- identification of any bias intrinsic in the evaluation tasks
- assessment of differential responsivity to training.

With reference to the first matter for investigation, analysis of untrained performances showed that older subjects and subjects of higher IQ tended to obtain higher scores than their younger counterparts and their lower IQ peers respectively on both Piagetian-based tasks and the learning material. However, this observation was not statistically significant for the sample in general. There was also no significant difference between the scores obtained by the boys and by the girls. On balance, therefore, neither the Piagetian tasks nor the learning material inherently discriminated against any particular group divided by age, IQ or sex.

The possibility of interaction between the efficacy of training and the three variables was assessed via the performances observed on the train task and on the posttest. There were no differential benefits from training with respect to these factors with the exception of the higher IQ Standard Nine boys who benefited less than other groups of subjects. It is therefore recommended that training in the normal school situation should be presented at the Standard Eight level for all pupils to derive maximum benefit. This would further have the advantage that pupils would be subjected to the training during their foundation year of the Standards Nine and Ten syllabuses (Chapter 1).

11.2.3 Piaget's First Chemical Experiment

Two subsidiary goals of the thesis were achieved. The colourless liquids task of Inhelder and Piaget was used as pretest to assess modes of combinatorial functioning. There have been few replications of the traditional task to establish norms of procedure and interpretation, despite the acceptance ot protocols and the reported behaviours as the operational definition of formal combinatorial thought. A technical procedure aimed at reducing logistical problems was therefore described (Appendix A) and the structure of the first chemical experiment was analysed (Chapter 4).

Results tied up closely with those reported by Dale (1970) but performances were below the ideal competence levels described by Inhelder and Piaget (1958). The present detailed analysis should assist other workers in clarifying the expected types of responses on this task. It was shown that neither the ability to solve the problem only nor the ability to generate a complete factorial array only is equivalent to formal combinatorial thought. Both these skills need to be mastered for competence in combinatorial reasoning. This finding supports the tenets of Inhelder and Piaget. The results observed led to the development of a measurement scale for the allocation of Piagetian levels in terms of the content area of the chemicals task.

11.3 Educational Implications

The foregoing results suggest that a revised view of the function of intellectual training is required. Not only is training a concern within the domain of educational research but this activity also has challenging practical implications for the classroom. Although the study is exploratory, it would appear from the results that training in combinatorial reasoning is able to offer large dividends for comparatively little effort if training were to be conducted on a group basis. There is no reason to believe that the training of large numbers of pupils is not practicable. While for the purposes of this research, training was carried out individually, the fifteen-minute group reinforcement session was conducted with groups of pupils and was found to proceed effectively and conveniently. The non-formal evidence seems to suggest, therefore, that all cognitive interventions in the routine learning environment, including initial training, could be carried out in groups i.e. class by class.

Implementation of training in the normal school situation would lead to the following educational improvements :

- Enhanced grasp of abstract concepts involving combinatorial reasoning.

- Reduction of a multiplicity of problems into a single basic combinatorial category i.e. a global view of such subject-matter would be afforded to the learner and the relationships between initially apparently unlinked facets of the subject-matter would be made clear.

- The understanding thus achieved would have desirable repercussions on the factual knowledge surrounding such combinatorial reasoning ts of the syllabus.

- The insight provided via enhanced combinatorial thought would have a ripple effect on other aspects of the syllabus which do not involve combinatorial reasoning.

- The positive attitudinal outcomes of enhanced achievement, namely, increased enjoyment of the subject and greater motivation, would be particularly beneficial in view of the current lack of interest in physical science shown by high school pupils.

The weight of evidence in the thesis has shown that training is able to promote generalisable combinatorial reasoning skills, the ability to grasp abstract concepts related to such skills and mastery of the relevant terminology. The practical teaching experience of the author has shown that instruments such as summaries and flow diagrams which clearly indicate the relationships among various aspects of the syllabus and which emphasise similarities and differences, are powerful aids to clarification and consolidation in science learning. In the light of this experience, the global view afforded by the training appears attractive. Further, personal observation of pupils in the classroom on a non-formal basis seems to suggest that any enhanced achievement in one or more aspects of the syllabus invites a ripple effect over that whole section of the syllabus. It is likely that such a ripple effect stems from the dual sources of increased understanding and positive affective views.

The apparently lasting effects of the training are suggested by an incident in the year following the experimental aspects of the training study. The author had by then taken up a position at the school where the research had been conducted. Several pupils who had participated in the training programme at Standard Eight level, expressed, uninvited, gratitude for the training which they had received. They said how useful the training had proved in their Standard Nine year and how easy the advised approach to combinatorial problems had been to remember and to apply.

The conclusion reached overall, is that further, extended exploration into the incorporation of training into science instruction of schools is necessary. Such further studies are warranted in terms of the potentially enormous benefits that may accrue in, not only science education in particular, but education as a whole.

11.4 Proposals for Future Work

It is suggested, to improve performance on different tasks, that many more training studies in all aspects of formal reasoning be carried out. In any study devoted to a particular logical operation, it is important to conduct more than one test to arrive at an overall impression of the child's abilities in the particular cognitive area under examination since generalising formal reasoning to a different subject-matter field is not automatic. Any training course must be tailored to suit the results of the screening test for each individual. For example, late formal subjects should be removed from the training procedure as they are likely not to benefit as indicated by the present study. In addition to the study of particular operations, further research should then be carried out into the outcome of training on multiple cognitive operations so as to study interactive effects.

Ideally, such training studies should be linked more to the classroom situation because of their marginal benefits. Once sustained experimental progress has been made, the teaching of logical operations could be integrated with the more usual classroom activities involving instruction on specific science concepts. An important facet of instruction would be the presentation of pupil exercises when formal reasoning skills must be considered and applied to the specific problems under consideration.

Continued research should eventually produce conclusive evidence on the realities of successful training. At such a stage, science teachers must be persuaded of the value of the application of such findings in their classrooms :

> *A major problem of science education (not unlike other areas of education) is the failure of research to affect practice.* (Yager, 1984, p. 35).

Educational research is, after all, ultimately intended to be applied in the practical educational situation.

APPENDIX A

TECHNICAL PROCEDURE FOR TROUBLE-FREE ADMINISTRATION OF PIAGET'S FIRST CHEMICAL EXPERIMENT

A.1 Equipment

The equipment consisted of five volumetric flasks with stoppers, clearly labelled from one to five. The first four flasks each had a capacity of 250 cm^3 while the last flask was smaller, with capacity 100 cm^3. The flasks contained, respectively,

(1) dilute sulphuric acid, 0,8 mol. dm^{-3}.
(2) distilled water.
(3) hydrogen peroxide, 0,9 mol. dm^{-3}.
(4) sodium thiosulphate ($Na_2S_2O_3.5H_2O$) solution, 0,1 mol. dm^{-3}.
(5) potassium iodide (KI) solution, 0,1 mol. dm^{-3}, designated by Inhelder and Piaget (1958) as solution g.

The relatively large size of the flasks enabled administration of the task several times before pausing to replenish solutions.

In addition, several racks of test-tubes were provided, in which the solutions could be combined by the subjects.

A.2 Preparation of Solutions

A.2.1 Concentrations of Solutions

Hydrogen peroxide reacts with iodide in acid solution :

$$H_2O_2 + 2H^+ + 2I^- \rightarrow \underset{\text{yellow}}{I_2} + 2H_2O$$

The concentrations of the solutions (refer to section A.1 above) were fairly high for the following reasons :

(i) The reaction velocity is comparatively slow, but increases with increasing acid concentration. Subjects could not be expected to mix combinations of solutions with the practical skill arising from analytical experience. The concentration of the sulphuric acid was such that an instantaneous yellow colour would appear on selecting the correct combination, without any stirring of the mixture being required.

(ii) An unmistakeable, intense yellow colour should be produced by the correct combination of solutions, irrespective of the relative volumes used by the subjects, which might result in large dilution factors for the active chemicals. Subjects were not limited as to the volume of solutions allowed other than by example (when demonstrating) and by remarks such as, *You are not going to have room for any more.* (Dale, 1978). It was felt that any limitation might distract the subjects from their task.

A.2.2 Stabilities of Solutions

The stabilisation of the solutions as far as possible was of concern because, not only does hydrogen peroxide decompose with time, but both sodium thiosulphate and potassium iodide solutions have a tendency to deteriorate with visible effect which must be avoided as one of the essentials of the experiment is that all five solutions should appear identical. (In fact subjects frequently compared solutions by close inspection and by smell). On the other hand, it would be desirable to avoid the inconvenience of preparing fresh solutions daily during the temporally condensed testing schedule.

The following measures, adapted from the chemistry textbook by Vogel (1959), eliminated these sources of trouble.

A.2.2.1 Hydrogen Peroxide Solution

Exposure to light was avoided whenever the solution was not in use, as light tends to hasten decomposition.

A.2.2.2 Sodium Thiosulphate Solution

There is usually an excess of carbon dioxide in the distilled water with which the solution is prepared. This may cause a slow decomposition with the formation of sulphur :

$$S_2O_3^{--} + H^+ \rightarrow H_2SO_3^- + S$$

yellow

Furthermore, bacterial action may also cause decomposition, particularly if the solution has been standing for some time. For these reasons, the solution was prepared with

(a) freshly boiled distilled water, and

(b) three drops of chloroform per litre of solution, which compound improves the keeping qualities of the solution.

Moreover, since bacterial activity is least for pH 9–10, the addition of 0,1 g of sodium carbonate per litre of solution ensured the correct pH (Vogel, 1959).

Finally, since exposure to light tends to accelerate decomposition, the solution was stored away from the light.

A.2.2.3 Potassium Iodide Solution

Potassium iodide solutions have a tendency to decompose within a few days, giving rise to a yellow colour which would alter the presentation and thus the design of the colourless chemicals task. This colour change was avoided by the use of

(a) iodate-free potassium iodide :

$$IO_3^- + 5I^- + 6H^+ \rightarrow \underset{\text{yellow}}{3I_2} + 3H_2O$$

The absence of iodate is indicated by testing the iodide with dilute sulphuric acid when no immediate yellow colouration should appear (Vogel, 1959).

(b) distilled water, as acid solutions of iodide are oxidised by oxygen of the air :

$$4I^- + O_2 + 4H^+ \rightarrow \underset{\text{yellow}}{2I_2} + 2H_2O$$

A.3 Prevention of Any Colour Formation Irrelevant to the Task

Apart from the measures described above, further steps are essential for trouble-free administration of the task.

Test-tubes must be clean to prevent various *'incorrect'* combinations of solutions leading to the formation of the yellow colour, caused by traces of chemicals residual from previous use. Tap water is adequate to rinse out the test-tubes, provided the following adjustment is made. In the presence of tap water (H_3O^+), the yellow colour may be produced with the hydrogen peroxide and potassium iodide solutions only. This can be avoided by making the hydrogen peroxide solution slightly alkaline with sodium hydroxide (Dale, 1978).

Sometimes certain combinations of solutions develop the yellow colour on standing. This may lead subjects to fallacious conclusions which can be prevented at the outset of the task by instructing subjects to search for immediate colour changes only.

Combinations of acid, hydrogen peroxide and sodium thiosulphate solutions (with or without water present as a fourth *'solution'*) result in a pale yellow cloudiness which could divert a subject's attention but should not be investigated as it is irrelevant to the task (Dale, 1978).

A.4 Additional Solutions for the Modified Task

A.4.1 Starch Solution

A paste of 1,0 g of soluble starch was made with a little water and the paste was poured with constant stirring into 100 cm^3 of boiling water and boiled for one minute (Vogel, 1959, p. 347). The common practice of preserving the solution with mercuric iodide was precluded by the chemical design of the posttest task. Consequently only freshly prepared starch solution was used. The solution was kept in a stoppered bottle and the supernatant liquid which was only very faintly opalescent and would not attract the attention of subjects, was poured off for use in the posttest task.

A.4.2 The Sulphuric Acid/Hydrogen Peroxide Mixture

This mixture consisted of a 1:1 by volume solution of sulphuric acid and hydrogen peroxide, 0,8 mol. dm^{-3} and 0,9 mol. dm^{-3} in final solution respectively. The reason for high concentrations has been discussed earlier.

APPENDIX B

LIST OF STANDARD QUESTIONS FOR THE PIAGETIAN PRE- AND POSTTESTS

This list is reproduced by courtesy of Dr. L.G. Dale.

QUESTIONS TO BE ASKED

Subjects should be encouraged to talk freely and questions should be used to encourage subjects to talk about what they are doing. Care must be taken to avoid intimidating nervous children by asking too many questions. Questions asked should be confined, as far as possible, to the following, although additional questions may sometimes be desirable in order to clarify how the subject is thinking.

A IF S FAILS TO OBTAIN YELLOW COLOUR

1. What else can you do?
2. Are you sure you've tried everything?
3. Have you tried using two (three, four, all) liquids?
4. Try something else.
5. Do you need all of them?

B IF S OBTAINS THE COLOUR THEN STOPS WITHOUT TESTING THE EFFECT OF EACH LIQUID

1. Which ones make the colour?
2. Can you make it in some other way?
3. Are all three (or four) necessary?
4. You can try again.

C IF S OBTAINS COLOUR BUT DOESN'T KNOW WHY

1. Make it again.
2. What makes the colour?
3. Try something else.
4. Use as few liquids as possible.
5. Are all three (or four) necessary?

D IF 4 INTERFERES

1 What made the colour go away?
2 Why doesn't the colour come?

E TO CHECK UNDERSTANDING

1 Which ones make the colour?
2 What does this one do? (point)
3 Tell me what each one does.
4 Show me (in response to an answer).
5 Make the colour again.
6 Do you need all of these?

F IF S MENTIONS WATER AS ONE OF THE LIQUIDS

1 Do you think there is water in any of the bottles?
2 Which one do you think is water?
3 Why do you think it is water?
4 What are the others?

G IF S IS NOT TALKING FREELY

1 What are you trying to do?
2 Why are you doing that?

FINAL THREE QUESTIONS

Q.1 Which ones must you use to get the colour?
Q.2 What does 2 do?
Q.3 What does 4 do?

APPENDIX C

PIAGET'S FIRST CHEMICAL EXPERIMENT : TYPICAL RESPONSES FOR EACH OF THE PIAGETIAN CATEGORIES

C.1 Response Assessed at the Late Formal Substage

Name: A.B. Date: 15/5

Time on task: 34 minutes

Liquid 1 KI
2 H_2SO_4
3 H_2O
4 H_2O_2
5 $Na_2S_2O_3$

t.t.	Liquid 1	2	3	4	5	Subject's Comments	Tester's Comments
1	√	√	√	√	√	This means that something is stopping the yellow colour, so I'll try with fours. It is possibly liquid 5, otherwise the colour might have appeared and then been bleached.	Order 5 4 3 2 1
2	√	√	√	√		Yes, liquid 5 prevents the colour.	Order 1 2 3 4. Yellow.
3			√	√		I'm going to look for another way of making the colour. Liquid 4 caused a colour change when I used 1,2,3 and 4. This means that liquid 4 is essential.	Order 4 3
4		√		√			Order 4 2
5	√			√		I've already tried 4 and 5 together in the combination 5 4 3 2 1 in my first test-tube. Combinations of twos do not work. Perhaps threes will give me yellow.	Order 4 1
6	√	√		√		Liquid 3 smells like water. It has no effect as it is absent here and present in t.t 2. I'll just check that liquid 3 does not give a	Order 4 1 2. Yellow.

Name: A.B. (continued) Date: 15/5

Time on task: 34 minutes

Liquid 1 KI
2 H_2SO_4
3 H_2O
4 H_2O_2
5 $Na_2S_2O_3$

t.t.	Liquid 1	2	3	4	5	Subject's Comments	Tester's Comments
7		√	√	√		yellow colour with any other combination. Of course, liquid 4 must be present in any combination I try.	Order 4 3 2
8	√		√	√		Now I have tried all combinations of threes. I have also tried all twos, either on their own or as the first stage of a larger combination. It could be that liquid 5 prevents the colour with certain combinations but not necessarily with others.	Order 4 3 1
9			√		√		
10		√			√		
11	√				√		
						There is still the possibility that liquid 5 could combine with three other liquids to give yellow. I am thinking how to do this most efficiently. 1, 2, 4 and 5 may work as liquids 5 and 3 could combine to prevent the colour in 1, 2 and 4 in the combination 1, 2, 3, 4 and 5.	
12	√	√		√	√	It is possible that liquid 3 is not water.	
13	√	√		√			Order 1 2 4. Yellow.

Name: A.B. (continued) Date: 15/5

Time on task: 34 minutes

Liquid 1 KI

2 H_2SO_4

3 H_2O

4 H_2O_2

5 $Na_2S_2O_3$

t.t.	Liquid 1	2	3	4	5	Subject's Comments	Tester's Comments
13	✓	✓		✓	✓	Liquid 5 bleaches the yellow. This means that liquid 3 has no effect at any time. Perhaps I should have investigated this sooner. I could have looked at these effects in t.t.6, but I would not have gained full information at thatstage. Summarising the problem, there is only one way of making the colour, using liquids 1, 2 and 4. Liquid 3 has no effect, while liquid 5 both prevents and bleaches the yellow colour.	

C.2 Response Assessed at the Early Formal Substage

Name: C.D. Date: 5/6 Liquid 1 KI

Time on task: 27 minutes 2 H_2O

3 H_2SO_4

4 H_2O_2

5 $Na_2S_2O_3$

t.t.	Liquid 1	2	3	4	5	Subject's Comments	Tester's Comments
1	✓	✓					Order 1 2
2	✓		✓				Order 1 3
3	✓			✓			Order 1 4
4	✓				✓		Order 1 5
5		✓	✓				Order 2 3, etc.
6		✓		✓			
7		✓			✓		
8			✓	✓			
9			✓		✓		
10				✓	✓	Can the colour come with any number of solutions?	Q.A.1
11	✓	✓	✓				
12	✓	✓		✓			
13	✓	✓			✓		
14	✓		✓	✓		All three are necessary as 3	Yellow. Q.1

Name: C.D. (continued) Date: 5/6

Time on task: 27 minutes

Liquid 1 KI
2 H_2O
3 H_2SO_4
4 H_2O_2
5 $Na_2S_2O_3$

t.t.	Liquid 1	2	3	4	5	Subject's Comments	Tester's Comments
						and 4 didn't work, 1 and 4 didn't work, nor did 1 and 3.	
							Q. B.2
15	✓		✓		✓		Order 1 3 5
16	✓			✓	✓		Order 1 4 5
17		✓	✓	✓			Order 2 3 4, etc.
18		✓	✓		✓		
19		✓		✓	✓		
20			✓	✓	✓		
21	✓	✓	✓	✓			Yellow. Q.1.
						All four solutions are essential as every combination with one of the four liquids missing didn't work.	
							Carry on with your investigation.
22	✓	✓	✓		✓		
23	✓	✓		✓	✓		
24	✓		✓	✓	✓	Solution No. 5 counteracts the yellow colour.	Order 1 3 4 5. Yellow produced and then disappears.
25		✓	✓	✓	✓		
26	✓	✓	✓	✓	✓	This is what I would have expected as No. 5 has a bleaching effect.	Colourless.

C.3 Response Assessed at the Transitional Stage

Name: E.F. Date: 19/5

Time on task: 40 minutes

Liquid 1 $Na_2S_2O_3$
2 H_2O
3 H_2O_2
4 H_2SO_4
5 KI

t.t.	Liquid 1	2	3	4	5	Subject's Comments	Tester's Comments
1	✓	✓					Order 1 2
2	✓		✓				Order 1 3
3	✓			✓			Order 1 4
4	✓				✓		Order 1 5
5		✓	✓				Order 2 3, etc.
6		✓		✓			
7		✓			✓		
8			✓	✓			
9			✓		✓		
1	✓	✓	✓				
2	✓		✓	✓			
3	✓			✓	✓		
2	✓	✓	✓	✓			
3	✓	✓		✓	✓		
3	✓	✓	✓	✓	✓		
4	✓	✓			✓		
4	✓	✓		✓	✓		(Repeated combination.)

Name: E.F.(continued) Date: 19/5

Time on task: 40 minutes

Liquid 1 $Na_2S_2O_3$

2 H_2O

3 H_2O_2

4 H_2SO_4

5 KI

	Liquid					Subject's Comments	Tester's Comments
	1	2	3	4	5		
[illegible]		✓	✓	✓			
		✓	✓	✓	✓		Yellow. Q.1
						You can't get the yellow colour with a combination of two solutions as I have tried all combinations of twos. Perhaps the colour can be made with three solutions but I can't tell that yet.	
[illegible]		✓	✓	✓			(Repeated combination.)
		✓	✓		✓		
		✓	✓	✓	✓	Oh, I made the colour the same way as before!	Yellow. (Repeated combination.)
[illegible]			✓	✓	✓	This proves that only three of the four solutions have to be used.	Yellow.
							Any three?
						Not 2 3 4, but certainly 3 4 5. Maybe 2 4 5.	
10		✓		✓	✓	No, not 2 4 5. Maybe 2 3 5	
11		✓	✓		✓	No, not 2 3 5. You have to choose the specific combination, 3 4 5	(Repeated combination.)
							Q.2
						No effect. Solution No. 2 could be water, comparing the contents of test-tube No. 5 with test-tube No. 8.	

Name: E.F. (continued) Date: 19/5

Time on task: 40 minutes

Liquid
1 $Na_2S_2O_3$
2 H_2O
3 H_2O_2
4 H_2SO_4
5 KI

t.t.	Liquid 1	2	3	4	5	Subject's Comments	Tester's Comments
							Q.3
						No effect, that is to say, Solution No. 1 actively stops the reaction which produces yellow. Look at test-tube No. 3. There is no colour there.	
							How many ways do you think the colour can be made?
						Only two ways, unless the order in which solutions are mixed makes a difference. I don't think there are any more combinations, as I have tried them all.	

C.4 Response Assessed at the Concrete Stage

Name: G.H. Date: 15/5

Time on task: 17 minutes

Liquid
1 $Na_2S_2O_3$
2 H_2SO_4
3 H_2O
4 H_2O_2
5 KI

t.t.	Liquid					Subject's Comments	Tester's Comments
	1	2	3	4	5		
1	✓						
2			✓	✓			Order 3 4
3	✓		✓				Order 3 1
3	✓	✓	✓				
3	✓	✓	✓	✓			
3	✓	✓	✓	✓	✓		
4	✓			✓			Order 1 4
4	✓		✓	✓			
4	✓	✓	✓	✓			(Repeated combination.)
5	✓	✓					
5	✓	✓	✓				(Repeated combination.)
5	✓	✓	✓	✓			(Repeated combination.)
5	✓	✓	✓	✓	✓		(Repeated combination.)
6	✓			✓			(Repeated combination.)
6	✓			✓	✓		
7			✓		✓		
7	✓		✓		✓		
8		✓		✓			
8		✓		✓	✓		Yellow. Q.1
						All three are necessary.	
							Why do you think so?
						It is just a feeling I have.	
						I'll try to prove it.	

Name: G.H. (continued) Date: 15/5

Time on task: 17 minutes

Liquid
1 $Na_2S_2O_3$
2 H_2SO_4
3 H_2O
4 H_2O_2
5 KI

t.t.	Liquid 1	2	3	4	5	Subject's Comments	Tester's Comments
9				✓	✓		
10		✓			✓	This proves that all three are necessary.	
							Q.1
						No, there is only one way to make the colour.	
							How do you know this?
						Because of what my friends have told me. In any case, there is no yellow colour with all five solutions. If you use only two solutions, you don't get yellow either. Four solutions also don't give you yellow. Only three solutions do.	
							Q.2
						Solution No. 1 prevents the yellow colour because it is an alkali and the other three liquids are acids. Whenever I tried No. 1 with the other solutions, the yellow colour did not come.	
							Q.3
						It is impossible to say what the effect of solution No. 3 is because you don't have enough information. You'd be able to say if you knew what the chemicals were.	

APPENDIX D

PLACEBO TREATMENT OF CONTROL SUBJECTS

D.1 Nature of the Task

The treatment received by control subjects replicated the activities of the members of the control group participating in a training study by Siegler and Atlas (1976). The rationale behind the selection of this task for the control subjects in this thesis is given in Chapter 5.

Siegler and Atlas (1976) conducted a programme to teach ten- and thirteen-year old boys and girls to execute a formal reasoning task, specifically, the detection of two-variable interactions in data. Each child was presented with four problems, each of which had two relevant and one irrelevant dimensions. The interactive patterns were stated as problems in the form of data sheets as shown in Table D.1. The problems involved an electric train whose speed (fast, slow or stationary) was determined by the way three knife switches were set. Such a train was physically present and attention was drawn to the analogy between the train and the data sheets as soon as pupils were given the data sheets.

The four different problems were classified according to Neale and Liebert's (1973) typology and involved additive interactions, catalytic interactions, terminative interactions and antagonistic interactions. An additive relationship means the absence of any interaction since each variable alone has some effect but the two combined have a greater effect. Both relevant switches down meant that the train would run fast. One but not the other down meant the train would run slowly. Neither down meant it would not move at all. A catalytic relationship means that both variables in conjunction are necessary to have any effect. Both relevant switches down indicated that the train would run fast and, in all other cases, the train would not go at all. A terminative relationship means that either variable singly or both in combination produce exactly the same effect. Either or both of the relevant switches down meant that the train would run slowly but if both were up, the train would not go. An antagonistic relationship means that both variables together produce a smaller effect than either separately. Both relevant switches down meant the train would run slowly. One but not the other down meant that it would run fast. Neither down indicated that the train would not move at all.

D.2 Materials

The pupils' task was to solve the four problems, each of which was presented on a data sheet, below which was stapled an answer sheet. As shown in Table D.1, the data sheet was an eight row by four column table. The first three columns of each row indicated a combination of positions in which the three switches could be set. The fourth column indicated the corresponding speed of the train for that particular switch setting. The eight possible settings of the switches were ordered randomly. Answer sheet tables (Table D.2) differed in two respects from the information on data pages : The fourth (train speed) column was blank and the eight rows were listed in a different randomly generated sequence. Answer sheets also included the possible pairs of switches, namely, 1 and 2, 1 and 3, and 2 and 3. Pupils were required to circle the controlling pair of switches and to indicate how the train functioned in terms of these two switches (Siegler and Atlas, 1976).

D.3 Administration of the Task

A sample data sheet was shown to pupils individually. It was explained that the sheet represented a train similar to the train set on display, with three switches and three possible speeds, namely, fast, slow and stationary. Each pupil was told that two of the switches were important in determining the train's speed on any one problem. The formats of the data and answer sheets were explained to pupils. They were told that they would be asked to fill in the last column of the answer sheet. To do this, they would first have to examine the data page to identify the two controlling switches and to discover their effect on the train's speed. They were then to write the solution down on the bottom of the answer sheet. To avoid direct reproduction of the eight rows from the data sheet, pupils, after having found the controlling pair of switches, were to fold the blank bottom of the data sheet in order to expose the lowest part of the answer sheet stapled beneath it. They were then to circle the pair of active switches and write down the corresponding speeds for all the different settings of these two switches. After this, pupils turned over the data page and used what they had written on the bottom of the answer sheet to fill in the top of the answer sheet (Siegler and Atlas, 1976).

Pupils were given twenty minutes to complete all four problems. The time limit proved ample for seventy-seven of the eighty-one subjects. The other subjects completed three of their problems without difficulty. Two of the four pupils were able to solve the remaining problem when given unlimited time. Contrary to the

Table D.1 Data Sheet for Placebo Task

DATA SHEET

Switch 1	Switch 2	Switch 3	Train goes
down	down	down	fast
up	down	down	slow
down	down	up	slow
down	up	down	fast
up	down	up	not at all
up	up	up	not at all
up	up	down	slow
down	up	up	slow

——————————— fold ———————————

NAME: ....

Table D.2 Answer Sheet for Placebo Task

ANSWER SHEET

Switch 1	Switch 2	Switch 3	Train goes
down	up	up	
down	down	up	
down	up	down	
up	down	up	
down	down	down	
up	up	down	
up	down	down	
up	up	up	

Which switches were important?

1 & 2 1 & 3 2 & 3

The way they worked was :

study of Siegler and Atlas, the first problem was not a practice task but all four problems were counted in assessment of performance.

Pupils received one problem of each type. Each of the switch-pairs was operative at least once in a given set of problems. The order of the four problems was presented as far as possible using a balanced Latin square design. This aimed to present each type of problem the same number of times in each position in the sequence and followed a problem of each other type the same number of times. For example, an antagonistic problem appeared equally often in the first, second, third and fourth positions. In addition, an antagonistic problem in a particular position followed additive, catalytic and terminative problems an equal number of times. The frequency of each pair of switches as the relevant dimensions within and across problem types was the same (Siegler and Atlas, 1976).

D.4 Results

The criterion for correct problem solutions was as used by Siegler and Atlas. A problem was considered solved only if the train speeds for all eight rows of the answer sheet were inserted accurately and the appropriate switch-pair was circled.

Table D.3 shows the percentages of correctly answered problems in the present study. The specific switch-pair which was active seems to make little difference. It also appears that the problem type makes little difference to performance but this was not tested statistically as these results are not relevant to the main theme of the thesis. The observed trend confirms the lack of problem type effects reported by Siegler and Atlas (1976). With untutored control subjects, they reported that 61% of additive problems were solved, 58% of catalytic and terminative problems and 55% of antagonistic problems. The percentages in the present study are higher owing to the older pupils used in this study.

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