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ABSTRACT

This paper argues in favor of using interactional strategies in the study of formal operations reasoning. Interactional designs allow a convergent approach to specifying processes underlying the interaction of variables. In contrast, current methodologies contain two inherent disadvantages: they have limited utility in specifying the processes underlying development, and their results are difficult to interpret. Interactional strategies were used in the design of two experiments on the development of formal operations competencies. The results of these experiments suggest that applying interactional strategies to the study of formal operations growth allows direct comparison between the strengths of existing age-related performance differences and the strengths of the experimentally manipulated treatments. This research design may also reveal catching up and readiness interactions that could result in new interpretations for developmental differences, allowing precise statements as to the nature of the interaction of maturational and experiential factors which determine formal operations development. (GO)

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Utility of Interactional Strategies in the Study of Formal Operations Reasoning

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There is widespread theoretical agreement that the acquisition of formal operations reasoning is dependent upon the interaction of maturational and experiential factors. Yet the designs of the large majority of studies in the area preclude discoveries concerning the nature of such interactions. In this paper, I would like to argue in favor of increased use of interactional designs, particularly those concurrently varying age and experiential factors.

Interactional designs are hardly a new idea; they are routinely described in undergraduate methodology texts (e.g., Neale & Liebert, 1973). Yet such designs are remarkably rare in the literature on cognitive development. Brainerd and Allen (1971), in reviewing conservation induction studies, cited only a single instance in which children of different ages were observed under instructed and uninstructed conditions in the same experiment. Similarly, Neimark (1975) cited but a single study of this type in the area of formal operations.

The paucity of interactional designs may be best understood from the vantage point of the type of questions that most current studies seek to answer. In the majority of studies of cognitive development, one of two basic questions is posed; each is linked to a distinct methodology. The first question concerns the changes that occur in untutored performance with age; the methodology used to answer such questions involves examining changes in knowledge on a task over an age range or assessing interrelationships among performance on several tasks over the age span. Examples of this strategy include Lovell's (1961) study of formal operations tasks, Elkind's (1961) study of conservation problems, Tomlinson-Keasey & Keasey's (1974) work on the relationship between cognitive and moral development, and Brainerd's (1973) study on the order of acquisition of transivity, conservation, and class inclusion skills. The second typical question in the cognitive developmental literature might be phrased "Can children this young master this skill after having this type of experience?" The usual methodology is to compare the effects of various training techniques on children of a particular age. Examples include Gelman's (1969) study of conservation of length and number, Brainerd and Allen's (1971a) study of the density problem, and my own study, with Bob and Diane Liebert, of the pendulum problem (Siegler, Liebert, & Liebert, 1973).

Each of these two strategies has advantages; however, like all methodologies, they are limited in the range of questions they can answer. One problem is that neither gives direct information on the relative responsivity to instruction of older and younger children. This can lead to substantial misinterpretation. For example, Brainerd and Allen (1971b) on the basis of existing studies, concluded that age was not substantially related to ability to benefit from conservation instruction In some studies, four-year-olds had been taught to conserve; in others, seven-year-olds had not benefited from instruction. However, in the only two conservation induction studies that I know of in which older and younger children were provided the same training, the older children benefited more (Kingsley & Hall, 1967; Siegler & Liebert, 1972). At the very least, these two studies raise questions about the conclusion derived by Brainerd and Allen from the non-interactional studies they reviewed.

A second disadvantage of the two prevalent strategies involves their relative lack of utility in specifying the processes underlying development. Even if it is learned that all children master the pendulum problem before the balance scale task (or vice versa), the finding says little about the processes underlying mastery of either task, not even that the processes are related. Nor am I aware of any at all specific models of how the processes underlying mastery of a particular Piagetian problem are related to those underlying mastery of other such tasks. The confusion engendered by these normative studies is illustrated by the directly opposing predictions drawn by researchers using the same (Piagetian) model, concerning the order of acquisition of such skills as conservation, class inclusion, and transitivity (cf. Brainerd, 1973).

The difficulty with training studies is more subtle. Such investigations may nominate various factors such as equilibration, reversibility,or modeling as important in the normative process, since they demonstrate that particular types of instruction can produce knowledge in non-knowers. However, it remains possible that such methods would also produce gains in those whose knowledge was relatively sophisticated already For example, instructions to rehearse might improve the recall performance of younger children, but this would not very strongly implicate rehearsal as a process underlying developmental differences in recall memory unless it could also be shown that older children, similarly instructed, benefited less.

This last argument thrusts me into the main topic of this paper, the advantages of interactional designs. There are two main types of interactional methodologies, concurrently varying either age and experiential or age and situational factors. I will only be discussing the former type, but most of the arguments apply in slightly modified form to the latter as well.

Simply stated, the most valuable feature of interactional designs is that they allow the uncovering of interactions. Consider two patterns of results that might emerge from designs simultaneously varying age and experiential factors. One could be labeled a "catching up" effect. If young children lack a particular skill that older ones possess, the effect of teaching the skill might be to narrow gaps in performance. Such patterns have emerged in the serial recall literature; the serial recall performance of younger children improves when they are encouraged to use organizational strategies, while older children, already organizing, are not as greatly affected by the instruction (e.g., Harris & Burke, 1972). This does not prove that increasing use of organization causes developmental increments in recall, but it does provide relatively high quality evidence that it or some functionally related competence is involved in the growth.

A second revealing pattern of results occurs when differences between younger and older children become greater as a function of identical instruction. This is a relatively precise experimental analog to the often murky developmental concept of readiness. Older children may possess capabilities and knowledge that are relevant but insufficient to generate complete problem solutions. In such cases, instruction may integrate existing knowledge, provide the final pieces in the puzzle, and thus spur relatively large increments in competence. Younger children, not as "ready," may not benefit to as great an extent from the identical instruction.

The benefits of the interactional strategy extend beyond the stage of empirical discovery, for inherent in the strategy's logic is a convergent approach to specifying processes underlying interactions. The first step is formulating an explanatory hypothesis; quite precise hypotheses may be suggested if several instructional factors have been varied in an additive or factorial manner and some combinations have yielded interactions with age and others have not. Once formulated, there are at least two ways of verifying the hypothesis. One involves the standard of predictive validity; if the designated process is in fact central, independent assessment of it should prove superior to age as a predictor of success on the original task. A second verification technique involves direct manipulation of the factor. If the key process has been identified, either improving children's proficiency on it through training or changing the task to eliminate the need to perform it should reduce developmental differences. Thus, the convergent strategy may allow for more rigorous specification of processes underlying cognitive development than is typical.

I have used interactional strategies in two recent experiments on the development of formal operations competencies, specifically the development of scientific reasoning. The first (Siegler & Liebert, 1975) concerned the ability to design a fully factorial experiment; the second (Siegler & Atlas, 1975) was, fittingly enough, on children's understanding of interactional patterns in data.

In the first experiment, 10- and 13-year olds were presented the task of making an electric train run. To do this, they needed to find the "correct" setting of four switches, each of which could be set either up or down. Actually, there was no single correct setting; the train was controlled by a foot pedal hidden underneath the experimenter's desk. Thus, to solve the problem, children needed to generate all 16 possible combinations (the equivalent of a 2 X 2 X 2 X 2 factorial design, if the four switches are viewed as factors, and up and down as their levels).

Prior to attempting the train problem the 10- and 13-year-olds were provided either a conceptual framework and two analog problems, the conceptual framework alone or no special training. The conceptual framework included explanations of the concepts of factors and levels and a description of an algorithm for generating tree diagrams and thereby identifying all of the possible solutions to problems. The analog problems provided trial runs for applying the concepts; children solved problems similar in form but different in content from the train problem.

The results of the experiment were clearcut (Table 1). Performance proved quite plastic; type of training accounted for 47% of the total variability in the data, age for 14%, and the interaction of the two factors for 4%. Without training, fifth and eighth graders performed very similarly; only one eighth and no fifth grader generated all 16 possible combinations in 16 trials. Provided both conceptual framework and analog problems, fifth and eighth graders again performed similarly; all 10 of the eighth graders and 7 of 10 fifth graders produced perfect factorial arrays. However, given conceptual framework alone training, the performance of the older children substantially exceeded that of the younger ones; relative to their uninstructed age peers, eighth graders benefited from the instruction while fifth graders did not. Thus, the interaction conformed to the readiness pattern described above.

The task then became to specify what accounted for the differential degrees of readiness of older and younger children to benefit from the conceptual framework alone instruction. A clue was provided by the finding that children's pattern of record keeping closely paralleled their pattern of success on the task (Table 2). All children had been encouraged in the instructions to record their responses with pencil and paper; they were told that the train problem might be difficult and that record keeping could reduce its difficulty. However, not all children accepted the advice; whether or not they did so proved to be highly correlated with the total number of combinations they generated ($r_{pb} = .64$). Thus record keeping appeared to be an important mediating device in children's combinatorial performance. Along with other evidence, this suggested that the differential reaction to the conceptual framework alone instruction was due to differential ability of 10- and 13-year-olds to anticipate the possible complexity of the problem. Newell and Simon (1972) described such differences as pertaining to the ability to set up the problem space; in everyday parlance, the process is somewhat akin to foresight. We are currently testing the foresight interpretation by examining the performance of children when the need for foresight on the problem is eliminated; by the logic of the readiness interaction, if foresight is the key factor, the manipulation should reduce or eliminate the developmental difference. Perhaps the most important point, though, is that the interpretation and the subsequent experiment would not have arisen except in the context of the interactional design.

The second experiment concerned children's understanding of interactional patterns in data. Ten- and 13-year-olds were shown data sheets (Table 3) that were analogous to the settings of the switches in the train problem. They were told that their job was to figure out which two of the three switches determined how fast the train would go. That is, the way that the two important switches were set--down and down, down and up, up and down, or up and up--would determine the train's speed; the children needed to find out how. No memory or time restrictions were present; children were given as much time as they wanted to solve the problems and were encouraged to write their solutions on another piece of paper. Then they were presented the combinations, in a different order, and asked to fill in the proper speeds (Table 4). Four types of interactional patterns were studied: additive, in which both switches down made the train go fast, either one down made it go slow, and neither down not at all; catalytic, in which both down meant fast and any other pattern not at all; terminative, in which either or both down meant slow and neither meant not at all; and antagonistic, in which both down meant slow, one but not the other down meant fast, and neither down meant not at all.

Training consisted of two parts: a conceptual framework that provided a general strategy for solving the problems and guided instruction on the first of the four tasks. The training followed directly from a flow diagram model of the requisites for solving the tasks (Figure 1). A balanced Latin Square Design was used so that each type of problem appeared equally often in each position of the four problem sequence and an equal number of times directly following each of the other types of problems.

In the first part of the experiment, which is the only one directly pertinent to this discussion, fifth and eighth graders were observed either instructed or uninstructed. A basically interactive pattern was observed, this time a catching-up interaction. Among uninstructed children a clear developmental difference was present; older children solved 63% of problems perfectly compared to 22% perfect solutions for younger children. In addition, 50% of the uninstructed 13-year-olds solved all of the test problems, versus 0% of the untutored 10-year-olds. Given instruction, however, the developmental difference disappeared: the solution rate for older children was 78%, versus 72% for younger ones, and 58% of each group solved all problems perfectly. The pattern strongly suggested that the problem solving strategy that was taught was redundant with knowledge that the eighth graders already had or could invent, while similar knowledge was not possessed by fifth graders. Thus, it appeared that understanding of the strategy underlay the developmental difference between uninstructed fifth and eighth graders. The next step is to specify more precisely the locus of the interaction.

The results of these two experiments suggest that applying interactional strategies to studying formal operations growth will prove fruitful. Such strategies allow direct comparison between the strengths of existing age-related performance differences and the strengths of the experimentally manipulated treatments. They also may reveal catching up and readiness interactions that in turn may suggest new interpretations for developmental differences. Thus, increased reliance on this methodology may enable us to go beyond the bland assertion that formal operations development results from an interaction of maturational and experiential factors to make precise statements as to the nature of the interactions.

Table 1

Percentage of Children Producing All Possible Combinations

Treatments	10-year-olds	13-year-olds
Conceptual framework with analogs	70	100
Conceptual framework alone	0	50
Control	0	10

Table 2

Percentage of Children Keeping Written Records

Treatments	10-year-olds	13-year-olds
Conceptual framework with analogs	90	100
Conceptual framework alone	10	90
Control	20	40

Table 3

An Additive Interaction

SWITCH 1	SWITCH 2	SWITCH 3	TRAIN GOES
Up	Down	Down	Slow
Up	Up	Up	Not at all
Down	Down	Down	Fast
Up	Down	Up	Slow
Down	Up	Up	Slow
Down	Down	Up	Fast
Down	Up	Down	Slow
Up	Up	Down	Not at all

Table 4

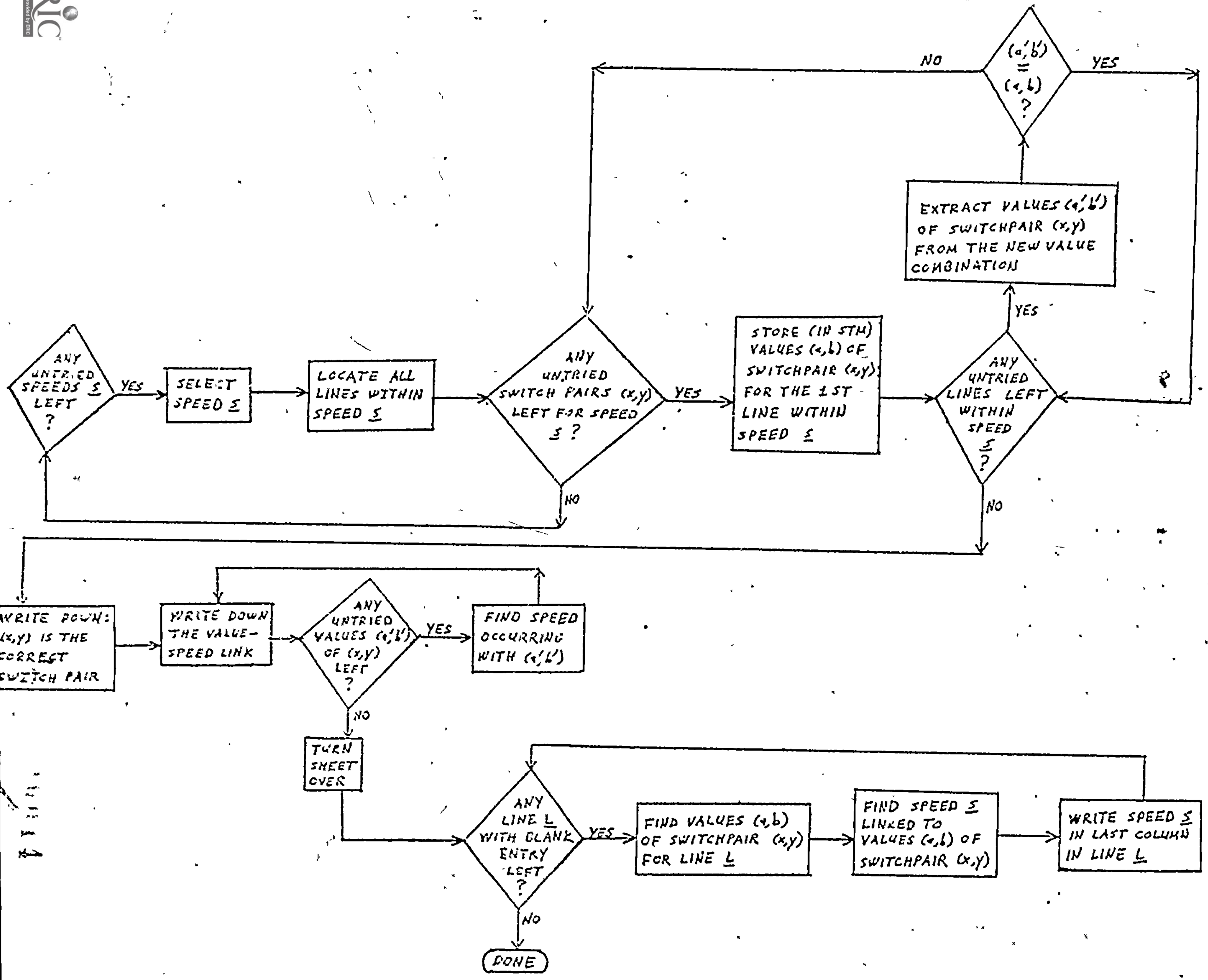
Answer Sheet

SWITCH 1	SWITCH 2	SWITCH 3	TRAIN GOES
Down	Up	Down	
Up	Down	Up	
Down	Down	Down	
Down	Down	Up	
Up	Up	Down	
Up	Down	Down	
Up	Up	Up	
Down	Up	Up	

Which switches were important?   1 & 2   1 & 3   2 & 3

The way they worked was:

Figure 1. Flow diagram used to derive training procedure in Siegler and Atlas (1975)



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