

CHAPTER 5

THE TRAINING PROCEDURE

5.1 Background

The planning of a training methodology aimed at the inducement of combinatorial reasoning revolved around four sequentially connected considerations.

Firstly, existing deficiencies in the way pupils tackled factorial science problems had been observed during previous personal teaching experience. For instance, pupils if presented with a formula of the type

$$\begin{aligned} q &= m\theta c \\ p &= mv \\ E_k &= \frac{1}{2}mv^2 \\ W &= I^2 Rt \end{aligned}$$

would usually obtain correct numerical solutions, given values of the quantities appearing on the right-hand side of the equation. However, they would frequently encounter difficulties if they were given problems which did not merely involve number substitution but required, at the next level of complexity, combinatorial reasoning and, at a further level, proportional reasoning. Pupils would often experience particular difficulty with exercises in which the combination of a number of equations was necessary.

Secondly, in remedying this situation, ideally four factors would appear to require attention :

- (i) Ability to read the question, that is, to identify the problem posed in a given example.
- (ii) The use of combinatorial reasoning skills.
- (iii) The use of proportional reasoning skills.
- (iv) The ability to formulate and test hypotheses. (This ability arises as a consequence of general development of formal reasoning abilities and is not structurally separate from (ii) and (iii) above.)

Thirdly, within the scope of the present study, it is not possible to cover all these points because of the limited manpower available to conduct the research, because the field of investigation is very broad and the study would be temporally extended and because literature has shown (Chapter 2) that more effective results are obtained by concentrating on only one aspect of formal reasoning competencies. The selection of combinatorial reasoning skills as the focus of the training was prompted by the identification by Piaget of the combinatorial system as the gateway to formal thought processes and this system therefore seemed a reasonable point of departure for a study aimed at the acceleration of intellectual development. On the same grounds which demand a single domain of investigation, restrictions to the research objective itself had to be demarcated. Since the study was directed towards acceleration of progression through the gateway to formal reasoning abilities, it was decided that the training should aim to remedy one of the main deficiencies in adolescents who have not reached the formal stage of thought, namely, the lack of a systematic approach. The establishment of a combinatorial system, complete for the numbers involved in a problem, has been identified by Piaget (Inhelder and Piaget, 1958, p. 116) as one of the two innovations which appear at the early formal substage. (The second innovation is understanding of the role of particular combinations among the total number of possible combinations. The formation and growth of these deductive reasoning abilities would clearly offer an extensive field of investigation on their own.)

Fourthly, the scope of the training having been decided upon, consideration next had to be given to the techniques available for executing the study. Since there is a lack of agreement as to what constitutes training, there is a corresponding diversity of training methodologies. Most training procedures, however, entail some presentation of explanations, either implicitly or in explicit verbal rules. The most successful studies reported thus far have utilised the learning cycle (Chapter 2). The present training method therefore aimed to incorporate as many aspects of the learning cycle as practicable. The extent to which this was done will be discussed once the training strategy has been fully described. At that point also, the training will be analysed in terms of meeting conditions for progressive differentiation, since the training technique, along Piagetian lines, had to be designed to function simultaneously as an Ausubelian advance organizer (Chapter 3).

5.2 Training Methodology

5.2.1 General

The training procedure was a modified version of the strategy devised by Siegler and Liebert (1975). Their strategy displays the essential features of two of the various broad categories into which Kuhn (1974) placed training techniques related to inducing conservation but into which training methods aimed at other modes of cognitive reorganisation may also be divided. Characteristic of the first category, the procedure employed by Siegler and Liebert trained the attention of the subject towards relevant dimensions of the task and away from irrelevant perceptual or semantic cues. Characteristic of the second category, their procedure taught a verbal rule which embodied the principle which should be used by the subject in solving the problem. These general properties of the two categories clearly allow considerable leeway in the design and execution of individual training studies and the author is aware of no other workers who have conducted similar training trials to those of Siegler and Liebert.

Siegler and Liebert (1975) sought to develop factorial design skills in ten- and thirteen-year olds whom they trained to solve a combinatorial problem. Uninstructed, neither age group was able to generate complete factorial designs. The previous teaching experience of the author suggested that most of the present subjects would also be unable to produce such factorial arrays, despite their relatively increased maturation. The actual position will be assessed via the performances of the control subjects as described in Chapter 6 and 7.

Siegler and Liebert found that the type of instruction had a significant effect on task performance. After subjection to instruction on the conceptual framework and on the solving of problems analogous to the posttest problem by the use of this framework, a sizeable majority of all the children was able to generate all possible combinations in solving the final task. When provided the conceptual framework alone, only the older children benefited. Of these thirteen-year olds, 50% were able to generate complete factorial arrays whereas 100% of them succeeded when given analogous problem instruction as well as the conceptual framework.

Since the objective of the present research is the benefit of all the pupils irrespective of age or intellectual ability, it would appear that a training procedure involving both conceptual framework presentation and analogous problems affords the best chance of responsiveness to instruction.

The method of training described below was similar to that of Siegler and Liebert but a major difference in presentation was the degree of emphasis on generality. The latter researchers directed their training towards the solution of a specific combinatorial problem to the extent that before training had commenced, subjects were confronted with the problem which they would have to solve afterwards. Within the wider scope of the present study, pupils were subjected to training without intimation of future tasks since the research objective was the development of factorial design skills which would be generalisable. Transfer effects and their importance have been discussed in Chapter 2.

5.2.2 Presentation of Conceptual Framework

Each pupil from the experimental group was trained individually.

The researcher explained that a systematic approach to combinatorial tasks was desirable in view of the large number of possible solutions to apparently simple problems. It was next explained that one good method of systematic procedure for a factorial design was consideration of factors and their levels which could be represented schematically in a tree diagram. Each pupil was shown the schematic tree diagram reproduced in Figure 5.1. Replicating the training procedure of Siegler and Liebert, factors were introduced as *anything you believe will have an effect on something else*. The example of a car's ability to go forward being dependent on the states of its motor, brake pedal and accelerator pedal was presented as illustration. Levels were introduced as *ways that factors can be*. It was explained that each factor contained two or more levels. A motor could be on or off, so *on* and *off* were levels of the motor factor.

Each pupil was next shown a structurally identical, labelled tree diagram depicting growth conditions for plants. The variables involved had to be reduced in number and simplified to suit the present illustration: the absence or presence of water; the absence or presence of sunshine; good or poor soil. This differed from the *car going forward* example which was presented again by Siegler and Liebert at this stage of their study. This example was substituted as it was felt that a fresh illustration might reinforce the conceptual framework more effectively. Furthermore, it was anticipated that pupils might fail to realise that the absence of something should be considered a level of the relevant factor unless an example of this type had been specifically pointed out to them. This expectation was later found to be justified and is discussed in Chapter 7.

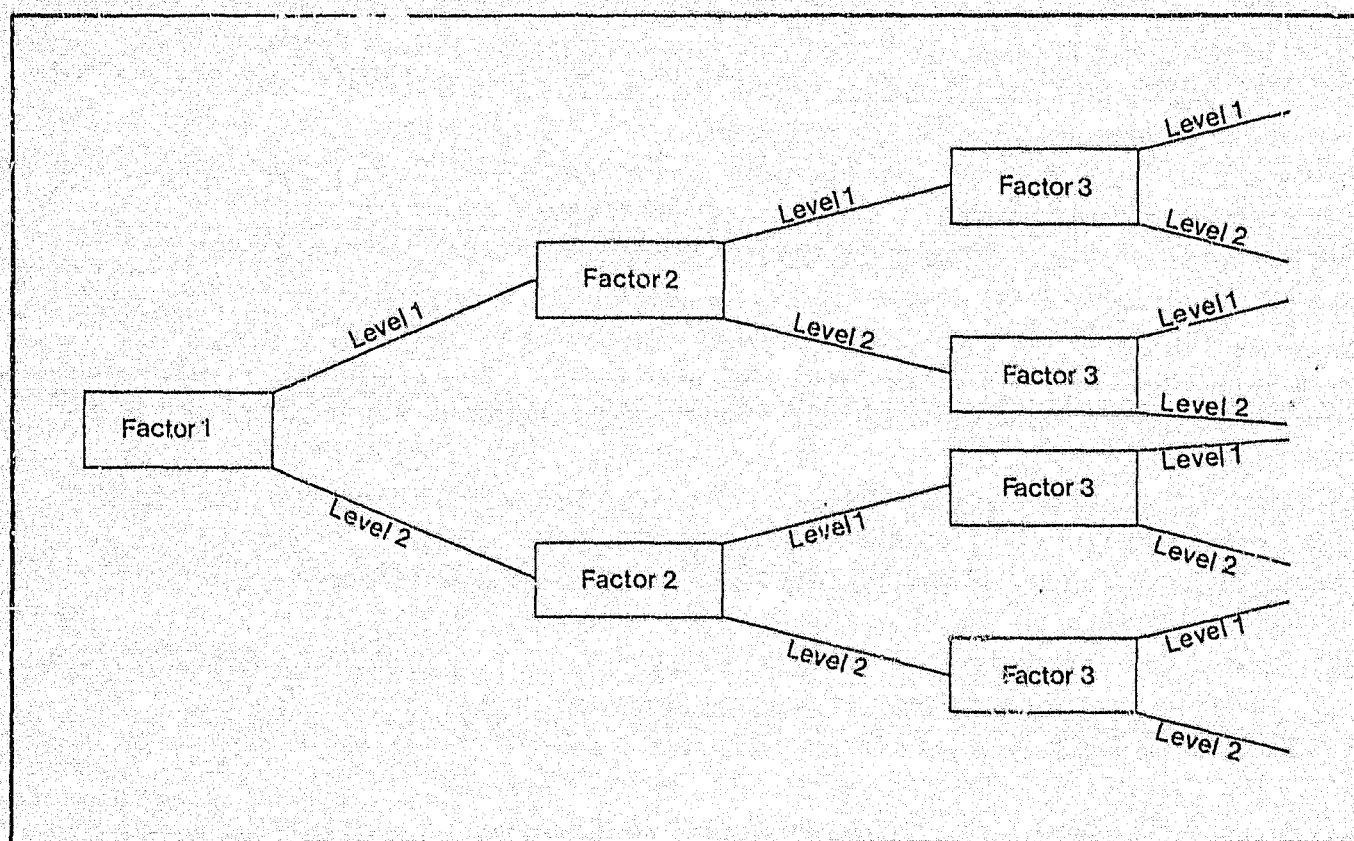


Figure 5.1 Schematic Tree Diagram which Indicates a Complete Factorial Array
(Modified from Siegler and Liebert (1975))

The schematic representation of growth conditions was used to explain how to extract all possible combinations of variables from a tree diagram. Moreover, the tree had been built up stepwise by the superposition of overhead projector transparencies so that it could be used to demonstrate the easiest way to construct tree diagrams. It was explained that after identifying the relevant factors and their levels a box should be drawn around the first factor, from which one branch should be drawn and labelled for each level of the factor. The algorithm of Siegler and Liebert was then given to each pupil :

You could continue adding factors indefinitely. Every time you would place a box at the end of each existing branch, write the name of the new factor in it, and extend branches from each box representing level one, level two, and so forth. Finally, you would write the names of the levels along the proper branches. (Siegler and Liebert, 1975).

5.2.3 Analogous Problems

Analogous tasks consisted of three carefully graded problems which were presented to pupils individually. The tasks were unconstrained, that is, all levels of each factor could be combined with all levels of the other factors

The first problem involved a cake recipe with eggs, milk and flour as possible ingredients and either oil, margarine or butter providing the fat content. This problem was devised to emphasise again that (i) the absence of something should be regarded as a level of the pertinent factor and (ii) each factor need not have only two levels. Each pupil was required to list the factors and levels, draw a complete tree diagram and read all of the possible combinations of the ingredients. Each step was supervised and any mistakes were discussed and corrected.

The second problem was similar to the task devised by Siegler and Liebert. This entailed the drawer of a filing cabinet which had a lock controlled by a series of knobs. Each knob could be turned to the left or to the right. The correct combination of knob positions would unlock the drawer. Siegler and Liebert presented this problem to their subjects as a practical task involving three knobs. In the present study, a pen-and-paper approach with four knobs was substituted. Each pupil was asked to produce all possible combinations of knob positions which could be tested to guarantee unlocking the drawer. This presentation of the problem

was chosen to avoid interpupil communication concerning a single correct manual combination which would have negated any training benefit from this task. The assignment was essentially the same as previously, except that only the minimum guidance was provided. By this stage, however, only thirteen of the eighty pupils hesitated before tackling the problem correctly without any prompting. Only eight pupils actually made any error.

The final problem concerned a *dream partner* in which each pupil was requested to suggest various physical types by drawing and interpreting a tree diagram representing two levels of height, two levels of build, three levels of hair colour and three levels of eye colour. By this stage all the pupils were able to carry out the task successfully without any assistance.

It is stressed here that the schematic tree diagram introduced in the conceptual framework and the analogous problems were all simpler than the tree diagram which would be required in the evaluation task described in the next chapter.

5.2.4 Duration of Training

Each pupil was trained for as much time as was necessary to develop skill in factorial design. The length of the training required by each individual was judged by the manner and the nature of responses to the problems. The average period of training was thirty-five minutes. It was apparent that in general Standard 8 pupils required a longer training period than Standard 9 pupils. Furthermore, IQ seemed to be a factor. Some lower IQ Standard 8 pupils needed more than one hour to master the training programme. Several higher IQ Standard 9 pupils required barely fifteen minutes of instruction and were able to generate complete factorial arrays after presentation of the conceptual framework only. The boy with the highest IQ in Standard 9 spontaneously supplemented the instructional material with creative suggestions about the relative weighting of the factors in a given experimental situation. However, this was exceptional as it was evident from both observation and later questioning that very few pupils understood the conceptual framework before the analogous problems had been presented.

5.2.5 Reinforcement of Training

Pupils were presented with the evaluation task described in the next chapter on the same day as the training or on the following day. If a weekend or absence

from school intervened, a brief recapitulation of the training programme was given before proceeding with the evaluation task.

The timetables for individual pupils involving the training procedure, the Piagetian-like evaluation task and Piagetian posttest were arranged in such a way that each pupil would complete the trio of tasks within three days. The interval between the execution of these tasks by the first pupil of the experimental group to be interviewed and by the last (eightieth) pupil was ninety-three days. This lapse of time made reinforcement of the training essential prior to presentation of the instruction on academic material. On the day before the lessons commenced, the pupils, in classes of fifteen to twenty, were exposed to reinforcement of the training. The reinforcement session lasted about fifteen minutes per class. The conceptual framework was first revised. Next, pupils were presented with a factorial problem involving four of the thirteen chemicals in the head of a safety match. The task, which was devised from information supplied by courtesy of The Lion Match Company, Elandsfontein, is reproduced in Figure 5.2. The pupils were given time to execute the task using a tree diagram after which they assessed their own performances from the correct solutions shown on an overhead projector transparency and explained by the researcher. Only 4% of the pupils made any error in their tree diagrams.

5.3 Analysis of the Training in Theoretical Terms

5.3.1 The Learning Cycle

It will be recalled that the training was designed to meet the Piagetian conditions for cognitive interventions which are most likely to be effective (Chapters 2 and 3). This aspect of the study will not be repeated here and the present paragraphs are centred on utilisation in the training of appropriate aspects of the learning cycle.

The initial or exploration phase of the learning cycle involves confrontation of the subject with new information which is not directly assimilable. Laboratory manipulation is often included in this phase. In the present study, presentation and discussion of research and industrial problems which demanded factorial arrays for solution comprised this phase. Since the training aimed at the development of generalisable combinatorial skills, a specific or limited situation was avoided at this stage.

THE HEAD OF A SOUTH AFRICAN SAFETY MATCH

Write down all possible combinations of the following constituents, which you would have to try in order to design the most satisfactory match head:

1. Potassium chlorate (KClO_3)
Particle size : coarse, medium, fine or very fine
2. Manganese dioxide (MnO_2)
Present or absent
3. Starch
Rye flour, maize flour or wheat flour
4. Glue
Temperature-sensitive or temperature-insensitive

Figure 5.2 The Factorial Problem Presented in Reinforcement of the Training

The invention or concept introduction phase of the cycle was not applicable in its strictest sense, namely, the employment of a discovery learning strategy. Training implies the learning of a technique as opposed to the learning of facts. Facts constitute the material normally assimilated in the invention phase. It would seem, however, that techniques such as mathematical procedures, etc., are better mastered by reception learning methods. The presentation of the conceptual framework was characterised, therefore, by a reception learning approach. This, of course, does not suggest that the thinking of a subject is co-ordinated for him since the formal properties of the training can be abstracted only by the subject himself.

Finally, the discovery or concept application phase of the cycle was implemented when each subject was required to investigate applications of the learning material in order to achieve reinforcement of the concepts labelled in the invention phase. In accordance with the conventional mode of this phase, subjects had to attempt these tasks, namely, the analogous problems, unaided and were assisted only if considerable difficulty was experienced.

All three phases involved the important training principle of social interaction. This was embodied in educator-educand interaction and contrasts with the self-administered training programme in printed format which has been used in some training studies. Peer interaction was excluded by the constraints imposed by the regular school schedule.

5.3.2 Progressive Differentiation

Since the research design required that the training and Ausubelian advance organizer should be synonymous, the training had to meet various conditions to function as ideational scaffolding in terms of the principle of progressive differentiation.

Since explicit expression of a factorial array was unfamiliar to the pupils, the type of organizer involved was expository in nature. The exposition had to make explicit the relationship with already existing knowledge (Hartley and Davies, 1976), discussed in Chapter 2 under the principle of integrative reconciliation. The introduction to the training required discussion at a high level of inclusiveness on the need for factorial design skills. The discussion was commenced by reference to general industrial processes which would link with the common experience of the

pupils. Since a large factory which produces explosives and chemicals is situated very close to the school, illustrations in the abstract discussion consisted of dynamite, sulphuric acid, etc. Once the training itself had begun, a high level of generality and inclusiveness was preserved in the presentation of the conceptual framework. The last stage of this presentation was somewhat less general and inclusive when the construction and use of a tree diagram was demonstrated for the case of growth conditions for plants. In order to reinforce integrative reconciliation, the Ausubelian recommendation of *cycling* from more general to more specific concepts and *backing up* again (Moreira, 1977, 1978) was followed by organising the instruction in a manner which allowed movement up and down the conceptual hierarchies as each piece of new information was presented. Finally, the analogous problems, at a still less general and inclusive level, provided carefully chosen links with the everyday experience of the pupils.

The process-orientation of the training fulfilled the requirements of an advance organizer. True to the Ausubelian definition of an advance organizer, context was emphasised throughout the training procedure as opposed to content, the latter being the characteristic feature of pretests, behavioural objectives and overviews (Hartley and Davies, 1976).

The training displayed, therefore, the properties of a series of Ausubelian advance organizers in terms of orientation, generality, inclusiveness and integrative reconciliation. An Ausubelian advance organizer further requires a higher degree of abstraction than that possessed by the succeeding, more differentiated material. A departure from the classic definition of an organizer was the use of more concrete, pictorial strategies rather than the classic abstract prose format. The broader definition of an organizer (Chapter 2) was adopted, given by West and Fensham (1974) as *an externally contrived aid to organizing the new learning for learners deficient in prior knowledge*.

The experimenter-provided pictorial strategy was chosen for several reasons. Firstly, the training study was also Piagetian-based and cognisance had to be taken of Piaget's insistence upon the child's manipulation of concrete referents as a necessary part of teaching for intellectual development (Chapter 2). Secondly, a pictorial strategy ought not invalidate the Ausubelian aspects of the investigation since several Ausubelian-based studies have reported success using non-written advance organizers (Chapter 2). Lastly, diagrams are often employed in science materials to

teach identification and classification and research has shown their effectiveness (Holliday, 1976; Holliday and Brunner, 1977).

5.4 Placebo Treatment

As the pupils in general were very marks-conscious and success-orientated, any valid inference from the training study demanded that the subjects in the control group should not be aware of having received no training.

The control subjects visited the researcher individually. To strengthen their belief that they were receiving treatment, they were each told that the nature of their approach to a problem was vital and that the present activity would assist them to achieve success in this direction. Wooden puzzles which were required to be taken apart and reassembled were then provided. After ten minutes of manipulating the puzzles, control subjects were presented with four written problems relating to an electric train, formulated to appear to be relevant to the evaluation task which was to follow and which also involved an electric train as described in the next chapter. Details of the train problems posed to the control group are given in Appendix D. Solution of the four problems required the detection of two-variable interactions in data. The skill of combinatorial thought processes and the skill of detection of interactive patterns in data are intertwined since the latter reasoning ability implies the control of variables. However, the placebo nature of the four tasks was assumed since the control group possessed, at most, non-given tacit rules. Control subjects were not given explicit discussion on any topic nor, obviously, did they have practice in the construction of tree diagrams.

Both experimental subjects and control subjects visited the researcher during the ninety-three day period mentioned in Section 5.2.4. The placebo treatment for each control subject lasted thirty-five minutes, that is, the same time as the average training session for an experimental subject.

Prior to instruction on the academic material, the control subjects, in small classes, attended *reinforcement* sessions which consisted of a repetition of the written placebo tasks. The sessions lasted fifteen minutes per class, corresponding to the time devoted to the reinforcement of the training given to each class of experimental subjects.

CHAPTER 6

THE EVALUATION TASK

6.1 Alternative Tasks to Piaget's First Chemical Experiment

The present chapter describes the development, presentation and execution of the task which was devised to evaluate the training in addition to the posttest. The rationale behind the use of a double means of assessment of training effects has been discussed in Chapters 2 and 3. The evaluation can be demarcated as aiming to analyse acquisition of the combinatorial reasoning scheme. The possibility of any effect of the instruction in combinatorial skills on the parallel development of other formal reasoning skills will be considered later (Chapter 10). The task at present under discussion and the posttest therefore possess similar logical structures but are set in different contexts. The contextual aspects prevent the assumption of high intertask reliability in the classification of responses into Piagetian stages, but it is these very aspects which increase the value of any conclusions concerning training benefits.

From a science educator's viewpoint, it seems far more important to be able to recognize when and for which elements it is appropriate to generate combinations than to learn a combinatorial algorithm.
(Wollman, 1982, p. 759).

For this reason thus expressed, the training carefully avoided limiting the articulation of logical operations to any specific situation. The two assessments therefore intended to probe the issue of whether subjects were able to apply the general concepts presented in training to the solution of novel problems i.e. achieve form/content dissociation. Transfer of training is further examined in Chapter 10.

The traditional Inhelder chemicals task (Chapter 4) functioned as posttest while the present combinatorial task instrument was devised along Piagetian lines. There are many departures from the traditional task described in the literature. Within the classic structuralist position, two main reasons for such departures can be identified. Firstly, many workers have encountered technical problems in administration of the chemicals task, as mentioned in Chapter 4. Secondly, the testing of large numbers of subjects becomes feasible only if testing time can be minimised. Subsidiary considerations revolve around convenience in administration such as ease of transport and economy of materials.

Staver and Harty (1979) are currently developing and refining a task instrument which in fact retains the content of the traditional task and therefore a brief resumé follows. The first four chemicals here consist of acid-base buffer solutions of pH 3, 5, 7 and 9 respectively. The fifth liquid, corresponding to Piaget's *g*, is Bogens' solution, viz. acid-base universal indicator. Combinations of the liquids are produced by mixing drop-wise on a white porcelain spot-plate. Each respondent is asked to reproduce the colour obtained on mixing equal amounts of two solutions and *g*. The former, unknown to the respondent, consist of buffers of pH 5 and 7. Subjects are therefore explicitly requested to achieve the colour using *g*, unlike Piaget's task where the use of *g* is only implied. The modification of Staver and Harty, in its present stage of development, suffers from the disadvantage that the colours obtained are seriously amount-dependent and may range from red to blue-green. Meanwhile, the promise of the method for swift assessment of performances provides its main advantage. The preliminary sample consisted of five respondents. Videotapes of the respondents were shown to trained raters. The raters were able to assign points on the basis of a checklist of seventeen statements where *each statement represented a possible behaviour which would infer the presence or absence of combinatorial analysis*. (Staver and Harty, 1979, p. 54). Allowance for both formal and concrete responses was made in the allocation of two points for each statement for the former type of response and one point for the latter type. The total score provided a rapid evaluation of Piagetian category of performance on the task.

Siegler and Liebert (1975) have pointed out that while the Inhelder chemicals experiment is an ingenious task, strategies of subjects can easily be obscured if they produce the yellow colour early in the trials sequence and are no longer motivated in ascertaining alternative ways of producing the colour. Dale (1970) found that subjects tackling the chemicals problem often discontinued their efforts after early location of the correct answer, even young adolescents from whom formal operations may presumably have been expected to some extent. This obstacle may also generate difficulties in the Piagetian-based instrument employed by Staver and Harty (1979) as well as in the modified colour change experiment developed as a paper-and-pencil test by Rowell and Hoffmann (1975). The drawback is shared by the electronic equivalents to the chemical experiment developed by Hale (1972, 1976) and DeLuca (1979). Furthermore, although an electronic device indubitably eliminates certain logistical problems, its use may aggravate the extraneous influence of intersubject communication owing to the single correct combination which cannot

be varied by a simple expedient such as switching the flask labels in the chemical experiment.

Combinatorial and permutational tasks allied to the first chemical experiment that avoid the possibility of premature solutions have been utilised by, *inter alia*, Elkind *et al* (1968) and Leskow and Smock (1970). In these studies, children were required to generate all possible combinations of differently coloured objects. The rationale of these tasks is that the generation of a complete factorial array requires the manipulation of propositions rather than objects since the ability to produce such an array by the systematic isolation of each variable in turn from the others which are held constant, is a characteristic of formal operational thought (Inhelder and Piaget, 1958; Karplus and Peterson, 1970; Sayre and Ball, 1975). While performances on these tasks may to some extent indicate Piagetian substages of intellectual development, the fact that they do not however have correct solutions or problem-related purposes, means that they fail to reveal hypothetico-deductive reasoning which is the other, and equally important, characteristic of formal thought (Inhelder and Piaget, 1958; Karplus and Peterson, 1970; Sayre and Ball, 1975). This is necessarily obscured in any task which does not permit the use of each feedback trial to isolate progressively the sole correct hypothesis from the complete set of solution hypotheses. Further, the interpretation of results in such a task may be complicated by the extraneous variable of differential motivation among subjects of different ages to persevere at an assignment which has no apparent goal (Reed, 1971).

Sills and Herron (1976) devised an electronic analogue which elicits a compromise between goal-directed problem-solving strategies and aimless procedures that are without an appropriate problem-related purpose. Their device, physically present before the subjects, incorporated a light which could be operated by a given combination of four switches. Respondents were asked to list all possible combinations of the switch settings. This paper-and-pencil measure allows presentation of the task in groups which drastically reduces administration time. Also in the domain of paper-and-pencil data-gathering instruments, the contribution of Good (1977) and Za' Rour and Gholam (1981) employs a similar task design. Students were shown a drawing of two powders, A and B, a liquid and a candle. The respondents were required to consider how a red colour might be achieved by producing combinations of two or more of the four items.

6.2 The Nature of the Evaluation Task

To allow extended observation of childrens' experimental approaches in the more relaxed clinical setting while preserving the motivating feature of a single correct solution, Siegler and Liebert (1975) invented a new instrument to which Inhelder and Piaget's first chemical experiment was directly relevant. The task design involved an electric train set, four knife switches and a foot pedal. Subjects were told that to make the train run, they needed to set each switch in the proper position, up or down. However, the current was actually controlled by the foot pedal which was hidden from view. This arrangement enabled the experimenter to delay at will each subject's discovery of the 'correct' combination.

The factorial task of Siegler and Liebert was employed in the present study. These workers had designed their experiment for a training study directed at ten- and thirteen-year olds. They reported that no uninstructed ten-year olds were able to produce all possible combinations while only ten per cent of uninstructed thirteen-year olds were able to do so. One might expect substantial growth in untutored performance on this task in the age range of the subjects in the present investigation. It was necessary to establish whether the design of Siegler and Liebert could be replicated or whether it would require modification to be sensitive to differences due to training between the present experimental and control subjects. With this objective, their design was replicated in a small pilot study involving four Standard 10 pupils and two high achieving Standard 9 pupils, all of whom were not participants in the training study. These pupils might be expected to exhibit a greater degree of cognitive competence than many of the Standards 8 and 9 pupils under investigation. Their degree of success on the task might be indicative of the maximum performance levels which could be achieved by the subjects. The results of the pilot study suggested that the basic design of Siegler and Liebert required slightly increased complexity for the present research. The modified design is described in the next section of this chapter.

6.3 Materials

The equipment consisted of an electric train set, a foot pedal and a box with five toggle switches. The circuit diagram is given in Figure 6.1. The wires were connected in such a way that it would seem to the subjects as if the five switches controlled the motion of the train. In fact the wires leading to the box from the

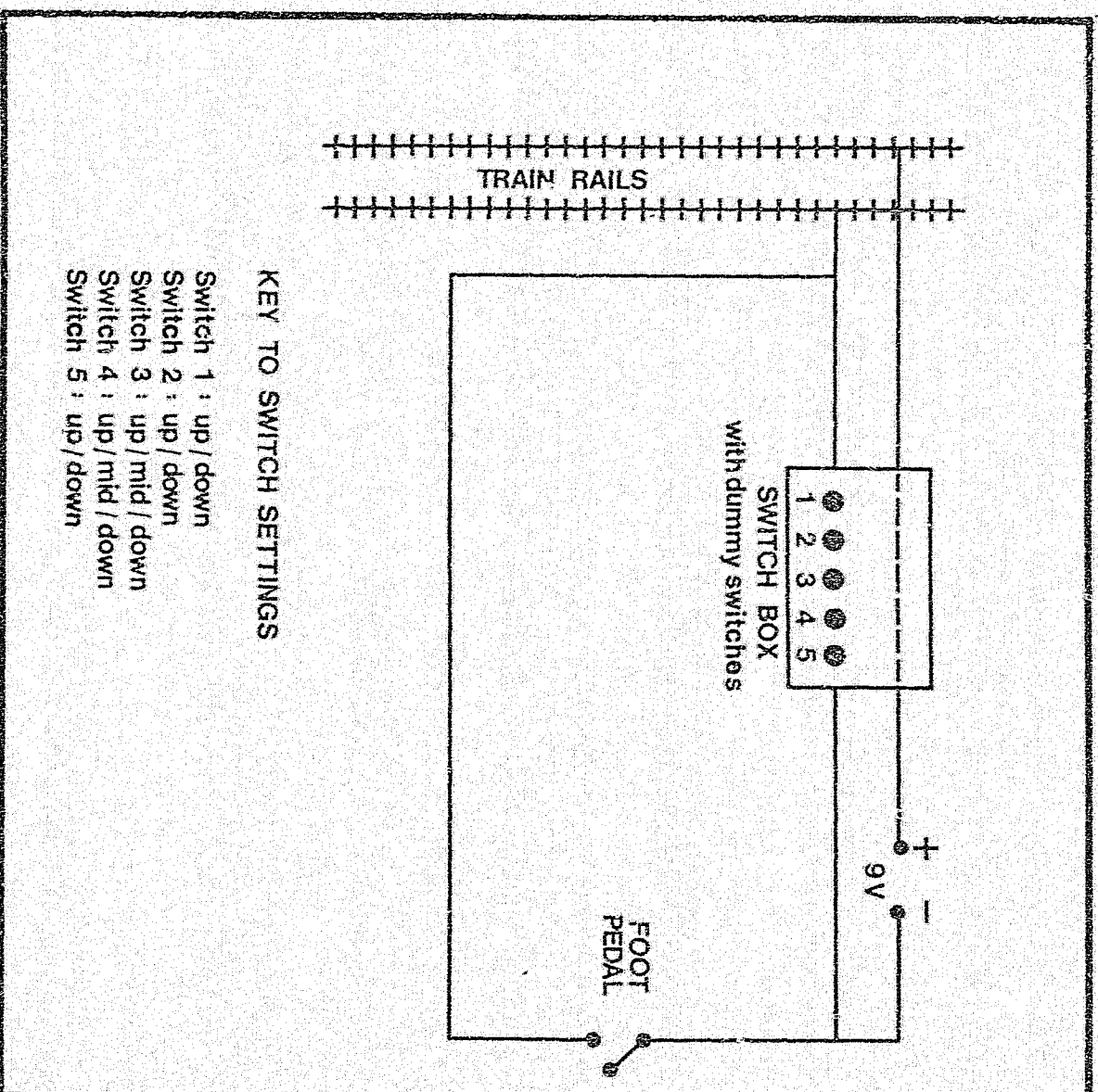


Figure 6.1 The Circuit Used in the Train Task

train track were not connected to the switches or to the power supply. The wires between the track and power supply were actually connected to the foot pedal concealed from view underneath the researcher's desk which enabled external control of the train.

The first, second and fifth switches on the box were two-way switches while the third and fourth switches were three-way switches. It was thought that this arrangement of switches would achieve the desired level of complexity for the task. The usual array of switches encountered in an electronic analogue to the chemicals task consists of a main *on/off* switch, corresponding to Piaget's *g*, and four other switches, corresponding to the other four colourless solutions. In the traditional task, the use of *g* is only implied. In Chapter 4, it was reported that a negligible proportion of subjects realised from watching the demonstration when the required yellow colour was produced for them, that *g* had to be present in the correct combinations of the liquids. However, the common experience of the pupils, both in the school laboratory and in the home, has shown that the main switch must be *on* for an electrical appliance to be operational. From the point of view of the subjects, therefore, the two tasks do not appear to be equivalent regarding one of the major dimensions of performance, information-processing load. In the chemicals task five variables are identified by subjects while the electronic analogue is seen to contain only four. It is possible that this difference does not significantly affect performance as DeLuca (1979) obtained a correlation of $\phi = 0.72$, $p < 0.01$, between the two tasks. It would however seem a more appropriate electronic design to incorporate five switches of which one has a somewhat different appearance from the others (cf. the smaller container used for liquid *g* in the traditional task). In any case, this is not a point at issue, since it did not really matter whether the present evaluation task was equivalent to the Piagetian task with respect to working memory demands. As the task was directed chiefly at assessing the effects of training, it had to reach that threshold of complexity which would enable differentiation among performances, particularly for subjects whose thought capacities prior to training had been rated as transitional between the concrete and formal stages.

The decision to combine the two types of switches asymmetrically with respect to one another arose from observations made in the pilot study. After examination of the design with four two-way switches that had been devised by Siegler and Liebert, the pilot study was first extended to a modification of the design incorporating five two-way switches. This arrangement seemed to promote the use of trial sequences such as

- First combination : down, up, down, up, down, for switches one to five respectively
- Second combination : up, down, up, down, up
- Third combination : down, down, up, down, down
- Fourth combination : up, up, down, up, up

These symmetrical but random patterns based on switch-reversing procedures soon confused subjects and tended to obscure from the researcher essential differences between random and systematic approaches. The present asymmetrical design purports to inhibit this strategy which might at first sight seem an attractive solution path and could result in bias against the control group.

6.4 Procedure

The task was presented to each pupil individually. All five switches were set in the *up* position when the pupil arrived and could see the train non-functioning. The pupil was told that *up* represented *off*. (The *up* position of a switch was thus designed to be equivalent to a solution absent from a specific combination in the traditional chemicals task.) It was explained that to make the train run, each of the five switches had to be set in the proper position. The two-way switches could be set either up or down and the three-way switches could be set up, midway or down.

Each pupil was supplied with pencil and paper and advised to keep a record of combinations which had been tested. This suggestion was put forward in the words of Siegler and Liebert (1975) :

Figure out all of the possible combinations, try them and you will be sure to find the solution. There are many possibilities and you don't want to repeat the same choices you already made, so you might want to keep a record of which choices you have tried and found not to work.

The purpose of this advice was to avoid performance strategies by control subjects which might reflect only the failure to recognise the possibility and legitimacy of written records rather than differential conceptual understanding between experimental and control groups.

While the pupil executed various switch settings, the researcher made a written record of the trials sequence. Each pupil had been told that a time delay in

the registering mechanism of the apparatus required a short wait after each new setting of the five switches. This ploy enabled the researcher to keep track of all attempts by merely watching the slowly executed trials attentively.

The locomotive was covertly started when sufficient trials had been performed to allocate a score on the task. This meant that at least forty of the seventy-two possible combinations were tested by each respondent. The 'correct' combination was varied with regard to both the switch setting and the number of trials required for solution of the problem. This was intended to lend credibility to the belief of the subjects that the wiring of the apparatus was changed frequently and that it would therefore not be feasible to ascertain the correct solution beforehand from their predecessors on the task.

6.5 Hypotheses to be Tested

6.5.1 Null Hypothesis 6.1

H_0 : There is no significant difference in the scores of the trained and untrained subjects.

H_1 : The trained subjects scored significantly higher than the untrained subjects.

6.5.2 Null Hypothesis 6.2

H_0 : There is no significant difference in the scores of the Standard Nine control subjects and the Standard Eight control subjects.

This hypothesis and the two hypotheses stated below specify the control group only in order to yield information about the discriminative qualities inherent in the train task itself.

6.5.3 Null Hypothesis 6.3

H_0 : There is no significant difference in the scores of the higher IQ control subjects and the lower IQ control subjects.

6.5.4 Null Hypothesis 6.4

H_0 : There is no significant difference in the scores of the boys in the control group and of the girls in the control group.

6.5.5 Null Hypotheses 6.5, 6.6 and 6.7

These repeat null hypotheses 6.2, 6.3 and 6.4 respectively but with reference to the experimental subjects.

These hypotheses have been formulated to reach conclusions about the differential effectiveness of training with respect to age, IQ and sex. The base-lines in this analysis will be the statistical decisions concerning the effect of these factors on the scores achieved by the control subjects (hypotheses 6.2, 6.3 and 6.4).

6.5.6 Null Hypothesis 6.8

H_0 : There is no significant difference in the scores of control subjects who kept written records and control subjects who did not do so.

H_1 : The control subjects who kept written records scored significantly higher than control subjects who did not do so.

Neimark and Lewis (1967) noted that lack of foresight as to possible complexity might limit the information-seeking strategies of nine- to eleven-year olds. Siegler and Liebert (1975) suggested that the use of an external memory aid was an important mediating process in the generation of combinations.

The null hypothesis under test has been restricted to control subjects only as it was anticipated that a vast majority of the experimental subjects would keep written records as a result of their training programme. Examination of record-keeping on the train task and its effects on achievement is expected to indicate whether record-keeping *per se* might have contributed to any superior performance by the experimental group.

6.6 The Construction of a Measurement Scale

6.6.1 The Validity of the Scale

6.6.1.1 Piagetian Criteria

Since the train task is logically analogous to Piaget's first chemical experiment, it would, at first sight, seem that Piagetian criteria should be used to construct a scale which strives to assign scores on combinatorial operations as validly as possible. According to Inhelder and Piaget (1958), the scheme of combination operations is

... manifested in the subjects' potential ability to link a set of base associations or correspondences with each other in all possible ways so as to draw from them the relationships of implication, disjunction, exclusion, etc. (Inhelder and Piaget, 1958, p. 107).

These criteria would not be satisfied by the assignment of scores on the sole basis of the number of distinct combinations generated as sometimes reported in the literature. Furthermore a systematic approach is a requisite but not a sufficient condition for formal combinatorial operations which in addition are characterised by hypothetico-deductive thinking as evidenced in the experimental context by explanations elicited from subjects. An example of a measurement of logical thinking which has met severe criticism is that of DeLuca (1978) with his electronic equivalent of Piaget's first chemical experiment, on the grounds of omission from the scoring criteria of the crucial factor of the absence or presence of systematic procedure (Hale, 1979).

6.6.1.2 Limits on Train Task Interpretation

In order to construct a suitable measurement scale, it was necessary to consider at the planning stage of the thesis whether the train task of Siegler and Liebert (1975), as a logical analogy to Piaget's first chemical experiment, is a valid replacement of the traditional task and, if not, which aspects of the latter task are reflected accurately in the train task. Siegler and Liebert (1975) conducted a preliminary study into a Piagetian alternative and did not claim to have validated their instrument and its testing protocol. The task is promising in concept and may be developed into a Piagetian equivalent after further investigation and refinement but such construct validation is unfortunately beyond the scope of this thesis.

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