

**PAIR PROBLEM SOLVING IN THE
LEARNING OF PHYSICAL SCIENCE**

IN KWA-ZULU SCHOOLS

BY

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ABSTRACT

Students have a tendency to skip steps in reasoning and miss facts when drawing conclusions during problem solving. Seeing that this poses a problem, it was thought that vocalizing thinking, using the method of pair problem-solving, would help ensure that students do not make these mistakes, but rather improve their ability of solving problems systematically.

The basic problem which the researcher addressed was:

To what extent will the pair problem-solving method improve the students' ability in solving physical science problems?

The people involved in the research were :

- i) Matric pupils from the secondary schools in Osizweni
- ii) Teachers of the schools involved

The interviews were done during one period per week for six weeks. At first pupils were given a pre-test and at the end of the interviews were given a post test. The two tests designed to be equivalent and the questions given to the experimental groups were the same as those given to the control group. Interviews carried out were tape recorded and also written down. The interviews and the tests scores were analyzed in order to determine to what extent the problem-solving skills of students improved as a result of the experiment.

The results found showed that there is great improvement in the ability to solve problems with experimental groups and insignificant improvement with the control group. The statistical

analysis showed that the improvement was great at at least 0,01 level of significance. There is also evidence of students solving problems systematically after they have done these interviews, and that there are other significant differences between the behavior of good and bad problem solvers.

The implications of these results for classroom teachers is that the think-aloud pair problem-solving method does improve the ability of students in solving physical science problems.

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DECLARATION

It is hereby declared that this dissertation is my own work, and has not been submitted previously for any degree in any University.

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CHAPTER 1

ORIENTATION AND OVERVIEW OF THE STUDY

1.1 INTRODUCTION

During the summer of 1986 the researcher, a participant in a three week institute, Problem Solving in Mathematics and Science, at the University of Massachusetts in Amherst (USA) was introduced to a process of thinking aloud for teaching, a process that is used with students experiencing difficulty in Mathematics at the college level. College students were brought in and interviewed by participants, including the researcher. The interviews done were video-taped. These were analysed in order to see whether the mistakes students made were systematic or were characteristic of the individuals. The results showed that the video taping helps students to analyse their problem solving abilities and thus improve them.

The experience the researcher acquired from participation in this program was that of being able to communicate one's thoughts in a step-by-step process. The researcher realised that a person can tell the next person exactly what he/she is thinking, while solving a particular

problem. It is difficult at first but, as the method is practiced, one gets used to the idea and gains skill in doing so.

This also teaches a person some listening skills. It is a difficult exercise to sit down and listen to anybody talking without interfering with their train of thought, more so when the one who is talking is trying to solve a particular problem. Pair problem solving helps one develop the skill of patiently listening to the next person and prompting them only to help them continue. The listener has, therefore, to give full concentration while honouring the problem solver's autonomy.

The procedure, as presented at the Amherst institute, is designed for pairs of students working as problem solvers and listeners. The problem solver is encouraged to explain and clarify every idea and the reasoning in a step-by-step problem solving process leading to the solution of the

problem, whether the solution is correct or not. The listener's role is defined as that of a prompter who should ask probing questions. The listener is specifically instructed not to contribute hints or suggestions and never volunteer assistance, but should always encourage the problem solver to think aloud. The two roles are clearly complementary, with that of the listener being to support the problem solver.

1.2 THE PROBLEM

Having taught Physical Science for four years in standard nine and ten, the researcher thought the process of pair problem solving would be useful to pupils at matric level because they have a tendency to skip steps in their problem solving methods which makes them jump to conclusions. It seems that they are not aware of how they think and proceed. Both verbalising and listening may create the awareness to make the process explicit and improvable. Some areas of difficulty, encountered by pupils when solving Physical Science problems, are to do with fractions and proportions. Seeing that these pose a problem, it is thought that vocalising, that is thinking aloud while solving a problem, would ensure that pupils neither skip steps in their reasoning nor miss facts when drawing conclusions, but solve problems in a systematic way, writing every step down.

People in general tend to jump to conclusions whenever they are faced with problems. This deprives them of a logical way of reviewing their thoughts step-by-step. These victims not only include people in general, but also graduates of the existing school system and pupils at schools. To the researcher, it became necessary to tackle this field with the aim of trying to improve problem solving methods in schools specifically and in society in general.

The method of pair problem solving may enable one not to skip steps by verbalising one's thinking. The researcher therefore thought this should be tried in Physical Science classes. There are not many changes that are needed in using this method. What is needed is a convenient arrangement of desks in a classroom, giving pupils clear instructions and monitoring their work.

1.2.1 Hypothesis

Practicing the solving of problems in pairs will improve the ability of standard ten pupils to solve physical science problems.

1.2.2 Null hypothesis

Practicing the solving of problems in pairs will not improve the ability of standard ten pupils to solve Physical Science problems.

1.3 PUPILS' ATTITUDES TOWARDS SCIENCE

The pupil brings to the already complex environment of the classroom so much in terms of prior experiences and preconceived notions that it is difficult to functionally differentiate between social influence and personal choice (Mason and Kahle, 1988:36).

[Many pupils are prepared to learn and be taught. One of the factors which discourages them is the way they are taught and the conditions under which they learn. In Black schools there is often no science apparatus and teachers have learned few skills for improvising science materials. It follows that the usual way of teaching science is by teacher talk and reading from the textbook, etc. This means that the teaching appears abstract and irrelevant to pupils' lives. In such a situation there is hardly any pupil participation, and this makes them dislike the subject, especially as they fear failing it.]

The teacher has been shown to be a powerful factor in affecting pupils' attitudes. The pair problem solving program pursued by this study seeks to encourage teachers to use that power meaningfully, by providing a stimulating learning environment for their pupils in such a way as to counteract some of the above-mentioned shortcomings. The pair problem solving process offers both members of the pair important and active roles in an interactive learning situation.

1.4 SCHOOL CHARACTERISTICS ✓

[There are three high schools involved in the development of the study presented here. In choosing the schools for this study a number of factors were considered. Some were the proximity of these schools, and the fact that they have much in common and that they differ in character from each other. Another factor was that they are all Black schools which made it convenient for the researcher. All these schools are in Kwa-Zulu in the area of Osizweni. All high schools in the area are community schools, almost all of which are characterised by:

- (i) shortage of classrooms
- (ii) very little science apparatus
- (iii) large pupil-teacher ratio (personal experience has shown this to vary from 30:1 to 100:1, the majority being nearer to 100:1).
- (iv) broken windows and doors and
- (v) a high percentage of teachers who do not possess teachers' certificates.

This kind of school setting makes a child develop a negative attitude towards learning, especially towards subjects like Physical Science, which are perceived as difficult. It is thought that certain kinds of strategies or skills should be developed in pupils in order to help them cope with the subject. Pair problem solving is one process skill which seems suitable for enabling pupils to solve Physical Science problems. Its suitability lies in the encouragement to become active and systematic in working with problems.]

1.5 PUPILS' CHARACTERISTICS

Problem solving is a process skill required by pupils. It requires background factual and conceptual knowledge. The situation in Black schools is such that pupils have:

[(i) a language problem, because the medium of instruction *also use pg 20-21* is English, whereas at home and when they interact with others they speak Zulu. For these pupils, while the natural way of conceptualising is in Zulu, they have to use a language in which they find it difficult to express concepts. Hence understanding of some concepts is difficult.]

(ii) rote learning dependence. Because of a lack of exposure to Physical Science apparatus and to other curriculum materials, pupils are encouraged to learn by rote. Teachers tend to deposit facts and formulae into pupils and withdraw them during examinations and when writing tests. There is virtually no pupil participation and no dialectical relationship between a pupil and his/her subject. As with working in a second language as the medium of instruction, this results in poor conceptual understanding and many pupil misconceptions.

It is thought that the above factors, which contribute to the pupils' poor conceptual understanding, can be counteracted by using pair problem solving. Pair problem solving, by requiring pupils to express their thinking process aloud to each other, should enable them to solve problems systematically, step-by-step in writing, clarify their own misconceptions, develop their ability to use language in their use and learning of concepts, and to understand concepts written in that particular language.

1.6 IMPLEMENTATION

At a practical level, certain procedures are already known for making pair problem solving as effective as possible. When the solver and listener sit side by side, interaction between them is limited and more attention is focused on the problem to be solved. An allowance of about ten minutes to achieve this arrangement of desks and for distribution of papers by the observers should be made. The observers observe each pair within the classroom as the problem solving program is in process, and monitor individual participation. After three weeks of problem solving, pairs are changed, so that pupils learn to communicate and/or interact with other classmates.

Since the original materials were designed for students in American Colleges, they needed some adaptation and some additions.

Some of the appendices therefore consist of materials used by the researcher in adapting the problem-solving process to the high school level. These materials include hand-outs designed for use by the pupils, specifically identifying each person's role in the problem solving process, along with hints as how best to perform in each role. Also included are the pre-test and post-test, written by pupils, that is, by both experimental and control groups. There is, in addition, a set of problems which the researcher has found effective for use in implementation of the problem solving process for matriculants.

CHAPTER 2

IMPORTANT ASPECTS OF SCIENCE LEARNING

2.1 INTRODUCTION

Knowledge, skills and understanding are important elements of science learning, but it is in problem solving that the child synthesises these components in order to answer a question, make a decision or achieve a goal (Reif in Gil-Perez 1989:27). The following is a critical discussion of aspects of science learning and their relation to problem solving.

2.2 METACOGNITION

Metacognition is the word which refers to what one knows or believes about oneself as a learner and how one controls and adjusts one's behaviour. It is how a person develops knowledge about his own thinking and the thinking of others. The development of metacognition requires children to observe and reflect on what they know and what they do not know. This process is greatly enhanced when a person verbalises his own thinking as in pair-problem solving, listens actively to others, and reads attentively. A person in this case develops the skill of self-interrogation and self-regulation. The basic skills of metacognition include:

- (i) Predicting the consequences of an action,
- (ii) Checking the result of one's own actions.
- (iii) Monitoring one's ongoing activity.
- (iv) Reality testing.

These skills are the basic characteristics of efficient thought. The teacher becomes a mediator of cognitive skills and general problem solving behaviour by encouraging meta cognitive behaviour in the learner and by bridging within subjects through the transfer of knowledge to real life situations. The teacher uses the different teaching techniques available to enhance analytical thinking, creative or lateral thinking, assimilation and accommodation of new knowledge, meaningful learning and real understanding.

If the learner reads attentively like in pair-problem solving he/she starts asking herself/himself questions like "Do I understand the question or the problem?" Teachers can do several things to help students develop metacognitive awareness; ask why and what, point out various aspects of problem solving that affect performance such as time, information given etc.; demonstrate how they can make decisions. Pair-problem solving gives people a chance of thinking aloud and it enhances their metacognitive skills.

2.3 WRITING TO LEARN SCIENCE

While pair problem solving is a step in the process of helping pupils to become successful independent problem solvers, writing becomes the next step in this development. Teachers can design writing activities for children, to help them develop critical thinking skills and also help them think about their own writing. Teachers can develop students' metacognitive strategies by asking questions about their work, questions like :

What problems are you trying to solve?

How did you go about doing that?

This makes students think about ways in which to expand and refine their ideas in written form. The metacognitive skills of reflection, careful reading, and paraphrasing to oneself can be developed in private or on paper, as well as in public in pair problem solving. Students should record on paper every thought and every step towards a solution. Teachers should not be concerned with students' grammar, sentence construction or organisation. If teachers want the pupils to concentrate on their problem solving as a process they should not be concerned with grading pupils on the correctness of their solutions. Instead, they should make written questions and comments addressing the process, such as:

Can you find the step you skipped? What happened to the unit of heat in this problem? or This problem might be clearer if you drew a diagram .

The teachers should also encourage students to write down their thoughts whenever they feel frustrated by a problem even during an examination. It is hoped that writing helps pupils make the transition from the language of symbol to the language of words. It also allows them to translate symbolic, mathematical information into the language of daily speech and thought. It is anticipated that writing with respect to problem solving would result in the following benefits for pupils:

- * They start to recognise the steps in problem solving that they often skip over.
- * They begin to value the importance of working problems systematically.
- * They begin to distinguish between what they know and what they need to learn.
- * It alerts the students to logical errors and gaps in procedure and analysis.

The process of thinking aloud and writing, along the lines described, help lay a foundation of reflective thinking on which the critical thinking, needed for problem solving --

2.4 INTEGRATING SCIENCE PROCESS SKILLS INTO THE REGULAR CURRICULUM:

The development of problem solving skills should not be seen as completely separate from other process skills. In the wider context other science process skills can also be integrated into the curriculum. Problem solving theory involves a series of steps from problem to solution. Critical thinking encompasses these steps, but it also goes beyond procedural thinking and cannot be reduced to a formula or list of steps to follow because it is also generative and creative. Critical thinking occurs when both the skills and disposition are integrated into and ultimately become intrinsic to the character of a person.

It is knowing not only how, but when to question something and knowing what kinds of questions to ask. A critical spirit is an attitude towards inquiry; a knowledge of the methods of reasoning and inquiry, and skill in applying them (Cornbleth in Walsh and Paul (undated p8).

Cornbleth as quoted by Walsh and Paul, further says "Critical thinking is a dynamic process of questioning and reasoning, of raising and pursuing questions about our own or other claims and conclusions, definitions and evidence. beliefs and actions". While critical thinking is not necessarily synonymous with all thought processes beyond memory, or problem solving, or decision making, or the scientific method, or reasoning; critical thinking skills used fair mindedly, underly overlap and complement these processes.

2.5 READING AND CRITICAL THINKING

One of the most critical stages of problem solving is to understand and represent both what is required by the problem and the relevant given information.

It follows that to be enlightened and to be able to solve problems one needs to be able to read critically or think critically while reading. This has two important consequences. The first, which has been dealt with in the previous section is that critical thinking must be developed along with problem solving. The second is that the way problems are set in tests and exercises should be such, that the pupils do not have to struggle unnecessarily with the reading.

When giving problems to pupils, the objective should be to test science rather than reading. In tests a teacher should use simple words and clearly stated concepts. Sentences should be short with familiar words.

Rakow and Steven (1987:30) maintain that, teachers who use a checklist (like the one in Appendix ((viii) p 108) to examine their own test items and those provided by test writers, can minimize the reading difficulties that may be interfering with their student's ability to demonstrate their science knowledge.

Cornbleth (in Walsh and Paul) develops this point and links it with both critical thinking and conceptual understanding. "With better readability, science tests will become more valid as measures of science literacy. Thinking critically while reading moves us from "knowledge" to 'knowing, from being "informed" to being "enlightened". It is thus true that developing problem solving skills without an adequate conceptual understanding is not enough to develop problem solving to its fullest extent". In questioning the traditional reliance of schools on a one right answer model of learning, the critical thinking movement is not denigrating the importance of knowledge in learning. Much of our essential knowledge is in large part "conceptual". By asking and discussing questions which encourage critical thinking, the student develops a deeper understanding of the concept and will begin to gain more and more skill in use of the concept. The acquisition of knowledge, a clear understanding of it and the skill to use it can be described as a person's knowledge base.

2.6 COMMENTS ABOUT THE KNOWLEDGE BASE

Problem solving in a science, such as physics, cannot be achieved without a considerable amount of knowledge. The knowledge base for any particular domain (such as mechanics) is the specialised knowledge required for solv-

ing problems in this domain . The knowledge base should have characteristics which facilitate the performance of specified kinds of tasks by specified kinds of person. If the knowledge base is to be functionally useful, it must be well adapted to the intended tasks to perform them.

The knowledge base should have the following characteristics:

- i) It should specify the entities of interest in the domain, the concept useful for their description, and the principles relating such concepts.
- ii) Concepts or principles should be accompanied by explicit knowledge and explicit procedures specifying when the concept or principle should be used.
- iii) It should be organised in such a way that it can be easily remembered and that the information in it can be selectively retrieved (so as to facilitate the decisions needed in searching for problem solutions).

A study conducted by Camacho and Good (1989:265) had some important implications for the knowledge base. The purpose of the study was to observe how problem solving performance is affected by conceptual knowledge of related chemistry concepts, principles and related mathematical skills. The technique used was the think aloud method adapted from the book by Whimbey and Lochhead (1982). The results found from this study showed that the lack of mathematical skills

was a hindrance for problem solving success. The unsuccessful subjects also showed inability in translating English language into chemical symbolic language; lacked needed basic knowledge; frequently invoked formulae; and had many guessing behaviours.

There are some probable errors which the teacher may encounter with students who are unable to solve problems. Some of these are not easy to discover and are not easily detectable. The concept acceleration is likely to be confused with the different and less precisely defined concept acceleration used in daily life because both of these concepts are denoted by the same word. Students also commonly confuse the concepts velocity and acceleration because both of them describe motion, although different features of the motion.

The following points can help to predict many of the errors commonly committed by the students if one examines the demands imposed by the procedures specifying the concept and taking into account the student's pre-existing knowledge. These are:

- * confusion with other concepts denoted by a similar symbol (including confusion with terminology used in everyday life.)

- * Confusion with other concepts describing different features of the same situation.

- * Error in applicability conditions in specification of values, example missing or wrong elements.
- * Error in specification of independent variables leading to ambiguities and confusion.
- * Error in specifying procedure.

The implications of these errors and the confusions are that teachers should be aware of the fact that the most common method of teaching problem solving in physics or other sciences relies predominantly on providing students with examples of problem solutions and with practice in solving related problems.

Ridgeway (1988:70) maintains that teachers should consider students' misconceptions because "students' misconceptions are often so well established that unless teachers identify and correct them before instruction and experimentation begin, the misconception can prove impossible to dislodge". This suggests that teachers would do well to check students' perceptions periodically, perhaps by requiring sketches to accompany solutions to homework or test problems. Misconceptions are "sign posts" that direct teachers and students toward problem areas, which they can then confront directly. They can be used as instructional aids. When a teacher presents a misconception that is troublesome for students, she/he forces them to test their conception against paradox and against their commonsense. They are usually discovered when students have the oppor-

tunity to present them to an attentive teacher, and the pair-problem solving classroom is an environment well suited for such dialogue.

By listening to students who are actively engaged in conceptual problem solving, the teacher can find instructional material for years to come.

2.7 THE ROLE OF LANGUAGE IN SCIENCE LEARNING FOR MATRICULANTS IN KWA-ZULU SCHOOLS

The situation in the schools, in which the research was done, is such that pupils have a language problem, because the medium of instruction is English, whereas at home and when they interact with others they speak Zulu. It is therefore necessary to look at the role of language in science learning .

2.7.1 ENGLISH AS A MEDIUM OF INSTRUCTION

[Early Christian Missionary Teachers who worked among the indigenous people in South Africa were mainly English speakers and therefore could not but use their language in their schools. Education as understood by these early teachers meant knowing and accepting things and ideas belonging to the western world or interpreting and evaluat-

ing things and ideas belonging to Africa from a western perspective. To achieve all these things the main language of instruction and westernization generally had to be English.]

2.7.2 PROBLEMS OF USING ENGLISH AS A MEDIUM OF INSTRUCTION

[Not all teachers are sufficiently articulate in English to be able to use it as a medium of instruction. The situation in schools is such that all subjects have to be taught in English yet the teachers themselves are not familiar with the language. The result is that there is little communication between the pupils and the teachers. The environment in which the children live is not supportive of English as a medium of instruction. Many pupils are not at home with English. Where they live, they speak Zulu, Xhosa, Sotho etc. with parents, peers and with all other people. At school they also speak Zulu, Xhosa, Sotho etc. with their classmates and with their teachers. The only time the pupils speak English is when a teacher asks a question during a lesson and they have to answer. This creates a problem because these children have to try and understand what they are being taught and what they read from their books which are written in English. The problem begins when the child has to understand English and writes in English. The researcher and her colleagues at school tried to minimize the language problem by forcing all pupils to speak English whenever they were inside the school

premises. The prefects were there to see to it that every pupil at school spoke English. An appeal was also made to teachers to encourage and motivate pupils to speak English. This was found to be helpful in that the pupils got used to speaking English among themselves and with teachers.]

2.7.3 LANGUAGE ACROSS THE CURRICULUM:

Lawrence Stenhouse (1985:37) describes a curriculum as "the means by which the experience of attempting to put an educational proposal into practice is made publicly available. It involves both content and method, and in its widest application takes account of the problem of implementation in the institutions of the educational system". Language across the curriculum is the teacher's regular concern with an active attention to the forms, meanings and sounds of learning. Such concern extends to the teacher's responsibility to ensure that learners understand and see effectively and appropriately the specific forms, meanings and sounds of the language of the subjects taught, to enable the use of the language beyond the classroom, in informal social contexts.

[High failure rates in standard 10, particularly, point to the lack of adequate preparation of matriculants. Such inadequacy is often rooted in language incompetence, the cause of which cannot be found in the English subject classroom alone, but across the curriculum in every subject

taught through English as a medium. Although particular references have not been found to support this contention, extensive personal experience and observation of learning and teaching situations support this view.]

Communication presupposes, primarily the use of a common language or code. There is thus a greater concern about language, for if curriculum is a form of communication, it must be articulated in language use. Language across the curriculum can hardly begin to work in a teacher-dominated classroom, where there is no opportunity for individualisation and group work. These two approaches have as one of their objects the exploration and negotiation of meanings in the language.

2.7.4 LANGUAGE AND SOCIETY:

[A study of language totally without reference to its social context inevitably leads to omission of some of the more complex and interesting aspects of language and to the loss of opportunities for further theoretical progress. With Black children the language of communication at home is different from the language of instruction at school. To these children a second language is a definite handicap and it has a permanent negative effect on intellectual development because there's a direct relationship between language competence and formal education. They often must think in one language and speak in another with the result that they become mentally uncertain and confused. Language, therefore, varies not only according to the social characteristics of the speaker, but also according to the social context in which he/she finds him/herself.]

2.7.5 LANGUAGE IN PAIR-PROBLEM SOLVING:

When children are solving problems they often have language problems. These children have to read the problem which is written in English and try to understand it. Thereafter they have to answer the question in English. Whenever they are thinking aloud they have to do so in English. So English does, to an extent, affect the performance of a problem solver, because the children in school are taught in English and Zulu yet they speak Zulu at home and, with their teacher and their classmates. This makes it difficult for children to interact with anyone in English. Pair-problem solving gives a chance of practising English. In pair-problem solving the use of English tends to improve the children's competence in the language but the correctness of the English used is not emphasised in order to avoid destroying the children's confidence.

The researcher at one stage did a project with standard 8 pupils which involved a similar use of language to that in pair problem solving. She took them for two periods a week for one month and taught them the concept of heat. Pupils were to improvise materials to be used for experimentation. Pupils were also encouraged to speak English among themselves throughout the period. It was found that students understood the concept of heat better when using improvised materials and most of all their English usage improved. The use of words like hot, temperature, heat etc. became better because they now had a better understanding of the meaning of the words and the difference in meaning

between them. This showed that encouraging pupils to speak English among themselves while working on a common meaningful task increases both the level of understanding of some concepts and the ability to use English.

2.8 SUMMARY

This chapter has dealt basically with some aspects of science learning. These are analysed as follows.

Metacognition is a controlling process which provides a learning framework in terms of thought and awareness. Pair problem solving accompanied by appropriate writing develops metacognition in relation to problem solving.

Critical thinking is an underlying and overlapping process which is essential for top class problem solving by linking it to other process skills. Critical thinking while reading is needed for the solution of problems because of the need to understand the problem clearly.

An adequate knowledge base which includes facts, concepts and principles, is a prerequisite for good problem solving. It is, however, in part built up by solving problems.

The use of English as a medium of instruction poses some language problems because it is a foreign language to the

teachers and pupils in Kwa-Zulu schools. The main value of pair problem solving seems to lie in the provision of the framework within which pupils can develop their own problem solving ability and/or be helped to do so while using and practising English as a medium of communication.

2.9 A CLOSING THOUGHT ON CHILDREN'S LEARNING

In concluding this chapter it is important that some assumptions about children, learning and knowledge are briefly discussed.

Children have both the competence and the right to make significant decisions concerning their own learning. They are likely to learn if given a choice in the selection of the materials they are supposed to use. When two or more children are interested in exploring the same problem or the same materials they will often choose to collaborate in some way. Children learn and develop intellectually not only at their own rate but also in their own style. (There is an individual pattern of growth for all living things). Children pass through similar stages of intellectual development... each in their own way, and at their own rate and in their own time. These assumptions suggest that the total separation of one curriculum into separate disciplines will inhibit learning. The particular key which opens a new door for a particular child is not predictable and may be missed by this fragmentation.

APPROACHING PROBLEM SOLVING

3.1 THEORY ON PROBLEM SOLVING

Polya in Gil-Perez (1990:139) argues that "solving a problem consists of finding a way which was not previously known, finding a way out of a difficult situation, to get round an obstacle, to reach an aim which can not be immediately reached by adequate means". The original development of the program of pair problem-solving was based only on careful observation of student problem-solving behaviour and on a long period of trial and error in the USA. This program acts as an aid to curriculum development rather than as a barrier to experimentation. Education, like engineering, needs to remain an empirically based science in which the advice of theorists is treated with scepticism. Whimbey and Lochhead (1982) argue that the ability to analyse complex material and solve problems is a skill just like any other skill such as the ability to play chess or the ability to drive an automobile. However, there is a peculiar difficulty involved in teaching analytical skill. Generally there are two phases to teaching a skill. First the skill is demonstrated to the student. He is then guided and corrected as he practices it. Analysing complex material is an activity which is generally done inside one's head. This makes it somewhat difficult for a teacher to teach and for a learner to learn. In other words, a beginner cannot observe how an expert thinks and solves problems. On the other hand an expert has trouble in demonstrating his technique to a begin-

ning student. There is one way to reduce this difficulty, that is to have people think aloud while they solve problems. If both students and experts vocalise their thoughts as they work through complex ideas and relationships, the steps that they take can be open to view.

The eventual objective of pair problem-solving is to get each student to be at all times both a listener and a problem solver. Thus when working on a problem the student should be able to listen to himself think, follow a chain of reasoning, and recognise some errors. When listening to a teacher, a student should act as a problem solver, thinking along with the teacher, puzzling out the issues and organising the materials. One can conceptualise this objective as the development of a self-correcting feedback loop in which students can observe and modify their own cognitive behaviour (Whimbey and Lochhead, 1982)

3.2 DEFINITION OF A PROBLEM AND ITS ROLE

3.2.1 DEFINITION OF A PROBLEM

["A problem is a situation presenting difficulties for which no obvious solution exist" (Polya, in Gil-Perez 1990:138).] When children are faced with providing a solution to a task they have not yet mastered, they are solving a problem (Reif in Gil-Perez 1990:138). [Krulik and Rudnick's definition (in Gil-Perez 1990:139) indicates consensus, "A problem is a situation, either quantitative or not, which demands a solution, to get round an obstacle, to reach an aim which cannot be immediately reached by adequate means."]

3.2.2 THE ROLE OF A PROBLEM

A well-formulated problem not only defines the range of permissible solutions, but also suggests the manner in which one pursues an inquiry. It often seems that the more clearly one formulates a problem, the more definite are the methods for solving that problem. "Any problem is formulated in terms of concepts embedded within a general conceptual system. This is true no matter how more or less clearly the problem is formulated; how more or less developed is the general conceptual system and theories. This system - by stating what sorts of things exist, what sort of properties and relations they may have, and how all this is related to what we observe - will also indicate "reasonable" methods for solving problems that arise. Obviously, the more explicit the conceptual system, the clearer can be the statement of the problem" (Freundlich, 1978:20). Suppose a student is requested to discover characteristics of a force between electrically charged bodies. This particular student has no clear conception of what force is. He then flounders and finds it difficult to solve the problem for he does not know what he is looking for.

Random or inappropriate problem-solving indicates an undeveloped conceptual system. This again shows that "the problem may point up the inadequacy of a conceptual system, forcing its replacement by a new system which may solve the problem. Thus a problem is a means of bringing about conceptual change" (Freundlich, 1978:20). The problem itself indicates reasonable methods for obtaining solutions. It is also important to note that a problem makes vague concepts more precise. The roles of a problem discussed above have some implications for classrooms.

i) A teacher needs to formulate problems within the students' conceptual systems but problems should show up the inadequacies of those systems so as to bring about conceptual change within students.

(ii) A teacher should present problems which allow him to test for conceptual change in the student by viewing the student's problem-solving procedures, that is, the kinds of questions the student asks himself and the information he takes to be relevant in solving the problem.

3.3 HOW CAN PROBLEM SOLVING BE EVALUATED

The evaluation of problem solving should be based on goals and should be done as one proceeds with the teaching - learning process. There are various ways one can use to evaluate problem-solving, some of them according to Walsh and Paul (undated) are;

- i) observation - here the teacher ascertains what the child actually does, that is, he/she observes the students' behaviours.
- ii) interviews - the teacher can use tapes so that the pupils may rewind them and listen to themselves solving problems.
- (iii) checklists - these serve as means of collecting and recording information quickly; they also help the teacher to refer to some points for consideration.
- (iv) paper-and-pencil tests help to evaluate the pupil in terms of individual achievement.
- (v) pair problem-solving as a means of self-evaluation and metacognition. In this study pair problem-solving is researched and is thus discussed in detail.

3.4 PAIR PROBLEM-SOLVING

Pair problem-solving, maintains Whimbey and Lochhead (1982), is a technique of helping students solve problems. It is an instructional aid where pupils who are working in pairs, have one acting as a problem solver and one as a listener. The problem solver solves a problem aloud while the listener listens to the solver and where necessary asks probing questions which do not lead directly to an answer. Asking pupils to express their thoughts aloud while they engage in problem-solving, externalises the thinking process, and gives the problem solver, as well as the listener, feedback on what is understood and what is still vaguely processed. This self-monitoring of one's thought processes is a higher order thinking skill referred to as 'metacognition'.

The anticipated advantages to pair problem-solving are that it would:

- * help pupils work through problems systematically, rather than jumping ahead and making guesses that have not been thought through.
- * help pupils find out which parts of a problem they understand - and where they get stuck.
- * provide pupils with an opportunity to change their

misconceptions.

- * make the problem more engaging
- * encourage the development of metacognitive skills
- * teach communication skills
- * expose teachers and pupils to various points of view and solution approaches
- * encourage the formation of study groups and a willingness to support each other.
- * foster co-operation as a social value as well as a classroom aid.

It is important to note that the use of the think-aloud interview and its principal product of real problem-solving performances allow the development of qualitative as well as quantitative criteria for determining the individual degree of success. The comparison of these criteria with qualitative problem-solving differences between students provides additional credibility for the think-aloud technique (Camacho and Good, 1989:265).

3.5 ROLES IN PAIR PROBLEM-SOLVING

3.5.1 The role of a problem solver.

The problem-solver is the one who is to solve a problem at hand. He/She first reads the problem aloud so that the listener can hear what he/she is reading. Thereafter

he/she should tell the listener what he/she sees the problem to be, that is, he/she should state what is wanted and how he is going to solve it. As he solves the problem he should verbalise each step thought of and write that down. All the steps should be written down on paper to make it possible for the listener to follow the solvers' thinking. When the problem solver thinks he has finished he tells the listener. If the listener has no further questions the roles change.

3.5.2 The role of the listener.

The listener's role is to listen to what the solver is saying and then ask questions. The listener should not help the solver in any way but should ask probing questions and ask for explanations where necessary. The questions should not lead to an answer but should be questions like "Why do you say that?" "By saying X what did you mean ?..." etc. Whenever the solver keeps quiet or stops thinking aloud the listener should ask him to think aloud so as to explain each step he is taking. The listener should always insist that the solver writes every step down on a paper.

3.5.3 The role of the teacher/facilitator

Pair problem-solving requires supervision. Teachers should move from pair to pair because students may work separately and compare answers. When students do this it

'short circuits' the metacognition involved in describing the solution process. Student pairs should be rotated throughout the term because working with a variety of partners allows for more diversity of thought and a more cohesive classroom. The listener should occasionally be asked to summarise the steps of the solver's solution to a third person to ensure that he has been listening.

For critical thinking to occur, students must feel free to make errors publicly. The essence of good problem-solving is self-correction. Teachers should avoid supplying answers to students or insist that certain strategies be employed in the solution of a problem. They should become facilitators of learning not sole dispensers of truth.

3.6 EDUCATIONAL IMPLICATIONS

Teachers should explicitly teach students the ancillary knowledge required to interpret scientific concepts and principles properly. Teachers should also teach them how to organise their entire knowledge in useful hierarchical form and ensure that they learn to integrate separate intellectual components so that they can use them jointly for problem-solving tasks.

Finally, students should be taught how to monitor their own problem-solving activities, as in pair problem-solving, so that they may solve problems more successfully.

CHAPTER 4
METHODOLOGY AND ACTION

4.1 SAMPLING

The researcher made use of available nearby schools in which physical science is taught. These schools are all in the Newcastle area. One is an aided catholic school, while the other two are Kwa-Zulu state schools. The pupils in both the control and experimental groups were selected at random from the standard 10 physical science classes. They were not selected according to their intellectual ability or other factors which could be expected to affect their problem solving performance.

The experimental group in School 1 was chosen on the basis of where the pupils sat, e.g. at the front or at the back of a classroom. In Schools 2 and 3 each science class was used as an experimental group. The control group comprised the rest of the standard ten Physical Science pupils in School 1 who were not in the experimental group for that school.

The number of pupils in School 1 who formed the experimental group were 14 and those who formed the control group were 11. In School 2 and 3 the pupils who formed the experimental group were 20 and 12 respectively. A total of 46 pupils

formed the experimental group whereas 11 formed the control group. The total number of pupils in this research was 57. Pupils mostly sit next to friends or people with whom they feel comfortable. This seating was not disturbed in the experimental groups. Later on when the pupils got used to the new method of problem-solving, pairs were changed to allow for more interaction with others.

The three schools used in the research, varied in many but not all aspects. It is worth noting what those variations were.

The differences and similarities in these schools are:

School 1 no laboratory; no library; about sixty percent qualified teachers; the teacher-pupil ratio is about 1:80.

School 2 has most of the necessary educational materials, science and biology laboratory; library; video rooms; photocopying machine etc. More than half of the teachers are

qualified, that is, have matric, a teaching certificate and / or a degree - the teacher-pupil ratio is about 1:32

School 3 no laboratory; no library; no standard physical structures exist in the school, that is, all buildings have been adapted for school use; less than half of the teachers are qualified. The teacher-pupil ratio is about 1:60]

4.2 [SELECTION OF PUPILS

The communities from whom these children are drawn are at different levels of Westernization. Some children are from rural areas, some from white farms and some from metropolitan areas like Johannesburg. The different degrees of Westernization might have an impact on the performance of the children. This may be because some pupils are more exposed to a variety of objects than others. For example, pupils who live in Johannesburg are more exposed to television than pupils whose homes are in rural areas. The similarity among the pupils in a school is that they have the same formal conceptual background. They have been subjected to the same educational methods and concepts because they all attended the same school in the same class and have been taught by the same teachers.]

4.3 METHOD OF IMPLEMENTATION

4.3.1 TESTING

A test was designed in order to test the abilities of pupils to solve science problems and to find out how much knowledge they have about the concepts involved. It was then decided that this test be given at the beginning and at the end of the research. The test was then divided into two parts. The odd questions were written at the beginning as a pre-test. The even questions were written at the end as a post-test. These tests were based on Newton's Laws, momentum and on work, energy and power. (see appendices (i) and (ii) p 76 and p 81).

Before they wrote a pre-test a revision of basic concepts on the relevant sections was done for all four groups. The pre-test was given before the beginning of the interviews whilst the post-test was given after the interviews. The testing was carried out such that the odd questions were given as a pre-test and the even questions were given as a post-test. The odd and the even questions were designed to be of equal difficulty and involving similar background knowledge (appendix (iii) p 85). Both tests were written for forty five minutes. Pupils were given the following

instructions: i) they had to show all their working and
ii) they had to give drawings or pictures as far as possible.

4.3.2 INTERVIEWS

The interviews were conducted in such a way that two pupils interviewed each other. One pupil became a problem-solver and the other pupil became a listener (see 3.3.2). The teachers were observers. Problems solved were based on the work that the pupils did or were taught. It became a revision to them with the advantage of using a different or a 'new' method.

4.4 HOW THE RESEARCH WAS CARRIED OUT

The researcher visited the selected schools as originally planned. The principals of these schools welcomed the idea of research on pair problem-solving. During the first visit, pupils at each school were addressed by the researcher and were told that the problem-solving programme was done as at the University of Massachusetts. Pupils were also told that they would write a pre-test and a post-test on the concepts of momentum, work, energy, power and on Newton's Laws. These were chosen because they are the topics covered in the first three chapters of the standard ten textbook, which meant the pupils would all have learnt those chapters by the time the research started.

Between the first and second visit each teacher revised the basic concepts of the three sections with the pupils. The

revision of the concepts was based on question and answer method with some explanations where necessary from the teacher. During the second visit all pupils were given the pre-test which they wrote during one period, that is for forty five minutes. After the test the experimental groups were given hand-outs on how the interviews were to be conducted and on questions which could be asked by a listener. This was to prepare them for the process of pair problem-solving. Selection of the problem solving pairs was done at random, but mostly friends formed pairs whereas other pairs were formed on the basis of where the pupils sat.

The process of pair problem solving was explained to the experimental group pupils thus:

* Pupils are to work in pairs. The pairs are to consist of the problem solver and the listener. The problem solver is the one who solves the problem and the listener listens attentively to the problem solver. The problem solver must explain each and every step to the listener. On the other hand the listener should ask probing questions like: 'Why do you say that?', 'What do you intend doing with that number?' etc.

* The pairs are not supposed to help each other. Pupils should use diagrams, drawings and pictures to represent

their thoughts as far as possible. Each step is to be written on its own line in a downward order so that one could follow his/her thinking and be able to analyse the drawing given in relation to the steps written.

The roles are to be changed as soon as the person thinks he/she has exhausted his/ her thinking or if a person got stuck and cannot solve the problem any further.

The researcher and the accompanying teacher thereafter demonstrated the process of problem-solving. After this pupils were given a chance of practising what they had observed.

All pupils were given the same problems to solve, that is, both the experimental and the control groups. The control group was told to use any kind of method they might prefer, whether in groups or individually. The experimental group was given instructions on how to operate and observed while they worked. Both groups were reminded that the medium of instruction is English, so they should speak English throughout the process.

The problems to be solved were taken from study aids (Physical Science standard nine and ten), Matric Preparatory Programme (Shell Maths and Science standard

ten), and from PROBLEM-SOLVING AND COMPREHENSION by Lochhead (1982). Some problems involved the use of numbers and formulae, while others were of different kind (see appendix (vi) p 92). The implementation of this interview process required revision and adaptation as the pupils progressed because it had to take into account varying classroom personalities, sizes and ability levels.

During the subsequent two visits, pupils in the experimental group solved problems using the process of pair problem-solving. The control group was given the same questions as the experimental group, but were not directed or observed. The researcher made it a point that the control group was solving the problems given to them, not studying anything else during that period. During the next two visits pairs were changed to enable pupils to interact with other pupils in the classroom. This was done to make them more aware of how different pupils solve their problems.

Tape recordings were made using a cassette tape recorder. This was done with the experimental group only. The emphasis was put again on speaking and writing English. Pupils were left alone as pairs so that they could be free when speaking English, because usually pupils avoid speaking English during the presence of their teachers. Pairs of pupils were recorded one at a time in a different

classroom so as to avoid disturbing the other pairs of pupils (see appendix (vii) p 97). Problems solved during the recording sessions were the same for other problem solving pairs so that the recordings were not affected by the work of other pupils. Giving pupils the same questions, also allowed the researcher to investigate whether the errors which pupils make are peculiar to some individuals or are common to almost all of the experimental group.

During the last visit but one, all pupils were given a post-test based on the same concepts and having the same level of difficulty as those of the first test.

On the last visit, the researcher and the teacher observer, together with the pupils, discussed the problems which had been solved during the interviews and the tests, which had been written. Pupils were given their test marks and a chance to comment on them. Both the experimental and the control groups came together for discussions, which were provided to help determine how much the pupils had benefited from the process of pair problem solving.

The three teachers who were involved in this project were teachers of mathematics and physical science in the three schools involved. Their qualifications vary in this way:

[The teacher from School 1 had a matric certificate and a teachers diploma. He has been a teacher for nine years. The teacher from School 2 had a degree in education and had taught for three years. The teacher from School 3 had a standard ten certificate with no teaching experience.] The teachers were not given the tests (to be written by pupils) before they were written by the pupils. This was done purposely to avoid the temptation of giving clues to pupils by the teachers.

4.5 ANALYSIS OF TESTS AND TEST SCORES

The purpose of analysing the test questions (see appendices (iii) and (iv) p 85 and p 87), is to show that the questions given to students were equivalent, that is, they were of equal difficulty. This also shows that the pre-test and the post-test were based on the same concepts. This was done to give validity to the test scores. The test scores (Appendix (ix) p 99) were converted into percentages for processing. They were used in calculating the standard deviations, the means, the t-tests (Tables 1 and Table 2 p 46) and the level of significance of the results found. It is hoped that the scores give a clear picture of whether the new method did improve the pupils' abilities in solving problems or not.

TABLE 1

MEANS AND STANDARD DEVIATIONS OF TESTS 1 AND 2

EXPERIMENTAL GROUP

SCHOOL	NO: IN A GROUP	MEAN X		STANDARD DEVIATION	
		TEST 1	TEST 2	TEST 1	TEST 2
1	14	38,3	59,7	16,62	15,65
2	20	39,4	60,2	11,2	14,74
3	12	40,7	61,1	16,03	10,26
CONTROL GROUP					
1	11	43,4	37,2	14,78	12,84

TABLE 2

T - TEST VALUES CALCULATED FROM TEST SCORES

EXPERIMENTAL GROUP

SCHOOL	DEGREE OF FREEDOM	VALUE OBTAINED	VALUE GIVEN	LEVEL OF SIGNIFICANCE
1	13	6,15*	3,012	0,01
2	19	5,46*	2,861	0,01
3	11	4,42*	3,106	0,01
CONTROL GROUP				
1	10	-3,14	3,169	0,01

* P < 0,01

CHAPTER 5
WHAT CAME OUT OF THE RESEARCH

5.1 INTRODUCTION

The result of this study are presented in terms of three major aspects of differential performance observed. The examples and evidence given are taken from both the pre-test and the post-test. The rationale behind the use of both tests is that, despite significant improvements from the pre-test to the post-test, for the experimental group, differential performance occurs in both tests. The observed aspects were:

- * Quantitative degree of problem-solving success of subjects
- * Specific knowledge about the concepts involved including mathematical skills.
- * General problem-solving characteristics

In this chapter, the aspects of differential performance, irrespective of the teaching done, are dealt with first. It is important to realise that a single procedure cannot change the total problem solving picture in a class of pupils. The overall picture of differential performance is therefore needed to understand the changes that took place among the groups in the research. The specific changes that occurred in the experimental groups, compared to the control group, are then examined and conclusions are drawn.

The specific changes that occurred in the experimental groups, compared to the control group, are then examined and conclusions are drawn.

5.2 QUANTITATIVE DEGREE OF PROBLEM-SOLVING SUCCESS OF SUBJECTS

This was based on the number of correct answers to all the questions given. When only part of the question/problem was solved, partial credit was assigned. A score of 4 was assigned for a completely correct answer.

For instance one subject (Beauty) of School 1 got one mark for question 13 because she wrote, $a = f/m = f/100 = 0$. She used the correct formula with the wrong figures. A total score was assigned if proper solutions were provided.

No mark was given to a student who got the question completely wrong or who did not attempt to solve a problem or who just guessed answers, like one subject (Phyll) of School 3, who just wrote A as an answer for question eight in the pre-test.

Below is a summary of the kind of difficulty posed by problems for the subjects . The persistence of some of the difficulties are shown by the existence of problems which proved to be difficult to most students in the post-test. Two examples of difficulties with post-test questions are: Most pupils did not attempt to solve problem number 11. A few approached its solution randomly.

For example : one subject wrote

$$\begin{aligned} F + F &= 4abN + 2abN \\ &= 6abN \end{aligned}$$

another one wrote

$$F = F$$

In number 13, subjects used a formula for Newton's Second Law of motion instead of also applying the system of pulleys.

For example : Answers given here were

$$a = 200/20 = 10$$

$$a = 400/40 = 10.$$

The subjects did not show where they got 400 and 200. It is most likely that they used the formula

$$F = ma$$

$$F = 30\text{kg} \times 10 = 300\text{N} \quad \text{and}$$

$$F = 10\text{kg} \times 10 = 100\text{N}$$

Somehow they either added the two answers to get 400 or subtracted to get 200

5.3 DIFFICULTIES WITH SCIENTIFIC KNOWLEDGE AND MATHEMATICAL SKILL

Probably the major problem solving differences observed were those related to the amount and quality of specific content knowledge expressed and applied by each subject. These relevant knowledge differences between unsuccessful and successful subjects are described in terms of a large number of misconceptions and knowledge gaps observed with respect to kinetics, Newton's Laws and mathematical skills.

For example:

Problem (no: 3) Post-test

- i) Generally students failed to conceptualise the problem adequately.
- ii) There was no confidence in solving this problem. Students wrote:

$$v = m/f = 5/20 = 0,25$$
$$p = 4 \times V_{ms} = 4V$$

Here it is not shown where they got 5 and 20

Problem (no: 5)

- i) Some students seemed not to understand the concept of (p) momentum. As a result guessing was used.
- ii) They used the formula $1/2 mv^2$ which is not for momentum but for energy. Students wrote:

$$\text{Momentum of both is } 1/2mv^2 = 1/2mv^2$$

The way the pupils answered some of the questions showed that a lack of basic science knowledge and mathematical skills hinders problem solving. Examples of this are :

(i) subject 2 in figure 2 below could not convert minutes into seconds. This indicates a technical difficulty.

(iii) other subjects, like in figure 1 demonstrated a lack of basic mathematical ability indicated by, for example, inability to deal properly with fractions

figure 1

40km /h ----->> car
 10km/h ----->> a plane
 40km/h----->> 10km/min x h
 X----->> 450km
 1800km = X 10km. 0,017
 40km = 10km . 0,017
 X 450km
 0,017km X = 1800km
 0,17km 0,17km
 X = 105,8 x 10km

figure 2

A - 40km m
 = 40km 60s
 B = 10km in 1min 60s
 = 10km in 60s
 A = n = 4km x 1h
 10km x 60s
 = 4km (12 x 60s)
 = 600
 = 4km x 720
 600
 4,8km for A

5.4 GENERAL PROBLEM-SOLVING CHARACTERISTICS OF PUPILS

The results found from this study showed that there was a great difference in behaviour between the pupils who were better problem solvers and those who were not. The pupils who had poor ability in solving problems showed the following:

- i) Poor translation of the English language into mathematical symbolic language. In figure 3 below, one subject had some difficulty in putting words into symbols. He wrote 3. R100 for the sentence; R100 less than triple John's weekly income.

Figure 3

Jim's weekly income R100 = John's weekly
income 3 R100 = 300 .

Hueys' weekly income 2. R300 + R20 = R620

Jim's weekly income - Hueys' weekly income
= 120/6 - 20 = R120

- ii) Many guessing behaviours (Fig 4). This subject also had some conceptual difficulties showed by saying that the difference in time is always two minutes. Here again he was guessing because there is no evidence of him trying to solve the problem systematically.

Figure 4

Clock A keeps the perfect time

Clock B is running faster

Clock -----> 6min

Clock-----> 8min faster by 2min

Clock B-----> 56 min

Clock A-----> 54 min

54 min have passed

- iii) Lack of basic knowledge (Fig 4 above). The error here is systematic in most pupils who take it that if A is 6 minutes and B is 8 minutes fast, it follows that if B is 56 minutes fast then A must be 54 minutes fast.

Pupils who were able to solve the problems better, like for instance the pupil in figure 5 below, showed the following.

- Systematic way of solving problems
- Coped with proportions easily
- Better understanding of the problem
- They read the whole problem and then restated the problem in their own scientific language.

Figure 5 (no 3 in post-test)

Let the mass of B be x therefore of A be $4x$

Data is $M_A = 4x$ $M_B = x$

$V_B = Mms$

$-V = ?$ (moves in opposite direction)

Solution: $M_A V_A + M_B V_B = M_{AB} V_{AB}$

$$\begin{aligned}
 4x (-V_a) + x V_{ms} &= 0 \text{ (MabVab stationary)} \\
 -V_a &= - \frac{x V_{ms}}{4x} \\
 &= - \frac{V_{ms}}{4} \\
 V_a &= 1/4 V_{ms}
 \end{aligned}$$

On the other hand most pupils in the control group found difficulty in solving problems because they solved problems randomly, worked individually and in small groups and also tried to use known formulae like in the following example.

Figure 6 (no 3 in post-test)

$$v = m/f = 5/20 = 0,25$$

$$P = 4 \times V_{ms} = 4v.$$

From this example there is evidence of failure to conceptualize the problem adequately. There was also no confidence in solving this problem. More of the problems solved by both groups are in appendix (x) (p 101).

5.5 HYPOTHESIS TESTING.

Pupils have a tendency to skip steps in reasoning and miss facts when drawing conclusions. Seeing that this poses a problem, it was thought that vocalising thinking would ensure that pupils do not skip steps in their reasoning nor miss facts in drawing conclusions, but improve their ability to solve problems by solving doing so systematically, step-by-step.

People involved in the research were standard ten pupils and some teachers. Materials used were the standard ten revision book, standard nine and ten textbooks and a book written by Whimbey and Lochhead - "Problem-Solving and Comprehension 1982".

For this study a statistical test was used for testing, that is, accepting or rejecting the null hypothesis at the 0,01 level of significance.

The scores used were taken from the tests written by pupils. There were significant changes in the scores from those of the pre-test to those of the post-test with the experimental groups. In Appendix ((ix) p 99) the size of the increase is shown by the average percentage found. There are various reasons for that. Some reasons may be:

- * the pupils in the experimental group were introduced to a different approach and observed, whereas those in the control group were not.

- * the use of this process by the experimental group made them develop a sense of independence which led them to exercise responsibility for their own learning.

From Table 2 (p57) the t-value for $df = 13$ (degree of freedom for School 1 Exp.group), is 3,012 but the value obtained for $t.(6,15)$ is greater than this. Again the obtained t-values for $df=19$ for School 2 and $df=11$ for School 3 are 5,46 and 4,42 respectively. These values are greater than the given value of $df=19$ (2,861) and $df=11$ (3,106). The difference between the mean scores is accepted as significant at the 0,01 level or better. For the control group the obtained value for $df=10$ is -3,14 which is less than the given value of 3,169.

It is, therefore, reasonable to attribute the increase in mean scores to the effect of the method used. The hypothesis is accepted and the null hypothesis is rejected. The differences between pre- and post-testing are significant in schools 1, 2 and 3. The method used was effective in the three groups as opposed to the method for the control group in school 1.

TABLE 2

T - TEST VALUES CALCULATED FROM TEST SCORES

EXPERIMENTAL GROUP

SCHOOL	DEGREE OF FREEDOM	VALUE OBTAINED	VALUE GIVEN	LEVEL OF SIGNIFICANCE
1	13	6,15*	3,012	0,01
2	19	5,46*	2,861	0,01
3	11	4,42*	3,106	0,01
CONTROL GROUP				
1	10	-3,14	3,169	0,01

* P < 0,01

TABLE 1

MEANS AND STANDARD DEVIATIONS OF TESTS 1 AND 2

EXPERIMENTAL GROUP

SCHOOL	NO: IN A GROUP	MEAN X		STANDARD DEVIATION	
		TEST 1	TEST 2	TEST 1	TEST 2
1	14	38,3	59,7	16,62	15,65
2	20	39,4	60,2	11,2	14,74
3	12	40,7	61,1	16,03	10,26
CONTROL GROUP					
1	11	43,4	37,2	14,78	12,84

Tape recording - interpretation

In the analysis of the tape and in further observation of the classes using the pair problem solving procedures, it was readily apparent that many of the pupils find the role of the listener the most difficult to fill. Their eagerness to participate in the process of solving a given problem is clearly audible on the tape and can usually be detected in the classroom where the process has been implemented. In both the taped session and in other classroom implementations, the researcher found that girls tend to restrain their enthusiasm and speak more quietly than boys. While this makes for less vital taping, it definitely contributes to a lower volume of sound in the classroom where the process is taking place.

The researcher also discovered that at some stage the pupil in group 2 said "40km" and wrote down 4km. Another one said "R100 less than triple Johns' weekly income" yet wrote Johns' weekly income 3. R100. On the other hand one pupil in group 3 showed facial and verbal lack of interest in solving the problem. She said "This problem is difficult, and I am tired now". Her problem was that she tried to use the formula when it was not needed.

From the written work, the post-tests, direct observation and the tapes it was clear that the pupils in the experimental group showed the characteristics of better problem solvers (Table 3 p 64) than pupils in the control group.

On the whole the researcher found the experiment exciting and the tape a true representation of the enthusiasm the pupils are displaying as they discover the excitement possible in pursuing the solution.

5.6 DISCUSSION AND CONCLUSION

The observations and results of this study have several implications for

- (i) a theory of problem solving and the
- (ii) utility of the think-aloud technique to observe problem-solving behaviours.

5.6.1 Development of Problem-solving Theory

Research into problem-solving skills in scientific domains, as argued by Camacho and Good, (1989:267), points toward the need for a holistic theory in which those problem-solving performance characteristics can be accounted for. Presumably the following observations about problem-solving characteristics are common across scientific domains:

5.6.1.1 The differential application of a core of principles and concepts that serves as a conceptual umbrella for a formal domain has been a major observation of this study. Successful subjects consistently evoked and correctly used a large number of principles (e.g. Newton's Laws etc.) to guide the solution process and to justify their answers and reasons.

5.6.1.2 The differential degree of motivation of subjects may be an important component to be considered in the growing development of problem-solving theory. In this study, motivation seems to be a success-determining factor. Most successful subjects clearly expressed interest in several ways during the activity of solving problems. They tended to spend more time working for an acceptable solution, tried to detect errors and they seemed to enjoy the challenge of solving the problems correctly. On the other hand, unsuccessful subjects exhibited a lack of motivation in providing answers and reasons by using guessing, and try to get rapid answers in one or two steps. This will be shown in the interpretation of tape recording.

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5.6.2 Usefulness of Think-Aloud Technique

It is important to note that the think-aloud interview and its principal product of real problem-solving performances allowed the development of quantitative and qualitative criteria for determining the individual degree of success (Appendix (ix) p 99) whose comparison with qualitative problem-solving differences (Table 3 p 64) provide additional credibility for the think-aloud technique.

Apparently, the path to effective problem solving is neither short nor direct. Considerable content-specific knowledge is needed and the solver must see how the various pieces of knowledge come together in the solution process. (Cafñacho and Good 1989:267).

TABLE 3

Problem - solving differences among subjects.

Poor problem solvers
tended to

1. Read the problem quickly and began solving it.
2. lose motivation or show lack of motivation and even to be tired soon
3. provide wrong answers and justify them with illogical reasons or too much guessing
4. make no checks which could show wrong answers and reasons.
5. show a lack of basic mathematics knowledge such as logarithmic laws, ratios and proportions.
6. use trial and error unnecessarily.
7. make careless mistakes which were not noted or discovered.
8. be silent very often and express a lot of insecurity about their verbalization.
9. make no comments about the problems and skip information on the problem.

Better problem solvers
tended to

- 1 Read the problem slowly and re-read again.
- 2 be well motivated by problems and the solution process
3. provide correct answers and reasons
4. make frequent checks of the work done to discover any inconsistency among steps, answers and reasons.
5. show proper knowledge and use of these and other mathematical skills.
6. use knowledge development strategy.
7. make few careless mistakes.
8. think aloud fluently
9. make proper comments about or beyond the problems' context.

CHAPTER 6

RESEARCH FINDINGS AND RECOMMENDATIONS

6.1 INTRODUCTION

This chapter summarises the research process, sets out the research findings and makes a number of recommendations.

6.2 SUMMARY OF THE RESEARCH PROCESS

6.2.1 Restatement of the problem

Students have a tendency to skip steps in reasoning and miss facts when drawing conclusions during problem solving. It was therefore thought that vocalising thinking, using the method of pair problem solving, would help ensure that students do not make these mistakes, but rather improve their ability to solve problems systematically.

6.2.2 Aim of study

The aim of the study was to find out to what extent the pair problem-solving method would improve the students' ability in solving physical science problems.

6.2.3 Methodology

The people involved in the research were:

* matric pupils and teachers of the schools in
Osizweni in Kwa-Zulu.

* pupils were selected at random from each Physical
Science class.

In the experimental groups the interviews were done during one period per week for six weeks. During the same time the control group practiced solving problems in traditional style. Pupils from the experimental and the control groups were given a pretest and a post-test. Interviews carried out were tape recorded and transcribed. These together with the test scores were analysed in order to determine to what extent the problem-solving skills of students improved as a result of the experiment.

6.3 RESEARCH FINDINGS

6.3.1 The findings of this study have generally confirmed several important observations reported by previous problem-solving studies in science. Some of these observations are:

* problem solving is negatively affected when rote memorisation rather than meaningful integration of knowledge is the clear choice of the subject.

* successful subjects spend more time initially with each problem developing a representation scheme before proceeding to formulas or equations.

* successful subjects demonstrated cross-checking strategies compared to the unsuccessful who used more trial-and-error and algorithm recall.

6.3.2 There are factors which showed little change during the program. These are shown in the figure below:

The pupil wrote 3. R100 for the sentence: R100 less than triple John's weekly income. Here the pupil showed the following:

- (i) poor mathematical skills
- (ii) lack of basic knowledge of certain concepts and
- (iii) difficulty in the translation of English to mathematical symbols.

6.3.3 There are other factors which changed for the better during the process of problem solving. The researcher observed the following while the students were solving problems.

- (i) level of interest
- (ii) communication skills
- (iii) listening skills
- (iv) moving from random problem solving to a more systematic way of solving problems.

- (v) greater overall success in the solution of problems

6.4 RECOMMENDATIONS

6.4.1 The importance of communication

The verbal communication between pupil and pupil, and between pupil and teacher, in problem solving is very important. In pair problem-solving, communication is both oral and written. The most important thing here is that there should be a flow of communication between the two parties either in writing or orally. This will ensure that the listener clearly understands what the problem solver is trying to communicate.

Placing pupils of the same standard in pairs facilitates communication, because these pupils use the same language. It is difficult though to get the students to write effectively. There is still much to be learned in the application of writing to the learning of physical science and mathematics. Teachers should put much emphasis on writing because it leaves a retraceable mind-map, which can be used as a source of reference by a student.

Every time teachers explain something to a class, or put up a sign on the chalkboard, they are making a prediction about the effect this would have as a means of communication. A message is more likely to succeed if it fits the pattern of understanding, attitudes, values and goals a receiver has. Communication effects are a result of certain forces. These are : the situation in which the communication is received, and in which the response may occur; the personality state of the receiver his/her group relationships and standards (Willbur, 1955:8)

It is therefore dangerous to assume any simple and direct relationship between a message and its effects without knowing all the other elements in the process.

Consequently teachers should make sure that they do not assume such a simple, direct relationship.

6.4.2 The role of verbalisation

Whimbey and Lochhead (1983) argue that educational theory ignores and discourages the importance of verbalisation. The primary advantage of bringing a thought to consciousness is that we may observe it. One is able to realise where one made a mistake and improve on that when one verbalises one's thought processes. This also makes one understand how the various parts are related to each other. To motivate continuous thought the teacher should often answer questions with more questions. This means that the teacher should not always

give answers but rather try to develop a sense of confidence among students by probing even further, and encouraging them to express what they think.

6.4.3 The role of the problem

Lochhead (1983:5) argues that, for a problem to be thought-provoking it must be challenging and capable of generating controversy. Moreover, the solution of the problem must be instructive. The problem should allow for several representations in its solution, that is pictures, diagrams, tables, graphs and hypothetical number substitutions. Problems should inform the general knowledge of the problem solver. While this may not be the only goal of the problem it is surely an important **auxiliary benefit** (Whimbey and Lochhead, 1983).

6.4.4 The role of the teacher

Perhaps the greatest incentive to working on a problem is the personal satisfaction that comes with a hard won correct solution. However, the solution may not be the most important goal. Concept formation and thought processes far outweigh any one solution in long term benefits (Whimbey and Lochhead, 1989:6). Frequently getting an answer from someone else's efforts is interpreted as a signal that thinking, at least on that problem, may cease. Students view teachers as an ultimate source of confirmation.

If teachers answer questions too easily, it makes students stop thinking and expect the teacher to give answers. The role of the teacher should rather be to facilitate thinking among students, and this can be done by encouraging them to solve problems on their own.

6.4.5 How teachers can make students better problem solvers

In helping students become better problem solvers, a teacher has to learn how they solve or try to solve problems; which problems they find difficult; what kind of errors they make and why they make them; what their misconceptions are and how these interfere with problem solving.

To find answers, one must take careful notes of what students do and say, and 'pair problem-solving' is one technique which facilitates this.

Learning about the problem solving behaviour of students and particularly their ability to reason using their knowledge of the topic, is a key issue in problem solving research. Teachers should always try to diagnose the students' problem-solving behaviour and prescribe an appropriate treatment.

6.4.6 A recommended approach to problem solving.

Start with a qualitative study of the situation, trying to define and delimit the problem, pointing out as clearly as possible what is to be investigated.

- * Formulate a hypothesis regarding the factors which may influence what is being investigated, paying particular attention to their inter-relationship and boundary conditions.
- * Elaborate and make explicit possible strategies for solutions before going ahead, thus avoiding pure trial and error. Look for different ways of solving problems so that answers might be compared and therefore demonstrate the coherence of the body of knowledge available to the solver.
- * Solve the problem while verbalising to the maximum, thus keeping to fundamental principles and avoiding as far as possible blind operations devoid of any meanings.
- * Carefully analyse the results in the light of the hypothesis formulated and in particular, taking into consideration the boundary conditions.

The five steps outlined are intended as general guidelines that will help to indicate and guard against certain 'methodological vices', such as the tendency to fall into blind operations or to think in terms of certainties rather than in hypotheses, which in turn inhibit the production of possible alternative routes to solutions and do not call the answers into question or elicit the analysis of results (Garrett, 1990 : 7). These guidelines should be given to students throughout the process of problem solving, depending on what problems arise.

6.4.7 Recommendations for further study

Classroom research into teaching techniques that improve students' problem solving abilities can begin by looking at some issues such as the following;

- * The use of non-standard problems to help students approach problem-solving as a task requiring reasoning.
- * Teaching students about the process of problem-solving. For example it is believed that knowing techniques for improving memory can lead to more effective remembering and therefore problem solving.

- * The use of other instructional strategies to pinpoint and eliminate students' misconceptions (Good and Smith, 1987:35).

6.5 CONCLUSION

As soon as one tries to define a problem solving methodology that ought to be taught to all students, a problem arises. It is not true that one single method can be the only one for solving problems. Some experts agree on the merit of using various special techniques, yet there is no consensus as to the best overall technique. This also poses a selection dilemma which cannot be ignored, for if one ignores this dilemma and imposes some procedure upon students, there may be some difficulties. Other students may not be able to grasp a particular procedure and thus remain behind them. This will prevent students from benefiting from the knowledge given.

This dilemma may be solved by allowing students more than one strategy or one problem solving method because conforming to one would be inefficient and ineffective. Drilling students in a particular problem-solving methodology actually denies them the opportunity to learn, because the key to problem solving lies in finding the appropriate method. On the other hand most students lack self-discipline and a sense of a systematic method of working.

They therefore need to be helped. One way of helping them can be teaching them to think aloud. A person who solves a problem by reflecting upon his method can learn from his mistakes and is bound to make progress (Whimbey and Lochhead, 1989).

6.6 SUMMARY

The problem solving approach begins with the students' prior knowledge and uses it to challenge them to solve applied problems whose solutions demonstrate powerful scientific and mathematical concepts. Students create their own meaning when they work collaboratively in pairs and in groups. In the process, they learn to reflect on their thought processes so they may judge for themselves whether their solutions do or do not make sense. They learn to think critically as well as quantitatively. Their anxieties about learning yield to a new confidence.

The effectiveness of this approach is determined by the ability of students to better understand the type of thinking that science entails. Students need to develop strategies for learning that goes beyond rote memorisation of formulae matched to sample problem-types.

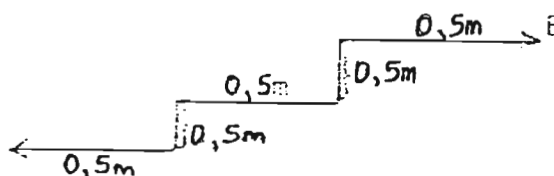
5. A roller skater has a mass of 50kg and moves with a velocity of 5ms^{-1} . He catches a ball of mass 2kg which is travelling horizontally with a velocity of 2ms^{-1} in the opposite direction. Which one of the ff. statements is correct?
- The rollerskater and the ball come to rest.
 - Both move in original direction of the ball.
 - Both move in original direction of the rollerskates
 - Both move at right angles to their original directions
 - None of the above
-

Work Energy Power :

6. A stone with a mass of 2kg lies on a table which is 1m high. A boy knocks the stone from the table, and it falls to the ground. The work done against gravity is

- 2J
 - 10J
 - 20J
 - 30J
 - Zero
-

7. A boy with a mass of 50kg ascends to the top of the stairs as shown in the figure.



The amount of work done by the boy against gravity is

- 100J
 - 200J
 - 300J
 - 400J
 - 500J
-

8. If the boy in (7) requires a force of 10N to move himself forward, the total amount of work done by the boy to move from position A to position B, is
- a) 85J b) 115J c) 150J d) 515J e) 985J
-

9. The bob of a pendulum moves from from rest through a vertical distance h in swinging freely from a point P. to its lowest point. The speed v of the bob at its lowest point is given by;
- a) $\sqrt{2gh}$ b) hg c) $h/2$ d) $\sqrt{hg/2}$ e) $2gh$
-

10. A motorcar with a mass of m kg, is accelerated by a force F until it reaches a velocity of v ms⁻¹. If the force increases to $2F$ and the velocity of the motorcar to $2v$ ms⁻¹, the increase in kinetic energy of the motor car is:
- a) $\frac{1}{2}mv^2$ b) $3/2mv^2$ c) $2mv^2$ d) $4mv^2$ e) $6mv^2$
-

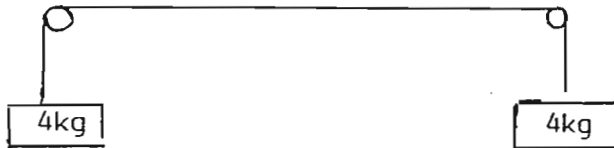
Newton's Laws

11. A force causes an acceleration of 30 ms⁻² on a body with mass of x kg. The magnitude of the force is
- a) $30x$ N b) $x/30$ N c) $30/x$ N d) $30x^2$ N e) $90x$ N
-

12. A body has inertia due to its
- a) movement
 - b) energy
 - c) momentum
 - d) mass
 - e) acceleration
-

13. A man leans against a rock (mass 50kg) with a force of 15N. If the rock does not move, the force exerted by the rock on the man is
- a) 0
 - b) $<15\text{N}$
 - c) $>15\text{N}$
 - d) 15N
 - e) 500N
-

14. Two masses hang at the ends of a chord over two frictionless pulleys as shown in the sketch



the tension in the chord is ;

- a) 0
 - b) 4N
 - c) 7N
 - d) 40N
 - e) 80N
-
15. Two spheres A and B with masses of 10kg and 5kg are placed at a distance of 0,5m apart. Which statement is true?

- a) The force between them is 200N
- b) A exerts the greater force
- c) B exerts the greater force
- d) The force exerted by A and B equals the force exerted by B on A.
- e) The force between them is 200×10^{-11} N

APPENDIX (ii)

Post - test:

Impulse and momentum :

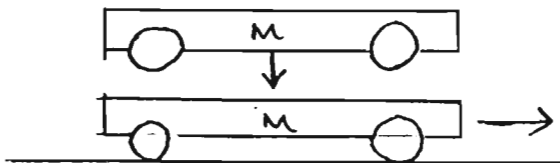
1. A bullet with a mass of 5×10^{-3} kg moves at a velocity of 200ms^{-1} as it strikes a sand bank. It penetrates the bank by 0,2m because of the constant retarding force. The bullet's momentum just before it strikes the sand bank will be :
- a) 10×10^{-2} b) 10×10^{-1} c) 10^{-3} d) 100×10^{-1} e) 2×10^{-2}
-

2. A cannon with a mass of 1000kg, fires a bomb with a mass of 20 kg at a velocity of 50ms^{-1} . The velocity of the cannon directly after it has fired the bomb is
- a) 10^{-2}ms^{-1} b) 10^{-1}ms^{-1} c) 1ms^{-1} d) 100ms^{-1} e) 1000ms^{-1}
-

3. Two trolleys A and B are locked together with a compressed spring between them. The mass of trolley A is four times that of B. If the spring is released, trolley B moves at a velocity of $V\text{ms}^{-1}$. What will the velocity of A be ?
- a) $\frac{1}{4} V$ b) $\frac{1}{2} V$ c) V d) $2V$ e) $4V$
-

4. A stone with a mass of 1kg is thrown vertically into the air at 4ms^{-1} .
- (i) the initial momentum vertically upwards is; and
- (ii) the momentum of the stone at its maximum height is
- a) 0 b) 1kgms^{-1} c) 2kgms^{-1} d) 3kgms^{-1} e) 4kgms^{-1}
-

5. A trolley with a mass of m kg, moves at a velocity of V ms^{-1} .
 A second identical trolley falls perpendicularly onto the first.
 The velocity of the two trolleys together is $\frac{1}{2} V$ ms^{-1} ,

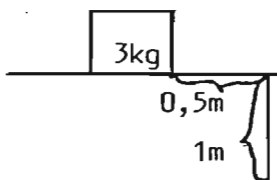


the momentum of the two trolleys together is :

- a) mv b) $m2v$ c) $(mv)^2$ d) $\frac{1}{2}mv$ e) $\frac{1}{2}mv^2$

Work Energy Power :

The following information is applicable to question 6 and 7



A boy pushes a brick with a mass of 3kg over a frictionless (surface) table for 0,5m so that it falls to the ground as shown in the figure.

6. The work done by the boy against gravity, is
 a) 15 J b) 30 J c) 45 J d) 90 J e) zero

7. If the boy requires a force of 10 N to push the brick to the end of the table, the work done by him will be
 a) 1,5 J b) 5 J c) 10 J d) 20 J e) 30 J .

8. A boy who weighs 400N runs up a flight of stairs in four minutes and stops at a point 60m vertically above the starting point. His useful power output against gravity is :
 a) 100 w b) 1000 w c) 60000 w d) 60 000 w e) 5×10^6 w

9. If E is the kinetic energy a given body acquires after travelling a fixed distance under the action of a constant resultant force of magnitude F , then:

- a) E is proportional to F
- b) E is proportional to $\frac{1}{2} F$
- c) E is proportional to F^2
- d) E is proportional to \sqrt{F}
- e) E is independent of F

10. A body falling freely from rest loses E joules of gravitational potential energy reaching a speed of $V \text{ms}^{-1}$. The mass of the body is

- a) $E/2g$
- b) $\frac{Eg}{V^2}$
- c) $\frac{2E}{V^2}$
- d) $\frac{2E}{g}$
- e) $2EV^2$

Newton's Laws :

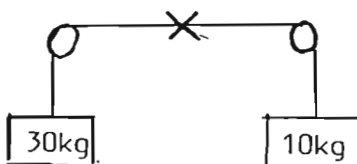
11. The acceleration of a body with a mass of $4b \text{kg}$, will be $a \text{ms}^{-2}$, if a force of F acts on it. The force necessary to accelerate a mass of $b \text{kg}$ by $2a \text{ms}^{-2}$ will be

- a) $\frac{1}{2}F$
- b) F
- c) $2F$
- d) $3F$
- e) $4F$

12. When a motorcar quickly turns to the right, all the passengers move to the left due to their

- a) Inertia
- b) velocity
- c) speed
- d) kinetic energy
- e) kinetic energy and speed.

The following information is applicable to questions 13 and 14. The movement of the system in the below fig. is frictionless and the mass of the cord is neglected.



13. Calculate the acceleration of the system.

- a) 5ms^{-2} b) 25ms^{-2} c) -5ms^{-2} d) 10ms^{-2} e) none of the above.
-

14. The tension in the cord is

- a) 300N b) 400N c) 100N d) 150N e) 200N
-

15. Two spheres A and B with masses of 20kg and 30kg are placed at a distance of 0,3m apart which statement is true ?

- a) B exerts the greater force than A .
b) A exerts the greater force than B
c) The force between them is $200 \times 10^{-11}\text{N}$
d) The force between them is 200N
e) The force exerted by A on B equals the force exerted by B on A.
-

APPENDIX (iii)

Analysing the questions :

Pre - Test (Impulse & Momentum)

Post - Test

- | | |
|---|---|
| <p>1. Recall formula $p = mv$
- recognition of $NS = kgms$ or $Ft = mv$
where unit $Ns =$ unit of P.</p> <p>2. Velocities are in opposite directions and change in velocity = the sum of the magnitudes. Also $a = \frac{Dv}{Dt}$</p> <p>3. Impulse = $Ft = Dmv$</p> <p>4. momentum change -- formula</p> <p>5. momentum change formulae</p> | <p>1. Recall formula $p = mv$ and ignore irrelevant information.</p> <p>2. mv (before = mv (after) = 0 algebraic sum of mv's of bomb + cannon = 0 or magnitude are equal but opposite in direction.</p> <p>3. mv (before) = mv (after).</p> <p>4. (i) $p = mv$ (simple use of)
(ii) at max $L : V =$ recall</p> <p>5. mv (before) = mv (after)</p> |
|---|---|

Work Energy Power :

- | | |
|---|---|
| <p>6. Recall $w.d. = mgh = \frac{1}{2}mv^2$</p> <p>7. $w.d. = mgh$</p> <p>8. $w.d.$ in moving each of horizontal distances of $0,5m$ from A to B, then add to $w.d.$ against gravity to get total.</p> | <p>6. $w.d. = mgh$ (no $w.d.$ against gravity)</p> <p>7. $w.d. = Fxs$</p> <p>8. Recall $P = \frac{W}{t}$
$= \frac{mgh}{t}$
change minutes into seconds</p> |
|---|---|

Pre - test :

9. $\frac{1}{2} mv^2 = mgh$
10. $K = \frac{1}{2}mv^2$
V 2V

Post - test :

9. w.d. = EK = F x S.
10. EK = $\frac{1}{2}mv^2$
= mgh = Ep.
-

Newton's Laws.

11. Recall : E = ma

12. Inertia

13. Newton's third law

14. T = mg

15. Universal gravitational law of Newton

- 11 F = ma

$$= b \times 2a = 2ab = \frac{1}{2}f$$

12. Inertia

13. Newton's second law
system of pulleys - find
a (ms^{-2})

14. T - mg = ma

15. Universal gravitational
law of Newton.
-

APPENDIX (iv)

ANSWERS TO PRE AND POST TEST

PRE-TEST

$$\begin{aligned} 1. \quad P &= mv \\ &= \text{kg} \times \text{ms}^{-1} \\ &= \text{kg ms}^{-1} \end{aligned}$$

$$\begin{aligned} 2. \quad A &= \frac{v - u}{t} \\ &= \frac{50 - (-30)}{0,1} \\ &= \frac{50 - 30}{0,1} \end{aligned}$$

$$\begin{aligned} 3. \quad P &= mv \\ V &= \frac{20}{5} \\ &= 4\text{ms}^{-1} \end{aligned}$$

$$\begin{aligned} 4. \quad P &= m_1 v_1 + m_2 u_2 \\ &= 1000\text{kg} \times 2 \text{ms}^{-1} + 500\text{kg} \times 0 \\ &= 2000 \text{kgms}^{-1} \end{aligned}$$

5. They will both move in the original direction of the skater.

POST- TEST

$$\begin{aligned} 1. \quad P &= 5 \times 10^{-3} \times 200 \\ &= 10 \times 10^{-1} \end{aligned}$$

$$\begin{aligned} 2. \quad M_1 V_1 &= M_2 V_2 \\ 1000 \text{ kg} \times V_c &= 20\text{kg} \times 50\text{ms}^{-1} \\ V_c &= \frac{1000}{1000} \text{ms}^{-1} \\ &= 1\text{ms}^{-1} \end{aligned}$$

$$\begin{aligned} 3. \quad \frac{xV_{ms}^{-1}}{4x} &= \frac{4xV_A \text{ms}^{-1}}{4x} \\ V_B \text{ms}^{-1} &= V_A \text{ms}^{-1} \\ \frac{1}{4} V_B &= V_A \text{ms}^{-1} \end{aligned}$$

$$\begin{aligned} 4. \quad (i) \quad P &= mv = 1\text{kg} \times 4\text{ms}^{-1} \\ &= 4 \text{kgms}^{-1} \\ (ii) \quad P &= mv = 1\text{kg} \times 0 \\ &= 0 \end{aligned}$$

$$\begin{aligned} 5. \quad P_{A+B} &= mv \\ &= 2m\text{kg} \times \frac{1}{2} v \text{ms}^{-1} \\ &= mv \end{aligned}$$

PRE - TEST

POST - TEST

6. $\frac{2\text{kg}}{\quad} \quad 1\text{m}$
no work done
against gravity

6. no work done against
gravity

7. $W = mgh$
 $= 50 \times 10 \times 1$
 $= 500 \text{ J}$

7. $E = F \times S$
 $= 10\text{n} \times 0,5$
 $= 5 \text{ J}$

8. A to 1 = 500J
1 to 2 $10\text{n} \times 1\text{m} = 10\text{J}$
2 to 3 $10\text{n} \times 0,5\text{m} = 5\text{J}$

 $T = 500 + 10 + 5 = 5,5 \text{ J}$

8. $P = \frac{W}{t} = \frac{F \times S}{t}$
 $= \frac{400\text{n} \times 60}{240}$
 $= 100\text{w}$

9. $\frac{1}{2}MV = mgh$
 $V^2 = \frac{mgh}{\frac{1}{2}m}$
 $V = \sqrt{2gm}$

9. $wd = F \times S$
 $E = F \times S$
 $E \propto F$

10. $FS = \frac{1}{2}mv^2$
 $2E = \frac{1}{2}m(2v)^2$
 $2E = \frac{1}{2}m4v^2$

 $E = mv^2$
 $E = mv^2 + \frac{1}{2}mv^2$

 $= \frac{3}{2}mv^2$

10. $E = mgh = E$
 $E = mgh = \frac{1}{2}mv^2$
 $\frac{2E}{v^2} = \frac{mv^2}{v^2}$

 $\frac{2E}{v^2} = m$

11. $F = ma$
 $= x\text{kg} \times 30\text{ms}^{-2}$
 $= 30x \text{ kg ms}^{-2}$
 $= 300 \times \text{N}$

11. $M = 45\text{kg}$; $A = a\text{ms}^{-2}$; $F = 4ab$
 bkg ; $A = 2 a\text{ms}^{-2}$; $F = 2abn$
2 abn is half 4 abn
 $\therefore F_2 = \frac{1}{2}F$

PRE-TEST

POST-TEST

12. mass

12. Inertia

13. 15 N

13. The unbalanced force is
 $300\text{n} - 100\text{n} = 200\text{n}$
 $A = \frac{f}{m} = \frac{200\text{n}}{40\text{kg}}$
 $= 5\text{ms}^{-2}$ in the direction
of the 30kg mass

14. $T = mg$
 $= 4\text{kg} \times 10\text{ms}^{-2}$
 $= 40\text{n}$

14. $T = mg = ma$ (for 10kg mass)
 $T = 100\text{n} = 50\text{n}$
 $T = 150\text{n}$ (The tension the
string is the accelerating
force for the smaller mass
OR
 $mg - T = ma$ (for 30kg mass)
 $300\text{n} - T = 150\text{n}$
 $T = 150\text{n}$ (mg - the
tension in the string is
the accelerating force to
the larger mass).

15. The force exerted by
A on B equals the
force exerted by
B on A

15. The force exerted by A on B
equals the force exerted by
B on A.

APPENDIX (v)

Instructions for Interviews

- (1) We are interested in the different ways that people solve problems. We will not be "scoring" your work in comparison with others. We will simply be describing the different methods people use.
- (2) Try to think out loud as much as possible, describing your ideas as thoroughly as you can. Our most common problem is not having enough verbal data in the interview.
- (3) Take your time. There is no time limit. The full interview can be used on one problem if necessary.
- (4) If you have conflicting ideas about a problem, try to explain what the conflict is.
- (5) Number any equations or pictures you write so that we can refer to them by number.
- (6) Work down the page when possible.
- (7) Remember to say as much as you can about what you are thinking.

Be a good problem explore (listener)

- Forget how you would solve the problem
- Keep the problem solver thinking aloud.
- If you do not understand what the Problem Solver is explaining, ask questions. Types of questions that could be asked are.
 1. What are you thinking about ?
 2. Tell me that again can you draw a picture of that ?

3. When you said X, what were you thinking?
4. Can you say more about that ?

Pointers

- Avoid interrupting the subject.
- Avoid excessive probing.
- Avoid giving the subject clues as to the correctness of answers?

APPENDIX (vi)

PROBLEMS TO BE SOLVED

1. Clock A keeps perfect time whereas clock B runs fast. When clock A says 6 min have passed, clock B says 8 min have passed. How many minutes have really passed when clock B says 56 minutes have passed?

2. A car travels 40km an hour and a plane travels 10km a minute. How far will the car travel while the plane travels 450km?

3. A man runs 1km in 10min and a car goes 50km an hour. At these rate, how far does the man go when the car goes 150km?

4. Jim's weekly income is R100.00 less than tripple John's weekly income. Huey's weekly income is R20.00 more than double John's weekly income. Huey's income is R120.00. What is Jim's income?

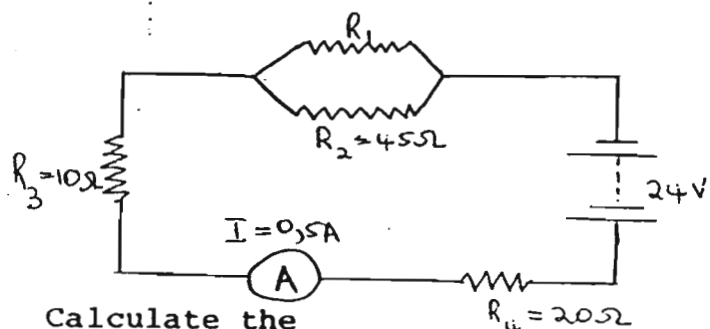
5. The bob of a pendulum moves from rest through a vertical distance h in swinging freely from a point P to its lowest point. The speed v of the bob at its lowest point will be :-
6. The P.D. between two parallel plates X and Y, situated in a vacuum, is V and the distance between them is D . A body of mass M and charge q is situated midway between X and Y. What will be the field strength at the body?
7. A spacecraft of mass M is moving with velocity V in free space when it explodes and breaks into two. After the explosion a mass M of the spacecraft remains stationary. What is the velocity of other part?
8. A force F is necessary to accelerate a mass of $4x$ to 2 ams^{-2} . What force is required to accelerate a mass x to 4 ams^{-2} .
9. If the crane operator receives 10 cents for a unit of 10^4 W , his earnings in 60 seconds will be what ?

10. When a current of I ampere is passed through a resistor, w joules of thermal energy is released in a certain time. When the current is doubled, find the energy released during the same time (assuming the resistance remains constant).
11. An electric motor does work at a rate of $1,2\text{kw}$. In one minute it does an amount of work, in joules of?
12. Two identical parallel conductors in air exerts forces of magnitude F on each other when carrying the same current. If the current in each is doubled and the distance between the two conductors trebled, calculate the magnitude of the new force each conductors exerts on the other.

13. The kinetic energy of a body travelling at a certain speed is E . What will be the kinetic energy of a body with half the mass and travelling at twice the speed?

14. A train left Durban headed west at the speed of 30 km per hour. At the same time the following day, another train left Durban headed west on the same track at 40 km per hour. If both trains proceed at a uniform speed, how many days will it take the second train to catch up to the first?

15. Consider the following and then answer the questions. The resistance of the ammeter is negligible.



Calculate the

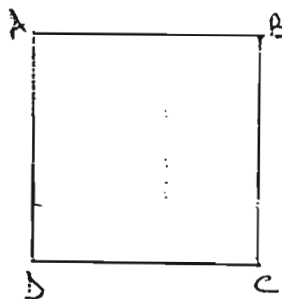
- Combined p.d. across R_1 and R_2
- p.d. across R_1 and R_3
- Value of R_1
- Current through R_1

16. A small positive test charge T is placed at a point $\frac{1}{4}$ of the distance between two equal positive point charge being nearer to A.



If the magnitude of the force exerted by A on the test charge is F , what will be the magnitude of the force exerted by B on the test charge ?

17. The diagram below shows a square field with sides 10m. A person walks around the perimeter from A to D via B and C, in 40 seconds. What is the magnitude of his average velocity for displacement from A to D, in ms^{-1} ?



18. If L stands for a length unit, T for a time unit and M for a mass unit, then the units for energy would be what ?

APPENDIX (vii)

Suggestions for Tape Analysis

1. Content Area

1) Error pattern/conceptual difficulty

What errors does the subject make ?

Is the error a " slip " or is it systematic?

Why do you think the subject made such an error?

- 2) Is there any segment of the tape which tells you something about the subject (attitude, behaviour etc), or about the problem solving technique, that you are interested in?

11. Evidences

- 1) Can you find other sections of the tape that support your interpretation or explanation of the nature and source of the error/phenomenon?

- 2) Do you think the error is peculiar to this person or is it common to a lot of people?

111. Evaluation

- 1) As an interview, what difficulties have you had? Is there anything that you should have (or have not) done during the interview?

- 2) Do you have a better understanding about the error pattern/phenomenon now? Do you think it has helped your understanding about your students as well?

- 3) Have you learned anything that you can bring back to your own classrooms? Can you think of any teaching strategy to address the error?

APPENDIX (viii)

Test item readability checklist.

Rate the questions using the following system:

- 5 - excellent
- 4 - good
- 3 - adequate
- 2 - poor
- 1 - unacceptable
- na - not applicable

..... experience and prior knowledge

..... appropriate vocabulary

..... appropriate sentence complexity

..... clear and understandable definitions and examples

..... reasoning skills appropriate for student' cognitive level

..... content clearly organized

..... clearly framed questions

Appendix (ix)

TEST SCORES

SCHOOL 1 EXPERIMENTAL GROUP

NAME	PRE-TEST (%)	POST-TEST (%)
1. BEAUTY	14	36
2. PATIENCE	10	46
3. GABRY	54	80
4. GODFREY	32	56
5. DELIA	20	58
6. JABU	38	50
7. TIM	30	60
8. JOY	46	52
9. CYRIL	42	74
10. VIV	28	30
11. REJOICE	48	68
12. RICH	18	40
13. PETROS	70	80
14. CECIL	48	46
AVERAGE :	35 %	56,9 %
	13 GAINS	1 LOSS

SCHOOL 1 CONTROL GROUP

NAME	PRE-TEST (%)	POST-TEST (%)
1. ALEC	20	12
2. CYRIL	48	46
3. ELVIS	56	52
4. JOE	68	56
5. GRACE	22	22
6. NOMA	36	32
7. JOSEPH	32	26
8. PAT	48	32
9. NOMSA	30	34
10. CAT	28	28
11. LENN	46	32
AVERAGE :	38,7 %	33,8 %
	1 Gain	8 Losses 2 No change

SCHOOL 2

NAME	PRE-TEST (%)	POST-TEST (%)
1. VERO	40	65
2. ELL	14	52
3. PHIL	37	57
4. FLOR	50	50
5. CLAUT	30	45
6. INNO	60	86
7. ALBERT	32	57
8. GRACIE	40	43
9. WELLI	45	71
10. PAT	32	56
11. VINCENT	40	46
12. JONES	30	29
13. ELVIS	50	71
14. ERNEST	30	43
15. GCWA	40	65
16. BLESS	40	50
17. SAM	50	86
18. OBED	43	71
19. PAUL	20	43
20. SIBU	25	57

AVERAGE : 37,3 %

57,2 %

18 GAINS

1 LOSS

1 NO CHANGE

SCHOOL 3

NAME	PRE-TEST (%)	POST-TEST (%)
1. GLORIA	56	62
2. MERC	62	70
3. NIC	54	66
4. LUCK	40	40
5. PAT	42	42
6. ARTHUR	36	60
7. QUEEN	18	56
8. PAM	18	48
9. TOM	52	62
10. BESS	28	56
11. PHYLL	28	50
12. EDISON	14	60

AVERAGE : 37,3 %

56 %

10 GAINS

2 UNCHANGED.

APPENDIX (X)

Tape analysis

Group 1

Subject 1 Clock A keeps the perfect time
 Clock B is running faster
 (1) Clock -----» 6 min
 Clock -----» 8 min faster by 2 min

 (2) Clock B -----» 56 min
 Clock A -----» 54 min
 .. 54 min have passed

Subject 2

40km/h -----» car
 10km/h -----» a plane
 40km/h -----» 10km/min x h
 x -----» 450 km

 40km/h -----» 10km/1 min x 60 min
 40km/60 min -----» 10km/min
 x -----» 450 km

$$\frac{18000\text{km}}{40\text{km}} = x \cdot 10\text{km} \cdot 0,017$$

$$x = \frac{10\text{ km} \cdot 0,017}{450\text{km}}$$

$$0,17\text{km} \cdot x = \frac{1800\text{km}^2}{450\text{km}}$$

$$0,17\text{km} \cdot x = 0,17\text{ km}$$

$$x = 105,8 \times 10\text{ km}$$

Subject 1:

Same difficulty with subject 1 of group 3 & subject 1 of group 2.

Conceptual difficulty

- * The subject thinks that the difference in time is constant
e.g. if clock B is 8 min past and clock A is 6 min past then
clock B is faster than clock A by 2 min. So if in clock B 56
min have passed the 54 min have passed in clock A
- * this error is systematic which shows that there is a lack of
comprehension.
- * this problem is common to other groups

GROUP__2

SUBJECT_1

:

A

b

6 min

8 min

56 min

6 min

8 min

B - 2 min

8 min - 2 min

6 min -

B

56 min

56

B - 2 min

56 min - 2 min

54 min -

real time.

SUBJECT__2 : A - 40 km m

= 40 km 60s

B = 10 km in 1 min 60s

= 10 km in 60s

A = n = 4km X 1h

10km X 60s

= 4km (12 X 60s)

= 600

= 4km X 720

600

4.8km for A

ANALYSIS

SUBJECT 1:

i) Subject 1 has conceptual difficulty.

- his/her error is systematic, that is, throughout the problem she maintained that the difference in time is constant.

(same difficulty with subject 1 of group 3)

SUBJECT 2:

- have a technical difficulty, have difficulty in converting minutes into seconds in a correct manner but he knows that 1 min = 60s.
- the subject writes 4km instead of 40 km and continues with that error.
- he also has conceptual difficulty. i.e. he could not understand the problem.

Group 3

Subject 1:

Conceptual difficulty

- 1) the subject thinks that the difference in time is constant, . . . e.g. if A is 6 min and B is 8 min fast; it follows that if B is 56 min then A will be 54 min fast.
- 2) this error is systematic which shows that there is a lack of comprehension.

Subject 2:

- Subject 2 has a problem of wanting to use a formula where it is unnecessary.
- The subject's attitude towards this problem is that it should be solved using one of the formulae of speed.

GROUP 4

SUBJECT 1:

Clock A 6min - Clock B 8min

Clock A Xmin - Clock B 56min

X - 6 X 56

8

- 42min

SUBJECT 2:

Car 50km - 60min

Man 1km - 10min

Car 150km - 3,60min

Man X - 3.10min

X - 150 X 30min

180min

- 25km

Car 0,66km/min - 10km/min

X - 450km/min

0,66km/m X 450km/min

10

= 29,7km/min

Group 5

Subject 1

Jim's weekly income R100,00 = John's weekly income 3 R100,00
R300,00. Hueys's weekly income 2. R300,00 + R20 = R620,00
Jims' weekly income x - Hueys' weekly income
" " " $\frac{120}{6} - 20$ -----» R120,00
0

He has difficulties in putting words into symbols e.g.

Subject 2

Jims' weekly income is R100
Hueys' income is R20,00 than double John's weekly
Hueys' real income -----» R120
John's income 50
Tripple Johns' income 50×3
= R150
Jims' income R150.00
- 100.00
= 50.00
.. Jims' income is R50.00
Jims' income weekly R100,00
Hueys' income is R120,00

Subject 1

He has difficulties in putting words into symbols. e.g. he writes
3. R100 for the sentence: R100 less than tripple John's weekly
income.

Questions not improved by the experimental Group.

Post - Tests questions:-

- No. 5
- a) Pupils used the formula for $E_p = mgh = Fs$ which is vertical, with a horizontal displacement.
 - b) They failed to differentiate between vertical and horizontal movement. (two directions).
 - c) They failed to conceptualize the problem adequately (i.e. how work done against gravity)
 - d) Others had no confidence in solving the problem and hence used random techniques.

- No 11
- a) Most pupils did not attempt this problem. A few used a random method of solving the problem e.g. $F+F=4abN+2abN=6abN$. ii) $F=F$.
 - b) In most cases it was guess work.
 - c) Rejoice Mazibuko (ess. group) got the problem right - thus:-

From Newton Secondary Law of Motion $F=Ma$

$$F = 4bkg \times am5^2$$

$$X = bkg \times 2am5^2$$

$$\frac{F}{x} = \frac{4ba}{2a}$$

$$2af = xba4$$

$$\frac{2aF}{4ba} = x$$

$$\frac{F}{2b} = x$$

$$x = \frac{1}{2}F$$

$$x = \frac{1}{2}F$$

$$x = \frac{1}{2}F$$

$$x = \frac{1}{2}F$$

here she missed b from $x = bkg \times 2am5^2$ thus she ended up with $\frac{F}{x} = \frac{4ba}{2a}$

otherwise I think she did her best.

No 13

Answers given here were $a = 200/20 = 10$

$a = 400/40 = 10$. They did not show where they got 400 & 200 but I guess they used the formula

$$F = 30kg \times 10 \quad \text{and} \quad F = 10 kg \times 10$$

$$= 300n$$

$$= 100n$$

and somehow they added the two to get 400 and other subtracted to get 200.

Students used a formula for Newtons Sec. Law of Motion instead of also applying the system of pulleys.

- e) Petros (esp group) got the problem right though he did not use the systematic approach to solving the problem.

$$F = 300\text{N} + 100\text{ N}$$
$$= 200\text{ N}$$

The total mass of the system is 40 kg.

$$= 200\text{ N} = 40\text{kg} \times a$$

$$a = 5\text{m/s}^2 \text{ (In the direction of the 30 kg object)}$$

No 14

- i) Pupils here used the formula $F = ma = 20 \times 10$.
 $T = mg$; Others just wrote g as an answer. I think here it was more of a guess work.
- ii) Pupils failed to conceptualize the problem adequately i.e. could not recognize that the tension in the string is the accelerating force. (i.e. $T - mg = ma$).

Questions not improved by control groups.

$$\text{No: 3} \quad v = \frac{m}{f} = \frac{5}{20} = 0,25$$

$$P = 4 \times Vm5 = 4V$$

Written by students

Generally

- i) Failure to conceptualize the problem adequately
- ii) Can't see where they got 5 and 20
- iii) There was no confidence in solving the problem

Specifically

Joseph Nkosi got the problem right:-

$$\begin{array}{ll} M_b = m & V_b = Vm5 \\ M_a = 4m & V_a = x \\ P_a = Mv & P_b = MV \\ 4m \times m5 & = MV \ m5 \\ x \ m5 & = \frac{MVm5}{4m} \\ x & = \frac{1}{4} V \end{array}$$

No 5: Momentum of both = $\frac{1}{2}mv$: $\frac{1}{2}mv^2$

- i) They used a wrong formula which is not for momentum but for energy $\frac{1}{2}mv^2$.
- ii) Mostly seemed not to understand the concept of \underline{P} .
- iii) Guessing was used.
- iv) Patrick Mabaso got right the first part but did not attempt the second part of the problem.

$$\begin{array}{l} p = mv \\ = 1\text{kg} \times 4\text{m5} \\ = 4\text{kgm5} \end{array}$$

No 6: The formula used is $W = mgh$

- i) They could not realize that there is no work done by the boy if the brick falls freely to the ground.
- ii) They could only think of the formula for work thinking that the data given should be used.

No 11

i) $F = 4 \text{ bkg} \times a\text{mS}^2 = 4F$

ii) $F = \frac{4\text{bkg}}{\text{bkg}} \times \frac{a\text{mS}^2}{2a\text{mS}^2} = 2F$

iii) $F + F = 4ab\text{N} + 2ab\text{N} = 6ab\text{N}$

iv) Pupils did not understand the problem adequately.

No 13

$$a = \frac{5}{20} = 0,25$$

i) I can't see where they got $\underline{5}$

ii) It seemed students had no confidence in solving this problem.

iii) Elvis Khumalo used the formula

$$F = mg$$

The resultant mass that is falling 20 kg.

$$\begin{aligned} \therefore W &= 20 \text{ kg} \times 10\text{mS}^2 \\ &= 200\text{N} \end{aligned}$$

$$\begin{aligned} a &= \frac{F}{m} \quad (\text{acceleration of the system}) \\ &= \frac{200 \text{ N}}{(30+10) \text{ kg}} \\ &= 5\text{mS}^2 \end{aligned}$$

No 14 Formula used was $T = mg = 40 \times 10$

i) They decided to use this formula because it was correct in the pre-test.

ii) Guess work

No 15 FN $m, m^2/r^2$ $F = \frac{Gm_1 m_2}{r^2}$

i) This shows a problem of relying/ using the formula even where it is not necessary.

ii) They failed to recognize that this is Newtons third Law stated differently.

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