets to investigate the use of mathematical language as a means of communicating mathematics being a core subject and the influence it has on academic achievement at the secondary school level in Rachuonyo region of Homabay County. In particular, the study investigates the intricacies involved in teaching mathematics. For example, do teachers use technical terms which are above the learners' level of understanding? The study further seeks to determine other factors related to mathematical language and how their interaction affects the performance of mathematics at secondary school level.

Key Words: Mathematical language, Secondary schools, Academic achievement.

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1. INTRODUCTION:

The aim of mathematical education is surely success for all students (MOEST 2003), (GoK 2007) and (Steen 1989), yet it seems to be a fact of life that whilst a few prosper in mathematics, a much greater number find mathematics difficult (all the references herein). Thus it is that, however successful a course may appear to be, there are students who begin to struggle and who will need appropriate help to be able to pursue mathematics further (Waititu 2008) and (Markovits etal 1988). Gray and Tall (1991) give evidence of younger children performing arithmetic which shows that when taught arithmetic procedures, the less able seek security in carrying out the process whilst the more able soon develop a more flexible kind of thinking in which notation is used to mean either a process to give a result or a concept to be manipulated at a higher level. Mathematical notation is central to the power of modern mathematics (Viner 1983) and (Abedi 2001). Sometimes formulae cannot be understood without a written or spoken explanation, but often they are sufficient by themselves, and sometimes they are difficult to read aloud or information is lost in the translation to words, as when several parenthetical factors are involved or when a complex structure like a matrix is manipulated. Like any other profession, mathematics also has its own brand of technical language. In some cases, a word in general usage has a different and specific meaning within mathematics. Examples are group, ring, field, category, term and factor. In other cases, specialist terms have been created which do not exist outside of mathematics e.g. tensor, homology, functor. All these constitute mathematical language.

Mathematical statements have their own moderately complex taxonomy, being divided into axioms, conjectures, theorems, lemmas and corollaries. And there are phrases in mathematics, used with specific meanings, such as "if and only if", "necessary and sufficient" and "without loss of generality". Such phrases are known as mathematical jargon (Kroll and Miller 1993). They form part of mathematical language which most students find difficult to comprehend. When mathematicians communicate with each other informally, they use phrases that help to convey ideas. Examples of some of the more idiomatic phrases are "kill this term", "vanish this interval" and "grow this variable". The vocabulary used in mathematical language is also visual. Diagrams are used informally on blackboards, as well as in published work. When used appropriately, diagrams display schematic information more easily (Goldin 1997).

Diagrams also help visually and aid intuitive calculations. Sometimes, as in a visual proof, a diagram even serves as complete justification for a proposition. A system of diagram conventions may evolve into a mathematical notation, for example, the Penrose graphical notation for tensor products. The grammar that determines whether a mathematical argument is or is not valid is mathematical logic. In principle, any series of mathematical statements can be written in a formal language, and an algorithm can apply the rules of logic to check that each statement follows from the previous ones. Various mathematicians, most notably Frege and Russell, attempted to achieve this in practice (Alan and David 1988), in order to place the whole of mathematics on an axiomatic basis for better understanding of the language used. Mathematics is used by mathematicians, who form a global community composed of speakers of many languages. It is also used by students of mathematics. As mathematics is a part of primary education in almost all countries, almost all educated people have some exposure to pure mathematics. It is interesting to note that there are very few cultural dependencies or barriers in modern mathematics. There are international mathematics competitions, such as the International Mathematical Olympiad, and international co-operation between professional mathematicians is commonplace. This paper therefore, sets to investigate the use of mathematical language as a means of communicating mathematics being a core subject and the influence it has on academic achievement at the secondary school level in Rachuonyo region of Homabay County. In particular, the study investigates the intricacies involved in teaching mathematics and the problems students face when answering mathematics problems with regard to the mathematical language used. For example, do teachers use technical terms which are above the learners' level of understanding? The study further seeks to determine other factors related to mathematical language and how their interaction affects the performance of mathematics at secondary school level.

2. PRELIMINARIES:

Mathematics as a language is used to communicate information about a wide range of different subjects. Here are three broad categories:

Mathematics describes the real world: many areas of mathematics originated with attempts to describe and solve real world phenomena - from measuring farms (geometry) to falling apples (calculus) to gambling (probability) (Goldin 1997). Mathematics is widely used in modern physics and engineering, and has been hugely successful in helping us to understand more about the universe around us from its largest scales (physical cosmology) to its smallest (quantum mechanics). Indeed, the very success of mathematics in this respect (Kroll and Miller 1993) has been a source of puzzlement for some philosophers.

Mathematical language gives a description of abstract structures: on the other hand, there are areas of pure mathematics which deal with abstract structures, which have no known physical counterparts at all (Gagné 1970). However, it is difficult to give any categorical examples here, as even the most abstract structures can be co-opted as models in some branch of physics (Ekenstam & Greger 1983).

Mathematical language gives a description of mathematics itself: mathematics can be used reflexively to describe itself. This is an area of mathematics called metamathematics (Chiarugi et al 1990). Mathematics can communicate a range of meanings that is as wide as (although different from) that of a natural language. Like English, or Latin, or Chinese, there are certain concepts for which mathematics is particularly well suited: it would be as foolish to attempt to write a love poem in the language of mathematics as to prove the Fundamental Theorem of Algebra using the English language. Mathematical language has what we call a procept defined as the amalgam of process and concept which is represented by the same symbolism, thus 2+3 represents the process of addition of 2 and 3, and the result of the process (5), 2+3x represents both the process of adding 2 to 3 times x and the resulting expression, sinx=opposite/hypotenuse represents both the process of calculating the sine as a ratio of lengths and also the value of the sine as the result of the calculation. First, we consider two categories of students. It is hypothesized (Baroody 1994 and Fong 1994) that less able students in mathematics (students who score D+ and below) have greater difficulties with the processes and concentrate on the lesser target of being able to carry them out satisfactorily whilst more successful students develop a more flexible method of handling notation, being able to see it either as a process to calculate a needed result or as an object to be manipulated as part of a more complex piece of symbolism (Bell 1978). In other words success comes from flexible proceptual thinking whilst short-term success but long-term failure comes from procedural thinking.

The inability of Conceptualizing mathematical language used: The more able students in mathematics (students who score C+ and above) are better at crystallizing a process into a concept and so may manipulate the concept with greater fluency than the less able who may still be operating at the process level. Processes occur in time and therefore are more difficult to conceive simultaneously in the mind than concepts.

For instance, the expression 2log105 + log108 – log102, can be thought of either as a process or as a concept. As a process it is an instruction to multiply the logarithm of 5 by 2, to add the logarithm of 8 and to subtract the logarithm of 2. As a process to be carried out in time it is a task which takes a long period of time whereby one may easily forget the beginning of the task as one approaches the end of it. Thus someone working at the process level will find it difficult to comprehend and hold in the mind for simplification purposes. However, seen as an object, it can be 'chunked' together as sub-objects, so that one may concentrate on the part 2log105, which equals $\log_{10}25$, and the whole expression reduces to $\log_{10}(25\times8\div2) = \log_{10}(100) = 2$. We therefore see (Kaur 1995) that the difficulties facing the less able (coordinating mental processes) are greater than those facing the more able (manipulating mental concepts) when it comes to comprehending the mathematical language used in this context because different students will give different meaning according to their level of understanding. A corollary of the hypothesis of failure in conceptualization is:

The constraints of the less able students: The more able are faced with conceptually easier mathematics (manipulating concepts) and so are progressively more likely to improve, whilst the less able are faced with a more difficult task (coordinating processes) and so are progressively more likely to fail. The difference is made even greater if the more able are manipulating symbols whose relationships are in some sense meaningful to them. Meanwhile the less able are likely to be constricted within a context wherein the symbols have a more inappropriate process meaning. For instance, (2+3)x and 2x+3x are totally different as processes. The first adds two and three and then multiplies the result by x, the second multiplies two by x, then multiplies three by x and then adds the two results together. Thus the student with only a process interpretation will find it difficult to conceive that these two symbols represent the same thing.

Meanwhile the student who sees these expressions as representing the product of the two calculations will be able to focus of the fact that the results are the same and thus see the expressions as being equivalent ways of expressing the same end-result. The more able are likely to benefit from seeing linkages and making connections between the crystallized concepts, because this new information reinforces and simplifies what they already know by placing it within a more secure knowledge structure. The more able need to remember less because they can reconstruct more. The less able see more information as a burden, as even more disjoint pieces of information to remember – an increased burden on a weaker back, leading to the greater probability of inevitable collapse (Stacey and Southwell 1996). The less able have a fundamentally different viewpoint. In addition to having less facility with mathematics, their difficulties are likely to manifest themselves in various ways, including:

(i) Being less likely to crystallize processes into manipulable concepts, thus imposing the greater burden of process coordination rather than concept manipulation,

(ii) Having fewer manipulable concepts, preferring to rely more on the security of carrying out familiar routinized processes,

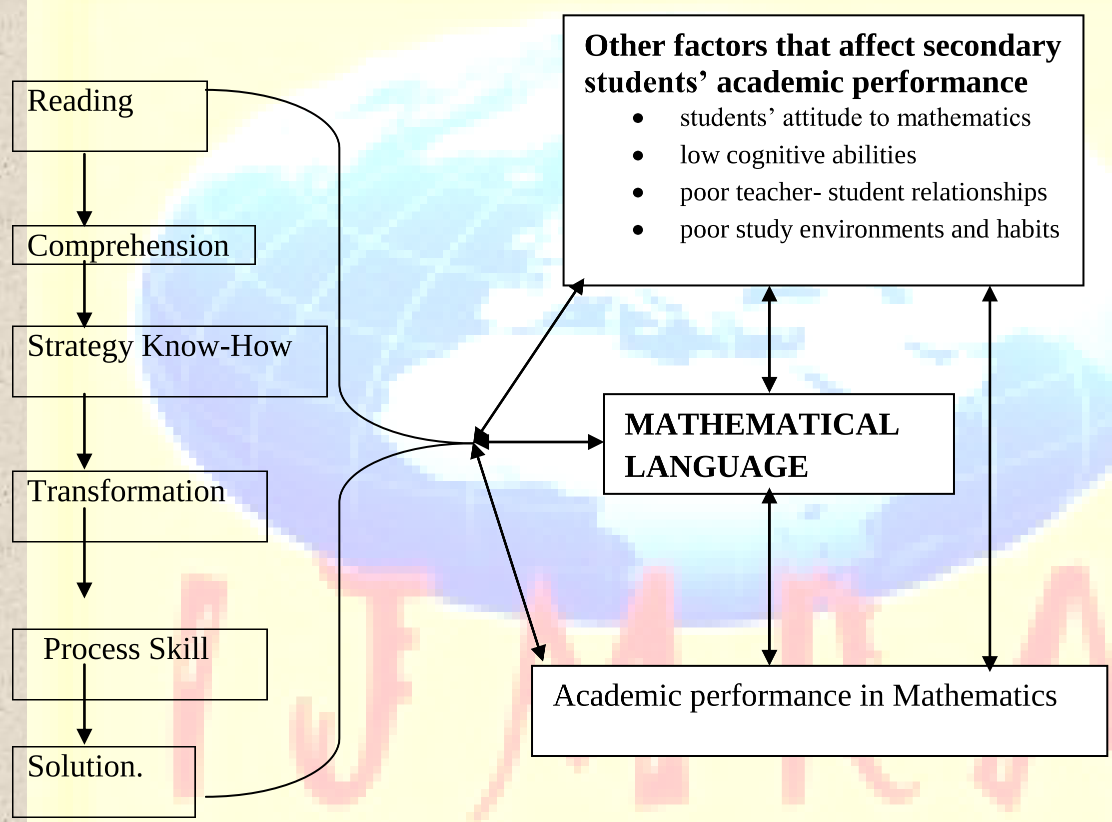
(iii) Through relying on routinized processes, being less likely to relate ideas in a meaningful way.

It is clear from the literature that the less able students are likely to need special treatment. If this is not done, the students are likely to become progressively more confused and in the long run they may not survive in post-secondary mathematics programmes.

The literature makes some suggestions as to what may be happening. For instance, Gagné (1970) postulates that there are four phases of learning: the apprehending phase, the acquisition phase, the storage phase and the retrieval phase. This might suggest that the more able can reach these four phases but, for the less able, the last phase may be of a problem. Perhaps the mind of the less able is like a flawed computer diskette. Sometimes, it will respond well to some mathematics problems (usually the easier ones) and it will 'blank out' to more difficult ones. But in his survey lecture at the 1988 Sixth International Congress on Mathematical Education in Budapest, Steen (1989) suggests that teachers normally act as if each student's mind is a blank slate - or an empty computer disk - on which effective teachers can record whatever information they like. Research in cognitive science suggests otherwise:

6. CONCEPTUAL FRAMEWORK:

Figure 1: A conceptual framework showing interactions between several factors and mathematical language and their overall effect on academic achievement.



From figure 1 above, we investigate how the students' competencies in reading affect their comprehension up to finding a solution to the mathematical problem. Next, we examine the relationship between these factors and the mathematical language used. If the answer is correct, could the wrong answer have been obtained due to mathematical language problem e.g. wrong interpretation by the students. Further, the figure illustrates the relationship between mathematical language and other factors e.g. students attitude towards mathematics and lastly the relationship between the academic performance of students and the effects of mathematical language used in general on the overall academic performance.

7. RESEARCH METHODOLOGY:

It is normally not easy to analyze the difficulties experienced by students when solving mathematical problems through investigating their written solutions. It may be more productive, when analyzing errors, to interview students, noting their verbalizations and thought patterns about the specific problems with which they were faced. It cannot be assumed that when an incorrect answer is given to a mathematical problem that the error occurred because the student lacked the necessary mathematical knowledge or skill. In written assignments, an interview technique may be used to find out the errors which students have made. A key assumption in this interview technique is that the types of errors students make will be consistent from one session to another. Nevertheless, it seems possible that one-to-one interviews, despite their limitations, do give greater insights into students thinking and difficulties which would not be possible purely from an analysis of paper and pencil solutions.

Sample:

The objective of this study is to gain insights into difficulties experienced by secondary school students when solving problems. As part of a study on mathematical problem solving by secondary school students in Rachuonyo region of Homabay County, 56 secondary school students from ten public secondary schools participated in this study. We used stratified sampling technique for the secondary schools whereby Rachuonyo region was divided into 8 strata and random sampling done within each stratum to get 8 secondary schools while the remaining 2 public secondary schools qualified automatically since there were only two “special category” secondary schools for the visually impaired students within the region. 6 students were picked randomly from the eight schools and 4 students were also picked randomly from each of the special schools. All the participants were at secondary school level.

Instruments:

An important criterion in choosing suitable mathematical tasks for this study was that they had to be “problems” for a majority of secondary school students. By the definition of a “problem” it had to be reasonably complex but approachable and requiring no specific high level mathematics. The problem had to be relevant to the secondary school mathematics curriculum and at a level which the problem solver did not have a readily accessible procedure that determines the solution. It should also require the problem solver to use heuristic strategies to approach the problem, to understand it and to proceed to a solution. Most importantly, the problem should be capable of stimulating enough interest in an individual to want to attempt a solution. The mathematical problems that were chosen had to have certain general structures that emphasized various components of the problem-solving process so that each could draw out a variety of problem-solving behaviours that were required in the present research. The mathematical problems used in this study can be categorized according to the research literature as “structured problems requiring productive thinking”; that is, tasks where problem-solving heuristics must be used by the problem solver. They are usually referred to as “non-routine or non-standard” process problems in the mathematics classroom context. Such problems are usually not solved by simple recall or the application of familiar algorithms even though a student may possess sufficient mathematical knowledge. A total of three non-routine problems were used in the study. The three problems were assembled from various sources. The Time problem was adapted from Baroody (1993). The Cat and Rabbit problem was adapted from Stacey and Kaur (1995) and Number problem was adapted from Fong (1994).

The Three Problems:

Time Problem

Miss Lee arrived at the concert hall 15 minutes before a concert began. However, due to some technical problems, the concert started 10 minutes later. The whole concert lasted for 2 hours 25 minutes. It was 10.30 pm when Miss Lee left the concert hall. At what time did Miss Lee arrive at the concert hall? Show all your working and explain it.

Cat and Rabbit Problem

A cat is chasing a rabbit. They are 160 metres apart. For every 9 metres that the cat runs, the rabbit jumps 7 metres. How much further must the cat run in order to overtake the rabbit? Show all your working and explain it.

Number Problem

The sum of two numbers is 36 and their difference is 12. Find the two numbers. Show all your working and explain it.

Procedure:

Interviews were conducted and the format used for the interviews consisted of the following oral procedure:

1. Read the question aloud.

(proceed to 2 if the question is read correctly, otherwise show correct words and symbols before proceeding to 2).

2. What do you need to find? What is the question asking for?

(proceed to 3 if student is able to comprehend the problem, otherwise ask questions to ensure understanding and comprehension like "How long was the concert?" before proceeding to 3).

3. Without doing any working, tell me how are you going to solve this problem? What are you going to have to do in order to solve this problem?

(proceed to 4)

4. What will you have to use to work out (such and such)? How will you work out to solve the problem? Show me how you solve the problem. Explain to me what are you doing as you solve the problem.

(proceed to 5).

5. How can you check to see if your answer is sensible? Study the problem again and decide if your answer is sensible.

The interviews were conducted one-to-one by the researcher and were audio-taped. The researcher took approximately half an hour to interview each student.

Apart from these three questions, other important questions were asked in the interview pertaining to their learning of mathematics e.g. how is your performance in mathematics in general? How is your relationship with your mathematics teacher? Does the teacher use simple terms or technical terms when teaching and are those terms in your mathematics text books? Does the teacher explain the difficult terms? Do you like mathematics word problems? What is your perception about mathematics?

Analysis of Interview Data:

The interviews that were conducted with the 56 secondary school students (related to their difficulties in solving problems) were audio-taped. These interviews were analyzed as follows: Reading, Comprehension, Strategy Know-How, Transformation, Process Skill and Solution. The following two-point categorizations in behavioral terms for each stage of the above structures were used to analyze the interview protocols.

Reading:

1. The student was able to read the problem without any difficulty.

2. The student was not able to read the problem and was helped with some of the words and/or symbols in the question.

As none of the students interviewed had any reading difficulty, there are no examples of difficulties at this stage which may have led to the inability of the students to go beyond this stage during the interview.

Comprehension:

1. The student (S) was able to comprehend the problem. This was confirmed by the responses to the questions the researcher (R) asked.

2. The student was not able to comprehend the problem. This was confirmed by the responses to the questions the researcher asked.

8. RESULTS AND DISCUSSION:

It was observed during the interviews that students were in the habit of trying to solve the current problem using only one strategy. They did not demonstrate any flexibility by trying a strategy and if it did not work, trying another. Students who worked their solutions using an inappropriate strategy were often not aware that the solution was incorrect. Furthermore, students made no attempt to check that their solutions were correct or whether the solutions satisfied the conditions in the problem. The results of the data analysis showed that students were not successful at obtaining solutions for the following reasons:

Lack of comprehension of the problem posed

Some students were faced with difficulties that they would not make any progress in solving the problem as they did not comprehend the problem; for example, they found the problem confusing as “too many sentences and workings” were involved and did not “know how to say” what was involved in a problem. They were unable to visualize how the cat and rabbit met, and did not comprehend the problem at all.

Lack of strategy knowledge

Some students, who had no difficulty comprehending the problem, were impeded in their progress in solving the problem as they appeared to have no knowledge of ways in which an unfamiliar or non-routine as well routine problem might be approached.

Inability to translate the problem into a mathematical form

Some students, who had a strategy to solve the problem, were impeded in their progress in solving the problem by their inability to translate the problem into a mathematical form (equations or open sentences). For example, for the Time problem, one student knew he had to “work backward” to find the solution but was not able to begin to work using the correct timing. For the Cat and Rabbit problem, a student was unable to use the difference of the distance between the cat and the rabbit for further computation. As for the Numbers problem, a student was unable to form two linear equations.

Inability to use the correct mathematics

Some students, who were able to translate the problem, were impeded in their progress in solving the problem by their inability to use the correct mathematics to solve the problem. Some students identified an appropriate operation or sequence of operations but did not know the procedures necessary to carry out these operations accurately. For example, for the Time problem, a student merely subtracted a smaller number from a bigger number at the hour and minute place value. For the Number problem, one student who had correctly formed two linear equations was unable to solve the two equations simultaneously and did not grasp the procedures involved in solving two linear equations. The results of the analysis of the data also showed that many times, the solution obtained by the students was incorrect and this could be attributed to the following reasons:

Inappropriate strategy used

The most common inappropriate strategy used to solve the three problems was number manipulation where students merely manipulated the data in the problem by trying to use the four operators *(+, -, ×, ÷)* to arrive at an answer. The use of formulae and tables (incomplete listing) to find the solution to the Cat and Rabbit problem also resulted in a number of incorrect solutions.

Incorrect formulation of the mathematical form

Several students, while working the Time problem, formulated the sums incorrectly

where they did not include the 10 minutes due to technical problems.

Computational errors

Several students obtained incorrect solutions owing to careless computations.

Imperfect mathematical knowledge

One student was not successful in obtaining the solution to the Number problem due to an imperfect knowledge of algebraic manipulations.

Misinterpretation of the problem

One student was not able to obtain the solution to the Number problem as he had interpreted that only one number was required to find in the problem. Therefore, it may be inferred that the difficulties experienced by secondary school students who were prevented from obtaining a correct solution were: (a) lack of comprehension of the

problem posed, (b) lack of strategy knowledge, (c) inability to translate the problem into mathematical form, and (d) inability to use the correct mathematics. Students obtained incorrect solutions for the following reasons: (a) an inappropriate strategy used, (b) incorrect formulation of the mathematical form, (c) computational errors, (d) imperfect mathematical knowledge, and (e) misinterpretation of the problem.

Kouba et al (1988) who developed a systematic procedure for analyzing errors found that students made a highest proportion of errors on Process Skills, followed by errors on the following order: Comprehension, Carelessness, Reading, Transformation, and Encoding.

Figures 2, 3 and 4 below also show that a high percentage of errors on Process Skills which is similar with the results of Kouba's study. The capital letters used in the figures 2,3 and 4 mean: A – Find question confusing, B- Lacks strategy, C – Unable to translate the mathematics problem into the required form, D – Erroneous calculation, E – Incorrect formulation of the problem and CORRECT – correct answer.

Category	A	B	C	D	E	CORRECT
Number (%)	3(5)	2(4)	8(14)	12(21)	9(16)	22(40)

Figure 2: Time Problem

Category	A	B	C	D	E	CORRECT
Number (%)	11(17)	3(5)	8(14)	11(17)	7(13)	16(34)

Figure 3: Cat and Rabbit Problem

Category	A	B	C	D	E	CORRECT
Number (%)	1(2)	1(2)	2(4)	3(5)	5(7)	44(80)

Figure 4: Numbers Problem

On the other questions asked, the students gave varied responses. Some admitted that mathematics is hard while some said it is easy if a student is hard working. Some students feared their teachers claiming that they are harsh and are not ready to answer questions from the students while they use very difficult terms that the students do not understand. Majority of the students (90%) confessed that they don't like questions that are too wordy as they are so confusing. On the study environment, many students especially the day scholars had the challenge of poor study environments at home as some of them lack basic requirements like paraffin to study at night.

9. CONCLUSIONS:

It was observed during the interviews that students were in the habit of attempting to solve the current problem using only one heuristic. They did not show any flexibility in seeking to solve the problems using more than one heuristic. This practice has implications for curriculum specialists and teacher educators. If the problem-solving curricula is to be successfully brought into the classrooms in secondary schools, these practices may have to be carefully examined and mathematics teachers be made aware of how they can successfully implement mathematical problem solving in the classroom. The difficulties experienced by secondary school students have important implications for classroom teachers. The simple interview format used in this research is easy to implement and could be adapted and used by classroom teachers to analyze their students' difficulties and hence remediate their difficulties. This study also shows that students must possess relevant knowledge and be able to coordinate their use of appropriate skills to solve problems. Furthermore, knowledge factors such as algorithmic knowledge, linguistic knowledge, conceptual knowledge, schematic knowledge and strategic knowledge are vital traits of problem-solving ability. For mathematics teachers to assist their students develop their problem-solving ability, it is essential that they aware of their difficulties first. This study has shown that diagnostic interviewing can provided comprehensive knowledge of students' thinking process. The interview responses are useful in that they can assist the mathematics teachers to focus on their students' difficulties during remediation.

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