DOCUMENT RESUME

ED 141 087 SE 022 547

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TITLE Chaining in Problem Solving: A Critique and Reinvestigation.
PUB DATE Apr 77
NOTE 27p.; Paper presented at the annual meeting of the American Educational Research Association (New York, New York, April 4-8, 1977); Contains occasional light type

EDRS PRICE MF-$0.83 HC-$2.06 Plus Postage.
DESCRIPTORS *Cognitive Development; *Educational Research; Elementary Education; Elementary School Mathematics; Learning; *Mathematics Education; *Problem Solving; Task Analysis
IDENTIFIERS Research Reports

ABSTRACT

This study investigated the question of whether young children can form response chains in problem solving. After reviewing the literature relating to chaining as a component of problem solving, the author argues that a test of chaining should be free of requirements to recall previously learned material, remember general information, or apply abstract principles. The current study used a task in which subjects were required to execute a sequence of trades. Subjects were drawn from kindergarten, third grade, sixth grade, and college populations, and were individually tested. Results indicated that college and sixth-grade students were able to solve all problems without hints. Younger students were able to solve the problems after a few trials. The author concluded that children were capable of forming chains at young ages. (SD)

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Chaining in Problem Solving: A Critique and Reinvestigation

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Paper to be presented at the Annual Meeting of the American Educational Research Association, New York, 1977.

Abstract

In contrast to previous studies, this study demonstrated that children, as young as five years old, can solve chaining problems. Such chaining ability develops without direct instruction. Previous studies and this one were analyzed in terms of task requirements and abilities. Few developmental differences were found in children's ability to solve fairly lengthy chaining problems. This study also shows how the specific methodologies and actual problem tasks used may alter the results obtained.

Chaining in Problem Solving: A Critique and Reinvestigation

Chaining, a sequence of actions in which each action depends upon the outcome of the last one, is a type of problem solving. Chaining occurs when the individual has to form new response chains or integrate previously separate actions. A problem exists when the goal is not directly obtainable by the performance of a simple act available in the individual's repertoire. Therefore, solution of a problem calls for either a novel action or a new integration of actions (Thorndike, 1393). As various definitions of problem-solving illustrate, chaining is essential to problem solving. For example, Duncker (1945) and Bartlett (1958) defined problem solution as a sequence of linked phases or steps which form a chain connecting initial conditions of a problem with its goal. Gagne (1966) has suggested a model of problem-solving which has four main characteristics. Sequential actions or chaining is listed as the first characteristic. According to Gagne's characterization of problem-solving, chaining involves an integration of a set of sequential events. The completion of one action causes another set of events to occur. Sequential actions in problem-solving are not intended to predict an unvarying sequence for any problem-solving task. However, this model does state that the successful completion of any step depends upon the completion of a previous step.

The chaining process is essential in most problem-solving. This is exemplified by the fact that most theories of problem-solving, including the General Problem Solver (Newell & Simon, 1972), assume chaining in problem solution. The fundamental process of integrating various parts in novel ways is an integral aspect of all problem-solving or creative acts. Chaining is, therefore, intrinsic to problem-solving as demonstrated by the definitions and theories of problem-solving.

This investigation of problem-solving provides important information for psychologists. Chaining may be seen as a basic or fundamental problem-solving ability. The ability of young children to form response chains, independent of direct instruction is useful in understanding children's successes or failures in other problem-solving situations. Although these other problem-solving situations may assume the ability to form chains, such ability may not be directly tested. The responses made by individuals at different developmental levels to the same problems should be useful in building a theory to describe how problem-solving ability is learned or develops.

The ability of young children to form response chains is a controversial issue; different results have been obtained by various researchers. The methodologies used, however, to test chaining are extremely important variables in determining the outcomes of these experiments. In young children, some tasks may facilitate chaining while others may inhibit it.

The fragility of chaining ability in young children suggests an important educational point. In many cases the children's failures to form chains may illustrate failures in teaching or in instructions. The instructions, the tasks themselves, and the entire educational design are extremely important variables in determining educational successes. Therefore, the test of any ability, such as chaining, must be designed carefully with consideration to the task requirements.

The successes or failures of young children to solve chaining problems may be related to their developmental level. If young children cannot succeed with these simple chaining problems, even after instruction and simplifications of the problems, perhaps then educators should not expect young children to succeed in those academic studies which involve chaining. Perhaps, the teaching of concepts which involve chaining should be postponed until the children are older. If, however, this study does demonstrate that young children can solve simple chaining problems, then there are other educational implications. If young children can succeed with this task, it can be concluded that chaining is an ability that develops at a very young age, and that in properly designed tasks educators can get children to succeed in situations which involve chaining.

The process of chaining itself has educational relevance. Chaining is a fundamental strategy used in education. Many educational tasks are taught by analyzing the material to be learned into its component parts and then teaching the separate parts. Putting elements together is a common educational procedure.

Maier (1929, 1936), Kendler and Kendler (1967), and Scandura (1974) have explored chaining as a type of problem-solving. These researchers used the concept of chaining in different ways. For example, in the Maier (1929) and Kendler and Kendler (1967) experiments, chaining involved connecting separate physical movements together in order to solve the problems. The Scandura (1974) experiment required the chaining of several separate abstract rules to solve problems. However, in all of these studies, the subjects had to discover the idea of chaining separate responses or rules together in a new context to successfully solve the problems. Therefore these studies examine the nature of chaining in problem-solving as previously defined.

<u>Maier's reasoning experiments</u>. Maier studied "reasoning" behavior in mazes in rats and human beings. His definition of reasoning as the ability to combine essential elements of isolated experiences, implying a spontaneous integration, is similar to the definition of chaining in problem-solving. During free exploration trials of separate parts of a maze, the subjects were allowed to familiarize themselves with separate

parts of the maze. They were never allowed to explore the entire maze together during the familiarization trials. Then, during the test trials, the subjects had to construct the route to the goal by integrating two separate experiences. Maier's subjects had repeated maze-running trials with such test situations using different combinations of correct routes (Maier, 1929, 1936). Below four years, children performed in the maze no better than chance would predict. According to Maier (1936) the ability to combine past experiences to reach a goal matures in different children at widely different ages, generally not before 6 years of age. He believed that the time of its appearance seems to be related to mental age or intelligence (Maier, 1936).

Kendler and Kendler's inference studies. In an attempt to support Hull's S-R learning theory, Kendler and Kendler (1967) conducted a series of experiments with children and adults. Hull (1943) and other behaviorists have explained problem-solving as a series of stimulus-response bonds. According to Hull, once the first response is initiated, the whole chain of responses can be made. Each response serves as a stimulus for the next response. Kendler and Kendler's (1967) problem involved joining together two separate, previously learned behavioral sequences. The testing situation involved an apparatus in which subjects were forced to make a number of choices. These choice responses had been learned previously in separate trials in which only part of the apparatus was exposed. The subjects (varying from three through nineteen years) had to press the correct button to receive a token to drop into the correct hole. In separate trials the subjects demonstrated that they had learned which button to manipulate to get each token and into which hole to insert the token. To solve the problem correctly, subjects had to chain the two previously separate behaviors together within one minute. Kendler and Kendler's task may be seen as chaining in problem-solving because the entire chain had not been learned together but a new response chain had to be formed which integrated previously separate actions.

Most of the five year olds or younger subjects in Kendler and Kendler's experiments failed to make the integration properly, i.e., either they never reached the solution or they made incorrect or extra responses during the trial. A majority of the college students solved the problem without making any errors. They concluded that when a paradigm that followed directly from Hullian theory was tested with young children, there was little or no evidence of reasoning or inference occurring. With increased maturity, this inference or integration ability became more available until with adult subjects correct problem-solving was the typical response. The probability of a direct solution increased monotonically with age, with the rate of increase the greatest between eight and twelve years old (Kendler & Kendler, 1967).

There have been a number of interpretations of Kendler and Kendler's (1967) findings. They interpreted their findings with reference to verbal representation or verbal mediation theory rather than in support of Hull's theory. This verbal mediation theory may be seen as part of the behaviorist notion of habit forming hierarchies. According to the behaviorist approach, alternative behavior patterns are arranged in preferred order of performance. The less favored behavior patterns would be chosen only when the more favored ones are blocked. Many behaviorists, including Kendler and Kendler, believe that the strength of a response low in the hierarchy could be increased through the process of a mediated generalization, often taking the form of a verbal mediation which acts as a liaison between the presentation of the stimuli and the occurrence of the response. Kendler and Kendler theorized that verbal mediation ability tends to develop with age and is not readily available in young children, their young subjects could not make the appropriate integrating response to form a chain. However, older subjects correctly used a verbal mediating response in order to solve the chaining problem.

Pascual-Leone and Smith (1969) offer an alternative interpretation of Kendler and Kendler's results. According to Pascual-Leone's M operator or central computing space theory, the power of M, or the maximum number of schemes that can be coordinated or integrated, increases with age. This theory predicts the results obtained by Kendler and Kendler (1967). The Kendler and Kendler task required the subjects to remember five independent bits of information (the instructions, the stimulus displays, two implications and the equivalence). Pascual-Leone and Smith theorized that children must be at least seven or eight years old in order to have a central computing space large enough to integrate five independent bits of information. Whether or not one agrees with Pascual-Leone's theory, their interpretation underscores the fact that Kendler and Kendler's task did demand a high memory load in order to solve the problem.

<u>Scandura's higher order rule problems</u>. Scandura (1974) conducted a study which demonstrated children's failure to chain separate responses together without instruction. His five through nine year old children were taught to interpret given trading rules. These simple rules showed the quantities of one object that could be traded for another type of object or objects, for example, two paper clips could be traded for three blue chips. The possible trades were illustrated on a card. Once a subject demonstrated an understanding of these simple rules, he had to

solve problems by actually making trades using composite rules. Composite rules were formed by combining two simple, compatible rules, thus making a trading chain. This experiment involved two groups, a control (uninstructed group) and an experimental (instructed group). The experimental subjects were shown two compatible rule cards and were asked to interpret each of them. The experimenter then demonstrated to this group how to combine rules by sliding rule cards together in an appropriate manner. During the training the experimental group did not actually make the trades. Eleven out of twelve experimental subjects were able to make trading chains by combining simple rule cards together to form composite rules. None of the subjects in the control group were able to form trading chains by inventing the idea of connecting simple rules together and then using the composite rules. Scandura (1974) showed that five- through nine-year-old children did not think of combining compatible rules together to form a trading chain unless they had received prior instruction to do so.

Comparisons of these Experiments

A task analysis was performed on all of these chaining experiments in order to determine the requirements of each task. All of the previous experiments required much more than just chaining ability. A purer test of chaining ability was, therefore, developed and used in this experiment.

Maier (1936), Kendler and Kendler (1967) and Scandura (1974) concluded that young children do not have the ability to form response chains involving the integration of previously separate actions. However, this writer believes that the failure of young children to make correct chaining responses in these studies was more a function of various complicating factors than of young children's inability to form response chains. Correct solution in the Maier (1936), Kendler and Kendler (1967) and Scandura (1974) chaining experiments might have been inhibited by the following complicating variables: correct recall and usage of previously learned material, forcing the subject to use more than one type of response or operator; requiring the subject to remember more information than individuals of that age usually can; understanding and applying abstract rules in a concrete example, as well as integrating the steps to form a unit in order to solve the problem.

A true test of whether young children can indeed form response chains should be free of these complicating factors. Such a task, should not require individuals to recall previously learned material, nor remember much information, nor apply abstract rules. Also, when different types of operators are required in the same problem, another variable has been introduced. In a more pure test of young children's chaining ability, all necessary material or information should be given in a readily usable form when the problem is presented initially. Also, individuals should be required to make only one type of response. The same type of operator (e.g., application of the same rule, or the same psychomotor activity) can be applied over and over to form a chain rather than requiring the individuals to make different responses. Problems presented in this fashion test young children's ability to form response chains independent of other complicating factors.

Table 1 summarizes eight points of similarity or difference between the five studies previously discussed and this study. The following is a discussion of the column titles.

~~1. The previous research either studied the chaining problem-solving~~ performance of young children alone or compared their performance to college students. Only this present study compared the performance of people at different developmental levels by tracing the development of these problem-solving abilities.

Table 1

Comparison of Variables in Chaining Problem-Solving Experiments

Author of Study	Age of Subjects	Recall of Previous Learning	Number of Steps Essential in Task	Subject Must Discover Proper Sequence	Possibility of Out-of-sequence Responses	Number of Types of Operators Required	Does a Repeated Use of the same Operator Solve the Problem?	Were Children Successful in Demonstrating Chaining?
Maier	(3-8 yrs.)	necessary	constant (2)	necessary for solution	no	1	yes	no
Kendler & Kendler	(5, 8 yrs. college)	necessary	constant (2)	no, given in problem itself	yes	2	no	no
Scandura	(5-8 yrs.)	not necessary	(3)	necessary for solution	no	3	no	no
Blumberg	(5 yrs.-college)	not necessary	varied (3-7)	necessary for solution	yes, S must correct out-of-sequence R	1	yes	yes

2. Some of the experiments required the subjects to learn material before the problems were presented. This material had to be recalled and used during the solution. The Scandura experiment and this one presented all of the relevant information for use during the actual problem solution.

3. All of the previous experiments required a constant number of steps to solve the problems. However, this number of steps was small, either two or three steps. Perhaps the number of steps that individuals can integrate successfully varies with development. Therefore, in the present study the performances of people of different ages were compared in problems requiring various numbers of steps.

4. Discovering the proper sequence of responses may be seen as a fundamental aspect of problem-solving for some of the experiments. Because of the task requirements of the Kendler and Kendler problems, the proper sequences of responding was presented in the stimulus situation itself. However, in all of the other experiments in order to solve the problem correctly, the subjects had to discover the proper sequence on their own.

5. Out of sequence responses tend to be extra, unnecessary steps. In the Maier and the Scandura experiments the subjects could not make out-of-sequence responses. In the Kendler and Kendler experiment, subjects could make out-of-sequence responses but then were considered non-solvers. In the present experiment, subjects could make out-of-sequence moves, although they had to correct them immediately in order to solve the problem.

6. The number of operators varied from experiment to experiment. (An operator may be defined as the type of response such as the particular physical manipulations or the application of different types of rules.) Some experiments used only one type of operator. Examples of experiments using one type of operator are the Maier and the present one. The type of

operator used involved physical movement in both of these experiments. The others used several different types of operators within one problem. For example, Kendler and Kendler required their subjects to do different types of manipulations (e.g., choosing among alternative responses, and turning buttons and inserting objects). Scandura's individuals had to apply abstract rules and also had to trade different qualities and quantities of objects correctly in order to solve the problems.

7. Chaining problems may involve the repetition of the same operator or may require the use of different operators. Repeating the same operator several times with a problem may be easier than performing different steps in order to form a chain. Other chaining experiments (not concerned with chaining abilities in children and hence not relevant here), e.g., Newell and Simon (1972) logical transformation problems, illustrate the difference between the number of types of operators required and repetition of the same step. Many different operators could be repeated in these logical transformation problems.

8. Were the children able to solve the chaining problems? The previous research failed to demonstrate that young children can solve chaining problems. The children in this study were successful. This author believes this contrast in results is due to their different task requirements.

Method

Subjects

There were twenty subjects in each of four groups: kindergarten, third grade children, sixth grade children, and college undergraduate students. The subjects were either randomly selected from their respective grades in a middle class suburban public school or college volunteers.

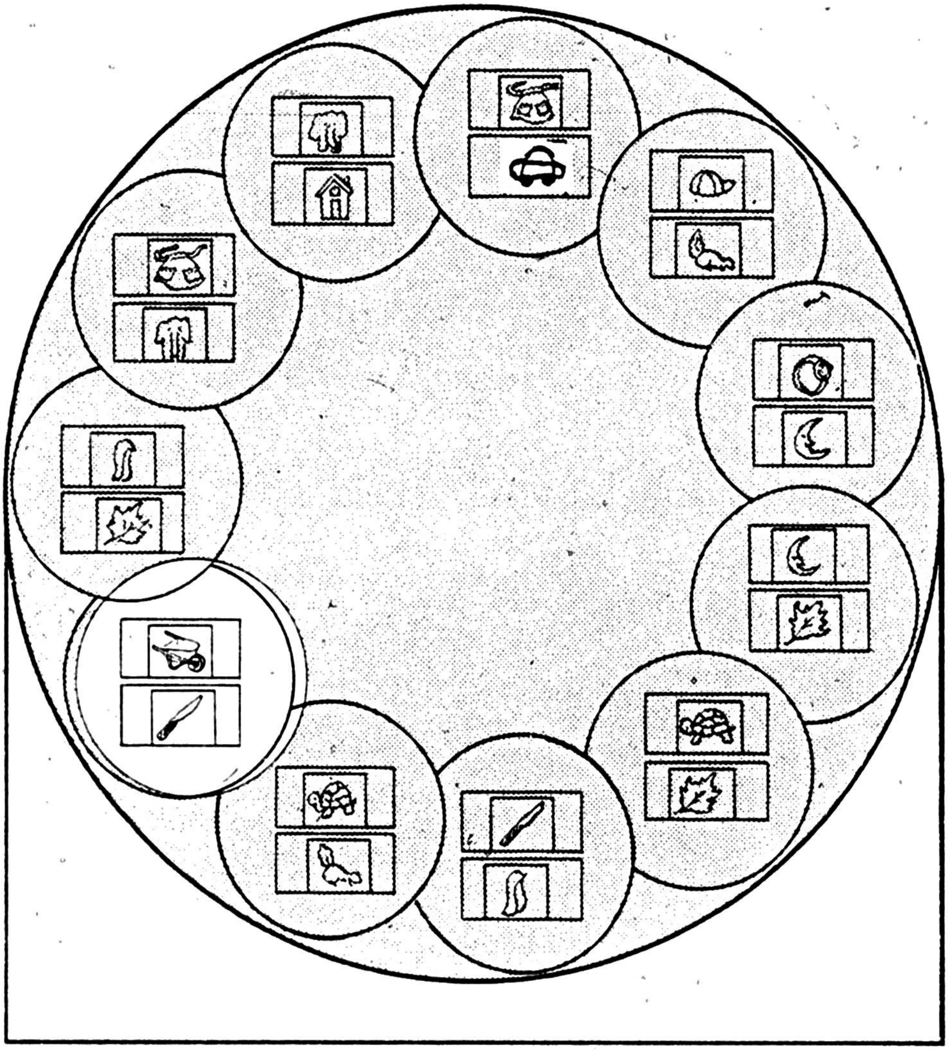

Figure 1. Illustration of trading board.

Materials and Apparatus

Trading board. A circular board which contained eleven sets of display containers arranged around the periphery of the circle. Each display container showed two different cards. A transparent plexiglass circular wheel was mounted over the board. A circular hole large enough to uncover one display container had been cut out of the plexiglass cover. The wheel could be rotated to allow subjects to obtain access to the actual trading cards. Figure 1 illustrates the lay-out of the trading board.

Object cards. Cards showing drawings of common objects were placed in the display containers. Within each display container two different object drawings were shown.

Goal-box container. One separate display container which resembled a picture frame and transparent cover was used to demonstrate the goal object-card. The goal object-card was placed inside this display container, permitting the subject to continuously view the goal object without having direct access to it.

Procedure

Each subject was tested individually. Prior to the problem-solving trials, the experimenters explained how the subject was to use the trading board to solve the problems. Each of the problems involved trading cards to reach a specific goal card. All of the trading cards for that problem were visible for the duration of each problem.

Once the subjects demonstrated that they knew how to make a single trade using the trading board, the actual problems were presented. For all of the problems the experimenter gave the subject the initial card and placed the goal-object in the goal-box while she said, "You have a ________________ and you want to get a ________________."

Different cards were used with each problem; arrangements of the cards on the board also varied with each problem. The order of object-card presentations around the board were randomly determined a priori for each problem. The patterns for each individual problem were the same for every subject.

The subjects were allowed to proceed on their own throughout the problems provided the trading rules were followed correctly. If an illegal move was attempted, the experimenter corrected the subject. While the subjects solved the problems, the experimenter recorded everything relevant that the subjects said and did.

Although the subjects were given three chances to solve the problems, the criterion of success required only one correct solution. The first problem required the integration of three separate trades in order to form a chain. Subjects had to think of the idea of making more than one trade. If after three unsuccessful attempts to solve the problem, two hints were given by the experimenter. The first hint was, "Look around the entire board." The second hint, which was given prior to the next trial, was, "You are allowed to make more than one trade." If a subject did not solve the problem correctly after both hints were given, an instructional sequence was initiated. If the subjects were still unsuccessful, the problems were next simplified in the instructional sequence. The simplifications of the problem involved manipulating the manner in which the information was displayed, e.g., with the correct trades arranged in order around the board; the amount of information given, e.g., with only the three trade containers filled; and the number of separate exchanges which must be connected together in order to solve the problem.

Longer chaining problems. Next, problems involving the integration of more than three trades were given. On each succeeding trial, the number of required trade links was increased by one (two for adult subjects). This procedure continued until either the subject was unsuccessful on two trials involving a given number of trade links or the subject solved problems involving the integration of nine separate trade links.

The ceiling level was defined as the longest chain that the subject performed successfully. Additional trials requiring fewer trade links in order to solve the problem were given to subjects once their ceiling level was determined. These additional trials were given in order to promote a feeling of success in the problem-solving situation.

Results

The results are reported according to the following questions: (1) Can individuals spontaneously integrate several independent exchanges to form barter chains? (2) Can individuals profit from compensatory instruction? How much of this instruction was needed before the individuals could succeed? and, (3) Can individuals form longer link trade chains (greater than three separate moves) and how long a chain can be made?

Integrating Exchanges to Form a Chain

Table 2 shows the percent of successful solution by age-grade group. A Chi-square test indicated a significant age-grade effect ($\chi^2 = 25.144$, $p < .05$). Sixth graders and college students all solved the problem without simplification, and most solved it on the first presentation (all but one person solved without any hints). Kindergarteners and third graders took longer to "catch on," but virtually all solved after the hints and a large number appeared to "catch on" between the first and second trials with no hints at all.

Table 2

Cumulative Percentages of Successful Integrations

by Subject Group

When Solved	Group Kindergarten	3rd Grade	6th Grade	Adult	Total
By first presentation	50%	45%	80%	90%	66%
By second presentation	70%	90%	90%	100%	88%
By third presentation	75%	90%	95%	100%	90%
By fourth presentation-hint "Look around the whole board"	85%	95%	100%	100%	95%
By fifth presentation-hint "You can make more than one trade"	90%	100%	100%	100%	98%
By sixth presentation First problem simplification	100%	100%	100%	100%	100%

Profit from Compensatory Instruction

As Table 2 indicates, only 10% of the subjects required any cueing or problem-simplification before they solved the problem. After three unsuccessful attempts to solve the problem, two hints were given. After giving these hints and two additional attempts to solve the problems, all but two kindergarten children integrated several independent exchanges to form barter chains. Both of these children were successful after the first problem-simplification. Thus, the proposed instructional procedure was not adequately tested.

Forming longer chains. All of the subjects formed successively longer link trade chains. Ninety-nine percent of the subjects were successful with the longest problems; only one kindergarten child failed to solve problems up to nine separate links. This child's ceiling level was five.

Discussion

The results of this research, which investigated the ability of young children to form chains clearly showed that both children and adults can solve these problems. Since even the youngest children were successful with these chaining problems, the compensatory instructional sequence was not tested. The only developmental difference observed with these chaining problems related to whether or not the subjects were successful on the first attempt. However, all of the subjects were able to form fairly lengthy chains.

The ability to form response chains through the repeated application of the same operators develops at a very young age. The only developmental trend in chaining ability observed in this experiment is related to whether or not the problem was solved on the first attempt. Of the younger two groups of subjects, about half solved the problem on the first attempt.

The change occurs sometime between the ages of the third graders and the sixth graders. In addition, at least three quarters of the individuals in this study were independently able to form chains without direct instruction or cueing. The failure of young children to form response chains in previous studies (e.g , Maier, 1936; Kendler & Kendler, 1967; and Scandura, 1974) may be attributed to task differences rather than actual chaining ability. The following summarizes the significant characteristics of the tasks which differed from this one. Successful solution in Maier's and in Kendler and Kendler's problems included recall of previous learning and discrimination between inappropriate and appropriate responses. In addition, Kendler and Kendler considered subjects to be successful only when the essential steps were made with no additional responses. In order to succeed in Scandura's problems, the subjects had to understand the meaning of an abstract task and that a single object could be equivalent to varying quantities of other objects. The Scandura task also required the integration of separate operators.

Perhaps the methodology used in this problem explains the high success rate. First, the preliminary instructions were given in a step-by-step fashion. Each aspect of the task was introduced one at a time. Before the next aspect of the problem was introduced, the experimenter determined that the children understood exactly what they were supposed to do. Second, the children had experience actually trading the object-cards before the problems were presented, thus demonstrating an understanding of what they were supposed to do in separate components of the problem. Third, the task requirements themselves tested chaining ability in an isolated context (isolated in that other abilities were not also tested). This was a purer test because it involved the following: (1) a concrete task, (2) a repeated use of only one type of operator, and (3) a slight reliance on previous learning.

This experiment demonstrated the importance of task requirements, competency and information-processing load were illustrated. In the earlier tests of chaining ability (Maier, 1936; Kendler & Kendler, 1967; and Scandura, 1974), the problems were more difficult and there were higher load requirements (e.g., reliance on previous learning, understanding an abstract task, or the required use of several different operators). However, in this experiment, the task load requirements were simpler and young children were successful with these chaining problems. These findings illustrate the distinction between competence and performance. Young children may know how to perform a particular skill, but this ability may not be evident from their performance on specific tasks. When the task requirements are changed, young children do solve the problems successfully, thus, demonstrating the ability in question. In some cases, with the revised problems, children can perform as well as adults do. The problems in the first experiment are a good example of young children not only demonstrating chaining ability but also being able to solve the problems as well as adults do. Research in other aspects of developmental psychology such as with probability learning (Wier, 1964; Green, Elliot, & Bancke, 1971) and with hypothesis testing (Phillips & Levine, 1975) illustrate, as this experiment replicates this finding, that young children can perform as well as adults on specific problem-solving tasks when the task is simplified, their information-processing capacities are not overtaxed, the instructions are changed or they are given some preliminary pretraining.

What Additional Research Should be Derived from this Study?

This study demonstrates that young children can solve chaining problems when such a test involves only chaining ability. Further demonstrations in other situations of such chaining ability might be useful. For example, if Scandura's (1974) task were redefined so that it involved the use of a concrete problem and a one-to-one trading correspondence, perhaps then, young children would be more successful in applying composite trading rules (i.e., from the combination of two simple rules) without instruction. If children were successful with this purer test of their ability, then we would have further proof that young children can solve problems involving chaining and that past failures might be attributed to various task requirements that differed from this one.

Conclusions

This study demonstrated that although chaining ability develops at a young age and that it can be used effectively by young children, older children and adults seem to "warm-up" to the task requirements sooner. The only developmental differences that were observed regarding chaining ability concerned whether or not individuals think of forming chains the first time they are given the opportunity to do so.

The results obtained in this experiment, in conjunction with previous research, underscores the educational importance of the task requirements and the instructions used. This study, together with previous chaining research, illustrates the importance of isolating a particular ability in order to test that ability more fairly. As is the case in the other studies and in many educational tests, a particular ability was tested within the context of other abilities.

Once an ability, such as chaining ability, has been demonstrated, then it can be used as a baseline to test that ability in the context of others. Since young children can succeed in chaining responses together, this chaining ability can be used in testing other abilities in young children. However, educational tests or psychological experiments which use this chaining ability have to be constructed carefully.

Young children did demonstrate the ability to connect responses together to form chains independent of direct instructions. If, as this study shows, young children can invent or integrate things without instruction, then the question can be raised, how much actually has to be taught directly. Perhaps, children can learn ideas involving a series when only parts of that chain are taught. The idea of teaching parts of chains should be further tested. The limits of chaining ideas or responses together should be tested in various contexts, with varying amounts taught, and with children of various cognitive levels.

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