Competence of matric physical science teachers in some basic problem-solving strategies

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The National Curriculum Statement for matric physical science places strong emphasis on the development of critical thinking and reasoning abilities of pupils. The successful implementation of this curriculum therefore requires teachers who are competent in the cognitive (intellectual) skills and strategies needed for learning science effectively. Testing of teachers' competence in this aspect is therefore important. I therefore analysed teachers' answers to questions that were carefully designed to test competence in some basic intellectual strategies that are important for problem solving in physical science courses. A total of 73 matric physical science teachers, from about 50 Dinaledi schools in the North West and KwaZulu-Natal provinces in South Africa, were tested in five intellectual strategies: clear representation of problems, identifying and focusing on the goal, identification and use of relevant principles, use of equations for deductions and proceeding step-by-step with the solution. The teachers' competence was poor in all the intellectual strategies tested. About 60% (the average performance in all 13 questions used for testing) of teachers tested were unable to solve the questions correctly. An important objective of the curriculum is the development of critical thinking, scientific reasoning and strategies of pupils. This study shows that the achievement of this objective will be seriously handicapped because of the lack of competence of many teachers in intellectual strategies. There is therefore a need to train teachers in order to increase their competence in this aspect.

Introduction

Intellectual skills and strategies[1] (also called thinking skills and strategies and cognitive skills and strategies) are generally believed to be the tools for all mental activities and competence in them is hence essential for the efficient learning and application of knowledge. Intellectual skills may be considered to be the basic building blocks of all mental activities, and familiar examples of them are reading skills, writing skills, mathematical skills, information gathering skills, organisation skills, reasoning skills, analysis skills and synthesis skills. Intellectual strategies are overall plans of action for managing, controlling and executing tasks such as decision-making and problem solving. They are broader than intellectual skills and the execution of a strategy generally needs competence in many individual skills.

There are many types of intellectual skills and strategies and these have been classified in many ways and at different levels of detail. Comprehensive classifications of them are given by Marzano et al.[1] and Jones and Idol[2]. Other classifications are given in some of the articles in a book edited by Costa[3,4,5]. This book, which has 85 articles by different authors, discusses many important features of intellectual skills and strategies.

Just as competence in physical skills is essential for performing physical activities, competence in intellectual skills and strategies is essential for performing mental activities. An increase in competence in this aspect could be expected to lead to more effective and more meaningful learning. It would enable us to organise and store knowledge (in memory) more efficiently and also to recall and apply this stored knowledge more effectively, for example for problem solving.[6] Furthermore, this competence would help to build positive attitudes, increase self-confidence and promote the ability to solve problems encountered in our daily lives. The improvement in pupils' intellectual abilities should be one of the major learning outcomes of educational courses because it is a more permanent aspect of education. The subject content learned is progressively forgotten but improvement in intellectual abilities will be more permanent and will help pupils to lead more successful lives.

The need for explicit training of pupils in schools in how to think was recognised in the United States in the early 1980s. The types of thinking skills and strategies that should be explicitly taught in the various subjects in schools (kindergarten to grade 12) were identified, mainly by theoretical analysis, and many programmes have been developed that integrated the teaching of thinking skills and strategies with the teaching of content knowledge. The mastery of thinking skills is a major learning outcome and competence in them is also tested at examinations. All these aspects are discussed in several articles by different authors in the book edited by Costa[3].

In South Africa, one of the major learning outcomes for matric physical science students in the new national curriculum is[7]: 'The learner is able to use process skills, critical thinking, scientific reasoning and strategies to investigate and solve problems in a variety of scientific, technological, environmental and everyday contexts'. Although this emphasises intellectual abilities, the syllabus and work schedules given to teachers are stated mainly in terms of acquisition of content knowledge. Furthermore, how students are evaluated at examinations also seems to place much greater emphasis on content knowledge than on intellectual abilities.

The successful implementation of the physical science curriculum depends on many factors, an important one being the competency of teachers. Case studies of the implementation of this curriculum in some classrooms have been done for science by Rogan[8] and by Velupillai et al.[9] for mathematics. Their studies indicate many serious difficulties associated with the implementation of the new curriculum, one of them being associated with under-qualified and inadequately trained teachers. The Centre for Development and Enterprise has conducted a study[10] on this curriculum and have made many recommendations on what needs to be done to reform mathematics and science education in South African schools. Some of these recommendations concern teachers and one of them is the assessment of teachers' knowledge followed by training programmes to rectify limitations in their knowledge and competence.

The research reported in this article concerns the testing of matric physical science teachers' competence in intellectual skills and strategies that are important for problem solving in physical science. This paper considers only the teachers' performance in the questions that tested competence in strategies. Their performance in the questions that tested intellectual skills will be reported in a later paper.

The study is important because teachers must be competent in intellectual skills and strategies for the successful implementation of the physical science curriculum, in which an important learning outcome is the development of pupils' intellectual abilities. This type of study has not been previously conducted on teachers in South Africa. Some studies have, however, been conducted on first-year university students by Drummond[11,12] and on Science Foundation students by Selvaratnam and Mavuso[13]. These studies show that more than half of the students tested were not competent in most of the intellectual skills and strategies that are needed for the effective study of science.

Objectives

The main objectives of the study were:

- To test, by carefully designed questions, the competence of matric physical science teachers in some basic intellectual strategies that are important for problem solving in physical science courses.
- To identify possible reasons for teachers' difficulties with strategies and to suggest methods for addressing these difficulties.

Strategies tested

The strategies selected for testing are those that are particularly important for problem solving in physics and chemistry.[14] Non-use of these strategies would lead to difficulties in problem solving and also often cause errors. The intellectual strategies tested were:

- clear representation of problems
- identification and focusing on the goal
- identification and use of relevant principles
- use of equations for deductions
- proceeding step-by-step with the solution.

Test questions

The test questions that were used are shown in Table 1. Testing competence in intellectual skills and strategies by using questions is often a difficult task because the questions should be designed so that any difficulty in answering them should only be because of a lack of competence in an intellectual skill or strategy and not because of any other reason, such as difficulty with subject content knowledge or with language. Questions were therefore designed such that they did not need recall of knowledge (principles) of subject content for answering them: the principles needed to answer were given in the questions themselves. Furthermore, an attempt was made to design questions that either do not involve scientific concepts or need only simple concepts (e.g. mass, density and concentration) and principles (e.g. the law of conservation of mass) for their solutions. All matric science teachers should be familiar with these concepts and principles and understand them. Some of the questions used in the test do not involve scientific concepts and even non-scientists should be able to answer them. Another criterion to be satisfied was that the solution to a question must not already be known to the persons tested. Unfamiliar questions were therefore designed to prevent any possibility of recall of correct solutions.

Subjects

The teachers tested were from about 50 Dinaledi schools in the North West (NW) and KwaZulu-Natal (KZN) provinces of South Africa. Dinaledi schools are special schools selected by the National Department of Education, where the teaching of mathematics, science and technology is particularly emphasised and supported. The teachers who wrote the tests were selected by the department to attend four-day workshops to upgrade their knowledge. NW teachers had two workshops (four days in July 2009 and four days in September 2009) and they were tested with two question papers. KZN teachers had only one workshop (in September 2009) and were tested with only one paper. The total number of NW teachers who wrote the test was 40 in July and 28 in September. Thirty-three KZN teachers wrote the test in September.

Question papers and their administration

Two question papers were used for testing. Paper 1 had 14 questions of which 7 tested intellectual strategies and 7 tested skills. Paper 2 had 11 questions, of which 6 tested strategies and 5 tested skills. KZN teachers wrote Paper 1 only. The tests were written on the first day of the workshops. No time limit was placed for answering the question paper. However, when about three-quarters of the teachers submitted their answer scripts, the other teachers were persuaded to do so.

Two types of questions were used for testing: multiple-choice and structured. Multiple-choice questions were the preferred type, mainly because they require less time to answer. Structured questions were used only when it was felt that more information could be obtained from the answers. Teachers wrote the answers to the questions on the question paper in space provided for this below each question. Space was also provided adjoining each question for 'rough work'. Five instructions were given on the front page of each question paper, two of which are particularly relevant for this study:

1. Some questions may appear difficult but they are not. If you reason logically, you will be able to answer them quickly. Note also that some of the data and information given in a question may not be necessary to answer the question.
2. Show all the steps in your reasoning. Also do all the rough work in the space provided adjoining each question, because the main objective of this test is to probe your thinking processes, and how you 'set about' the solution of the problem.

The questions that were used for testing competence in intellectual strategies are given in Table 1. Questions 1, 2, 3, 6, 8, 10 and 12 are from Paper 1 while the others are from Paper 2.

Results and discussion

The teachers' performance in each of the questions in Table 1 is indicated in the last three columns of the table. The data in these columns are the percentages of teachers who correctly answered each question in the NW province, KZN province and in both provinces combined. It can be seen that the teachers' performance was poor in most of the questions. From here onwards, the overall performance of the teachers in both provinces will be discussed.

Clear representation of problems

An important strategy that aids the solution of some types of problems is a clear representation initially of all the relevant information (e.g. the data given and the goal) concerning the problem in a clear, concise and coordinated manner, for example as a table, graph, diagram or equation. When all the information relevant to the solution to a problem is collected together concisely and coordinated in one place, it is easier to focus on the solution to the problem, without being distracted. The main objective of Questions 1–5 was to check whether teachers' difficulties in solving these problems were associated with their not representing the problems clearly.

Question 1 is easy to solve if all the relevant information given in the question is first represented in a coordinated manner, for example by representing it on a line, as shown in Figure 1.

From this line diagram it is easy to see that the substance will be a liquid at 50 °C, a gas at 90 °C and a solid at -50 °C. The solution does not require much scientific knowledge and also does not need any reasoning. What is required is the ability to represent the relevant information in a coordinated manner, for example as a line diagram. Despite the problem's simplicity, about 30% of the teachers tested were unable to solve it. Of the teachers who failed, none tried to represent the problem pictorially. Many teachers who solved the problem correctly also did not represent it pictorially and some answered only parts of the question correctly. These teachers probably solved each part of the problem separately: this takes more time and effort than that needed for obtaining the answers to the three parts of the question from a single line diagram.

Question 2 tested the ability to represent quantitatively two items of information on a line diagram (Question 2a) and as an equation (Question 2b). Even though the representation of information on a line diagram is not a difficult task, about 50% of the teachers tested were unable to do this. About 35% of them did not even attempt the solution, which suggests a lack of confidence in their ability to handle and translate verbal information into a diagram. Question 2b tested ability to represent the information in a verbal statement, which related the masses of two substances A and B, as an equation (the equation is $m_A = m_C - 8$). About half of the teachers tested could not do this and about 35% did not even attempt a solution. The ability to identify quantitative information in statements and then represent this information as equations is an important skill. This is mainly because equations, being concise and precise, are better than statements for organising, recalling and using knowledge.[6,15] To illustrate the importance of transforming information in statements into equations, consider the following problem from MENSA[16]: A cup and a saucer together weigh twelve ounces. The cup weighs twice as much as the saucer. How much does the saucer weigh? The best method for solving problems of this type would be to transform the information given into equations and then solve these equations. The equations relating the information given in this problem are (x = weight of cup, y = weight of saucer): $x + y = 12$ and $x = 2y$, from which $y = 4$ and $x = 8$.

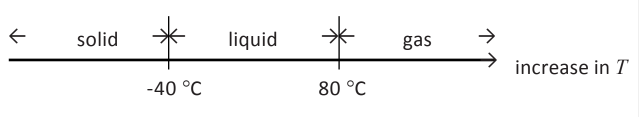
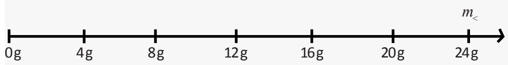


FIGURE 1: Representation of data on a line diagram.

TABLE 1: The questions used to test the five intellectual strategies, classified by strategy.

Questions	Correct (%)		
	NW	KZN	NW + KZN
Clear presentation of problems			
1. A solid substance melts at -40 °C to form a liquid and the liquid boils at 80 °C to form a gas. Will the substance be a solid, liquid or gas when its temperature is: (a) 50 °C (b) 90 °C (c) -50 °C	70	66	68
2. This question concerns the masses of three objects A, B and C. The mass of A (given symbol, m_A) is larger than the mass of B (symbol, m_B) by 6 g but is smaller than the mass of C (i.e. m_c) by 8 g. The mass of C is 20 g.			
(a) The mass of C (i.e. m_c) has been represented on the line drawn below. Similarly, represent the masses of A and B on this line. 	48	57	52
(b) Write the equation that relates m_A and m_c	45	57	51
3. 5 g of a gaseous substance A is present initially in a closed 2 L vessel at 20 °C. When heated to 300 °C, it partially breaks down to give 1 g of gas B and 0.8 g of gas C.			
(a) Which one of the following correctly represents the substances present in the vessel at 300 °C? (i) A only (ii) A, B and C (iii) B and C only (iv) B only	50	75	62
(b) Calculate the mass of A present in the vessel at 300 °C by applying the law of conservation of mass, which states that the total mass of all substances present before a chemical reaction is equal to the total mass after the reaction.	35	42	28
4. This question concerns corresponding times, on a particular day, in Johannesburg (JHB), Sydney (SYD) and New York (NY). When it is 12:00 in JHB, it is 06:00 in NY, and when it is 16:00 in SYD it is 08:00 in JHB. When it is 18:00 in SYD, what will be the time in:			
(a) JHB?	54	-	54
(b) NY?	50	-	50
5. 1.00 mol of ethanol (which is a liquid) is dissolved in 1.00 dm³ of water. The concentration (c) of ethanol in the solution then obtained will be: (Note: c is defined by the equation $c = n/V$, where n = amount (moles) and V = volume of solution.) (a) 1.00 mol/dm³ (b) less than 1.00 mol/dm³ (c) greater than 1.00 mol/dm³ (d) 0.50 mol/dm³	11	-	11
Identification and focusing on the goal			
6. 5 g of gaseous N_2O_4 is present in a closed 2 L vessel at 20 °C. When heated to 300 °C, with the volume of the vessel being kept constant, 2 g of N_2O_4 dissociates into NO_2 according to the equation $N_2O_4(g) \rightarrow 2NO_2(g)$. Calculate the density of the gas mixture present in the vessel at 300 °C.	65	45	59
7. The mole fraction (x_A) of a gas A in a mixture of gases at a pressure p and temperature T is 0.2. (Note: $x_A = n_A/n$, where n_A = moles of A and n = total moles). What will be its mole fraction if:			
(a) the pressure is doubled from p to $2p$?	14	-	14
(b) the temperature is doubled from T to $2T$?	18	-	18
Identification and use of the relevant principles			
8. A closed vessel contains a mixture of two gases A and B at a temperature T and pressure p. The mass of A is 1.2 g and the total mass of A and B is 2 g. The gases do not react with each other. What will be the mass of A present in the vessel if the pressure is doubled from p to $2p$?	40	60	49
9. The volume of a liquid increases when temperature is increased. If the volume of a sample of liquid water is 10 cm³ at a temperature T, its volume when the temperature is doubled from T to $2T$ will be: (a) 20 cm³ (b) 10 cm³ (c) 5 cm³ (d) greater than 10 cm³ but less than 20 cm³	25	-	25
Use of equations for deductions			
10. The questions below concern density (d) which is defined by the equation $d = m/V$, where m = mass and V = volume. Give reasons for your answers.			
(a) If the density of a gas present in a closed vessel is x at a temperature T, which one of the following would be its density if the temperature is doubled to $2T$? Volume is kept constant. (i) $½x$ (ii) x (iii) $2x$ (iv) $4x$ (v) x^2	18	27	22
(b) Will the density of a liquid increase, decrease or remain unchanged if its temperature is increased? (Note: the volume of a liquid always increases when its temperature is increased.)	68	60	65
11. To determine the molar mass (M) of an ideal gas, a student measures the volume (V) of a known mass (m) of the gas at a known temperature (T). Is there sufficient data to calculate the molar mass? If not, what further data are required? (Note: $M = m/n$ and $pV = nRT$, where n = amount (moles), p = pressure, R = constant.)	21	-	21
Proceeding step-by-step with the solution			
12. Use the equation $t = k/N$ (where N = number of men employed to do some task, t = time needed to do the task, k = a constant), to calculate the time needed by 4 men to do some task if 3 men need 12 h to do the same task.	45	66	55
13. A car travels at 80 km/h for 2 h and then at 100 km/h for 3 h. Calculate the average speed of the car. (Note: average speed = total distance travelled/time).	54	-	54

NW, North West province teachers; KZN, KwaZulu-Natal province teachers; NW + KZN, combined data.

Question 3 mainly tested whether teachers recognised the importance of initially reading the problem carefully and clarifying it to aid its solution. Because substance A breaks down only partially, there will be unreacted A in the vessel and the substances present after reaction will therefore be A, B and C. About 40% of the teachers tested thought incorrectly that the substances present were B and C only. Discussions with the teachers, after the test, indicated that most of them had no difficulty in recognising that there was also undissociated A. Their difficulty in the test was probably associated with their rushing into the solution without first carefully reading the problem clarifying it.

Question 4 is a simple non-science problem. Its solution is not difficult if the data and the goal are first represented in a coordinated manner in one place. A good way of doing this is to construct a table as shown in Table 2.

Because the information needed to solve the problem is collected together concisely in one place in a coordinated manner, it is easy to focus on the solution to the problem, without distraction. Because 16:00 in Sydney = 08:00 in Johannesburg, it is easy to deduce (by adding 2 h to both) that 18:00 in Sydney = 10:00 in Johannesburg. Using this time (10:00) in Johannesburg, it is easy to similarly deduce (using the information 12:00 in Johannesburg = 06:00 in New York) that the time in New York is 04:00 when it is 10:00 in Johannesburg (part (b) of the question). About half of the teachers could not solve this problem. Most of them did not clearly represent the problem by collecting together all the relevant information in one place. They either did not recognise the importance of doing this or were unable to do this.

Question 5 also mainly tested whether teachers initially clarified the problem, without rushing into its solution. The V term in the equation $c = n/V$ is the volume of solution (and not the volume of solvent). The volume of solution, which is equal to the sum of the volumes of the solvent (water) and solute (ethanol), must evidently be greater than the volume of solvent (1.00 dm^3) and will therefore be greater than 1.00 dm^3. The concentration of ethanol (by equation $c = n/V$) will therefore be less than 1.00 mol/dm^3, because n = 1.00 mol and V is greater than 1.00 dm^3. Despite the simplicity of the problem, the performance of the teachers was very poor. About 90% of them had difficulty: most thought that the concentration was 1.00 mol/dm^3. Most teachers' errors in this problem were probably associated with their rushing into the solution without first trying to clarify the problem and present it clearly.

Questions 1–5 do not involve difficult concepts. The solutions to these problems, however, need handling and processing of many items of information (concepts, data and goal).

TABLE 2: Representation of data and goal as a table.

	New York	Johannesburg	Sydney
Data	06:00	12:00	
		08:00	16:00
Goal	?	?	18:00

There is evidence[17,18] that many people have difficulty with simultaneously processing many items of information and this has been attributed to limitations in working (short-term) memory. Coordinating all the relevant information in one place, for example in a diagram or table, would help to overcome this difficulty, at least partially, and therefore aid problem solving.

Identification and focusing on the goal

Questions 6 and 7 tested whether the teachers identified the goal explicitly and focused on it sharply when solving the problems, without being distracted by irrelevant information. There is ample evidence[14,19] to show that this is a crucial strategy for successful problem solving.

Question 6 is easy to solve if we write the defining equation for the required quantity ($d = m/V$) and then focus on it. This equation shows that to calculate d we need only m and V. Because these are given in the data (m = 5.0 g, V = 2.0 L), d can easily be calculated: d = 5.0 g/2.0 L. Though this calculation is very easy, about 40% of teachers had difficulty. Their answer scripts showed that their difficulties were mainly because they did not start the solution by focusing on the defining equation $d = m/V$. Instead, they tried to solve the problem by manipulating the irrelevant data given.

Question 7, like Question 6, is also easy to solve if we start its solution with the defining equation for mole fraction (x_A) of A, which is $x_A = n_A/n$. This equation shows that x_A depends only on n_A (moles of A) and n (total number of moles). Because the amount of a substance (n) is a basic physical quantity (four other basic physical quantities are length, mass, time and temperature), it does not depend on any other quantity. Therefore x_A will not change when pressure or temperature is changed. Despite the problem's simplicity, about 85% of teachers were unable to solve it. This suggests that most teachers did not focus sharply on the defining equation to solve the problem.

Identification and use of the relevant principles

Questions 8 and 9 tested whether teachers recognised that to solve any problem it is necessary to initially identify the principles that need to be used to obtain the solution (because deductions and calculations must always be based on principles). Recognition of the principles needed would sharpen and guide problem solving and also help to avoid errors.

Question 8 involves a basic physical quantity (mass), which will not therefore depend on any other quantity. The mass of substance A present in the vessel therefore will not change when pressure is changed: it will be 1.2 g. Despite the problem's simplicity, about 50% of the teachers tested were unable to solve it correctly. Most of them thought incorrectly that mass would be doubled when pressure was doubled and a few thought that mass would be halved. These errors were probably the result of their not recognising that deductions must always be based on principles. Though no principle relates mass and pressure, most teachers implicitly assumed that mass is directly proportional to pressure and hence would double when pressure is doubled.

Question 9, like Question 8, needed the identification and use of the relevant principles for its solution. The statement given, 'The volume (V) of a liquid increases when its temperature (T) is increased' is a qualitative statement and cannot therefore be used to do any calculation. From this statement we can deduce that the final volume will be greater than the initial volume (which is 10.0 cm^3). We also know from experience that the volume of a liquid (e.g. water) increases only slightly when temperature is increased and that it does not double when temperature is doubled. The final volume will therefore be slightly greater than 10.0 cm^3 but less than 20.0 cm^3. About 75% of the teachers thought incorrectly that volume would double from 10.0 cm^3 to 20.0 cm^3 when temperature is doubled. Their error may be attributed to their not recognising the need to first identify explicitly the principle that should be used to obtain the solution. Instead, they made the incorrect assumption that the volume of a liquid is directly proportional to its temperature.

Use of equations for deductions

Questions 10 and 11 tested whether teachers used the important strategy of making use of equations for deductions. For Question 10, the solutions are easy if the equation $d = m/V$ is used for deducing the required answers. This equation shows that d depends only on m and V and therefore that d can change *only* if m or V changes. A change in temperature can affect d only if it changes m or V. Consider part (a) of the question. Because V is kept constant, and also because a change in temperature will not change mass, it can easily be concluded from the equation $d = m/V$ that d will not change if temperature is changed. More than 75% of teachers however thought incorrectly that d would be doubled if temperature was doubled. For part (b) of the question, the performance was better: 65% of teachers answered it correctly. The poor performance of teachers in this question may be attributed to their not using the important strategy of using equations to deduce the answers.

Question 11 mainly tested whether teachers recognised the necessity for deriving, as the first step, an appropriate equation that can be used for deducing the required answer. To deduce whether volume (V), mass (m) and temperature (T) are sufficient to calculate the molar mass (M) of a gas, it is necessary to derive first the equation that relates M to V, m and T. This equation, which can be derived by combining the two given equations $M = m/n$ and $pV = nRT$, is $M = mRT/pV$. This equation shows that to determine M we need values for m, R, T, p and V. The information given (V, m and T) is therefore not sufficient to determine M. The teachers' performance in this question was very poor. About 80% of them did not know how to set about solving the problem. They did not recognise the need for the initial derivation of the equation $M = mRT/pV$ from which the required answer has to be deduced.

Questions 10 and 11 illustrate a very important use of equations. It should be remembered that equations are storehouses of knowledge. They should therefore be used not only for calculations but also for making deductions. The use of equations for deductions is generally much easier and better than the use of verbal reasoning for this purpose. Question 11 illustrates this clearly. It is very difficult to answer this question using verbal reasoning.

Proceeding step-by-step with the solution

Questions 12 and 13 mainly tested whether a step-by-step procedure (and therefore step-by-step reasoning) was used for the solutions, with emphasis being placed on solving one step at a time. In Question 12 the goal is the calculation, using the equation $t = k/N$, of the time (t) needed by four men (i.e. $N = 4$) to do some task. For this calculation, the value of k must be known but is not given. The first step in the calculation must therefore be to calculate k and this can be done by substituting the given data (N = 3 men, t = 12 h) into the equation $k = Nt$ (this equation can be obtained by rearranging $t = k/N$) and then calculating: k = 3 men x 12 h = 36 men.h. This value of k can then be used to do the required calculation: $t = k/N$ = 36 men.h/4 men = 9 h. Though this is an easy calculation, 45% of the teachers could not do it. Their answer scripts showed that the main reason for their difficulty was their attempting to do the calculation in one step: by applying the equation only once (it has to be applied twice and for this step-by-step reasoning is required).

Question 13 also tested whether a step-by-step procedure was used for the solution of the problem. The defining equation $s = d/t$ shows that to calculate s it is necessary to first calculate d and t. Because d = (80 km/h x 2 h) + (100 km/h x 3 h) = 460 km and t = 2 h + 3 h = 5 h, it is easy to calculate s: $s = d/t$ = 460 km/5 h = 92 km/h. Despite the familiarity and simplicity of this problem, about 45% of teachers were unable to do this calculation. Their answer scripts showed that the main difficulty was because they did not proceed step-by-step. Many attempted to solve the problem in one step by manipulating the given data.

Summary

The main objective of this study was to test the competence of matric physical science teachers, from Dinaledi schools in the North West and KwaZulu-Natal provinces, in some important intellectual strategies. The strategies tested were basic strategies that are crucially important for successful problem solving in science courses. Most of them would also help pupils to cope with problems encountered in their daily lives

TABLE 3: The percentage of teachers who incorrectly answered questions testing each strategy.

Strategy	Incorrect (%)
1. Clear presentation of problems	53
2. Identification and focusing on the goal	62
3. Identification and use of the relevant principles	63
4. Use of equations for deductions	67
5. Proceeding step-by-step with the solution	45
Average	**58**

and therefore to achieve greater success in their lives. Because these strategies are of fundamental importance, they should become automatic mental operations or habits of the mind.

A summary of the teachers' performance in each of the strategies tested is shown in Table 3. The teachers' competence was poor in all the strategies tested. Even though the teachers' competence in them was poor, the strategies themselves are not difficult to understand and to use. Consider, for example, the two strategies 'Identification and focusing on the goal' and 'Proceeding step-by-step with the solution'. These strategies do not involve difficult concepts and are not difficult to understand. Difficulties associated with these strategies, in the author's experience, are mainly caused by non-recognition of the importance of these strategies for successful problem solving.

The teachers' lack of competence in intellectual strategies and skills would seriously handicap the successful implementation of the matric physical science curriculum because this curriculum places strong emphasis on the training of pupils in various types of intellectual abilities. It would not be reasonable to expect teachers who are not very competent in intellectual skills and strategies to train pupils in them. A prerequisite for curriculum change is teacher change. This aspect has been discussed, along with other aspects, by Rogan[8] for the learning of science and by Velupillai et al[9] for the learning of mathematics. Training of teachers in intellectual skills and strategies should therefore be considered to be a priority.

Recommendations

The following approaches may help in increasing the competency of teachers in intellectual skills and strategies.

Pre-service training of teachers

In pre-service courses, greater attention should be paid to the development of the competence of teachers in the various types of intellectual skills and strategies that are important for the efficient learning and application of knowledge in physical science courses.

Conduction of workshops

Workshops should be conducted for teachers to increase their competence in intellectual skills and strategies. Universities in each province should be entrusted with the task of conducting workshops in that province because many workshops will generally be needed to ensure acquisition of intellectual abilities. The progress of teachers must also be continuously monitored.

Provision of written material

Written material on intellectual skills and strategies must be made available to teachers. This could be in the form of a monograph, or in quarterly (or monthly) newsletters/bulletins that also deal with other aspects concerning the curriculum.

Integration of intellectual skills/strategies with subject content

The matric syllabus and schedules of work are presently stated only in terms of acquisition of content knowledge. They should be expanded to include training in explicitly identified intellectual skills and strategies. The training in intellectual abilities should be integrated, throughout the course, with the learning of subject content.

Intellectual skills/strategies in examination questions

Because how teachers teach and how pupils learn are determined predominantly by the types of questions set at examinations, and not by the objectives stated in the curriculum, it is essential that examination question papers have some questions testing intellectual skills and strategies. Because of the crucial importance of examination question papers for the achievement of the stated objectives of any curriculum, an examination board of experts would be needed in each subject to monitor the question papers and improve them annually.

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