DOCUMENT RESUME

ED 249 920 IR 011 339

AUTHOR Pea, Roy D.; Hawkins, Jan
TITLE Children's Planning Processes in a Chore-Scheduling Task. Technical Report No. 11.
INSTITUTION Bank Street Coll. of Education, New York, NY. Center for Children and Technology.
PUB DATE Mar 84
NOTE 44p.; For related document, see IR 011 358.
PUB TYPE Reports - Research/Technical (143)

EDRS PRICE MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS Age Differences; Classroom Research; Comparative Analysis; *Critical Path Method; Intermediate Grades; *Planning; Preadolescents; *Problem Solving; Sequential Approach; *Task Analysis

ABSTRACT

This paper provides a detailed empirical account of the performances of 8- to 9-year-olds and 11- to 12-year-olds on a chore-scheduling task developed to assess the dynamics of planning processes. In developing the planning task for revealing different levels of planning proficiency, five critical aspects of planning were taken into account: the need for planning is often not recognized; background knowledge of the situation is necessary for planning; planning is more likely when the situation is complex and novel; planning is a revisionary process; and planning decisions are made at different levels of abstractions. Thirty-two students in a private school in Manhattan were given multiple opportunities to construct the shortest path for accomplishing a series of classroom chores. Careful examination of the processes and products of planning activities across different trials--specifically, think-aloud protocols, strategies for problem solution, and route efficiency--revealed considerable developmental progress within sessions for both younger and older children, and significant age differences; e.g., older children engaged in significantly more higher-level decision making during planning processes. A reference list, the scoring system for featural analysis, and coding categories and definitions for process analysis are included. (Author/THC)

CENTER FOR CHILDREN AND TECHNOLOGY

Children's Planning Processes in a Chore-Scheduling Task

Roy D. Pea and Jan Hawkins

Technical Report No. 11

March 1984

Bank Street College of Education 610 West 112th Street NY, NY 10025

Children's Planning Processes
in a Chore-Scheduling Task

Roy D. Pea and Jan Hawkins

Technical Report No. 11

March 1984

CENTER FOR CHILDREN AND TECHNOLOGY
Bank Street College of Education
610 West 112th Street
New York, NY 10025

[Revised version to appear in S.L. Friedman, E.K. Scholnick & R.R. Cocking (Eds.), Blueprints for thinking: The development of social and cognitive planning skills. Cambridge: Cambridge University Press, 1984.]

Children's Planning Processes in a Chore-Scheduling Task*

Roy D. Pea & Jan Hawkins
Center for Children and Technology
Bank Street College of Education

Introduction

In order to successfully accomplish a coordinated set of activities in the achievement of an overall goal, it is useful to learn skills of planning. A plan is a representation, in some form, of a set of actions designed to produce an intended outcome once put into action. Plans are often never put into action, but their adequacy cannot otherwise be reality tested. Furthermore, a plan can exist at various levels of specificity, and may be designed in different representational forms (e.g. talk, text, images, blueprints).

A general model of planning consists of four components: the planner must first construct a representation of the planning situation, including the problem and goal; she must construct the plan to achieve that goal; execute the plan; and she must remember the planning process. These four interrelated components of the planning process are discussed in detail elsewhere (Pea, 1982), and each presents major developmental challenges. These model components are frequently discussed as if they take place in sequence, but an important feature of actual planning performances is that any of the components may be thought about, used, or modified anywhere in the process of constructing and carrying out a plan. This sort of revision is especially apparent when we examine the planning processes involved in composing a text (e.g. Flower & Hayes, 1981). Thus, for example, attempts to construct a plan may lead to redefining of goals, while trying to execute the plan often results in revisions of the structure of the plan. Planning is thus inherently recursive in nature.

In this paper, we narrow our focus from these multiple complexities to an analysis of the second component of the planning model in a developmental context: the processes and products which emerge when children construct a plan. While our emphasis will be on understanding how children construct plans in a context where the problem situation is defined for them, we recognize in our task design and analyses that the planning model components may have mutually revisionary influences during the course of planning activities.

How do children's planning efforts at different ages relate to these model components for high level planning skills? We know very little about the development of such high level skills. Therefore, in order to reveal how children are planning, we needed to design a task that would take into account what is known about the features of plan construction, especially information about when planning is likely to be done by children, and that would allow observers to see and analyze the process of plan construction as it occurs.

In developing the planning task for revealing different levels of planning proficiency, five critical aspects of planning were taken into account. These five aspects are discussed in turn.

The need for planning is often not recognized

Planning activities appear to often be tied to specific situations. People learn to apply planning skills in particular situations; it is not necessarily the case that all situations in which planning would be appropriate are recognized as requiring planning efforts. For example, some complex sequences of action are well-practiced routines for individuals, like getting to work in the morning using several modes of public transportation. Conversely, there are non-routine situations where planning efforts would enhance the quality of outcomes, yet where individuals fail to engage in plan construction.

For example, in our previous work interviewing 8 to 12 year-old children about planning (Pea, 1982), no children reported that they engaged in planning when doing school work, although they knew what planning was and could describe situations in which plans are important. Thus, a task context was needed where it would be expected that most children would naturally recognize the value of planning.

Background knowledge of the situation is necessary for planning

Related to the situational character of planning is the importance of an adequate knowledge base about the planning context so that appropriate moves can be developed, and hypothetically carried out. For example, one might be very hard-pressed to plan an African safari not because of poor planning skills, but because one does not know about key safari activities, probable hardships, the necessary supplies, staff, maps, and the contingencies among events that would constrain the development of such a plan. It is important that the planner have sufficient knowledge about the content of the planning problem. Otherwise the substance of plans is more like fantasy material than a realistic blueprint for action.

Planning is more likely when the situation is complex and novel

Planning is most frequently required and best revealed in situations of sufficient complexity and novelty so that the means for achieving a goal are not obvious, and alternative courses of action may be reasonably considered. Effective planners must be able to consider and hypothetically execute different courses of action in order to assess the best means of achieving a goal. As noted above, planners must have a sufficiently rich knowledge base for the domain to anticipate the consequences or "commitments" (Stefik 1981a, 1981b) of specific actions in a plan. For example, doing one action early in a sequence of actions may preclude the possibility of choosing a different desirable action later. Thus we required a situation sufficiently complex, yet well known to children, in order to assess their abilities to experiment with alternatives in the course of planning.

Planning is a revisionary process

Planning must be characterized as revisionary. In considering alternatives, effective planners edit and revise their plans. They flexibly use both "top-down" approaches which proceed from abstract decisions (e.g. to seek a mortgage) to increasingly specific ones (e.g. which bank to seek the mortgage with), and "bottom-up" approaches which note emergent concrete properties of the plan or the planning environment (e.g. a specific bank is offering very low interest rates), and add data-driven decisions to the plan. Planners might go through several cycles of revision in considering the consequences of differently organized schemes of action. In understanding children's planning, it is important to provide a context where these revisionary efforts can be revealed. Are children able to revise their plans to be more effective on the basis of information gleaned from considering alternatives courses of action? How does this ability to incorporate information over the course of planning reveal itself developmentally?

Planning decisions are made at different levels of abstraction

Finally, planning decisions can be made at different levels of abstraction. For example, a plan can be generated hierarchically from a consideration of the problem situation as a whole. One may begin very abstractly ("I would like to see a movie tonight with someone"), and proceed by progressively refining or concretizing the plan to a specific alternative ("I will leave with Sam to walk down Broadway toward the Thalia at 95th Street to see The Last Metro at 7:30 p.m. tonight"). Alternatively, planning can occur more concretely as a sequence of local decisions without an overall framework for the situation. Such "planning in action" (Rogoff & Gardner, 1983) is probably more important in everyday activities than preplanning before action. On a comparable note, Scardamalia &

Bereiter (1984) describe the efforts of the fourth-grader at planning to write as more like a "rehearsal" or a first draft of what they will end up with as text than like a plan. We were interested in understanding how children come to generate frameworks for the planning situation. The experimental task should be able to reveal different skill levels of children's decision-making in their planning efforts.

In sum, it is necessary to consider particular features of the task situation used for assessment in order to reveal abilities of the planner. With respect to the situation, the planning context should be sufficiently complex that alternative courses of action are reasonably available; the situation must be one where it is plausible that children will see planning as appropriate; and it must be a context where children have sufficient knowledge of the domain so that planning is possible. With respect to the planner's abilities, the task should reveal: whether alternative plan designs are considered, and whether the planner tries them out and thinks through their consequences; the characteristics of revisions; and the types and levels of abstraction in planning decisions.

We decided that a classroom-chore scheduling situation similar to a task developed by Hayes-Roth & Hayes-Roth (1979) met these requirements for a planning situation. In consultation with teachers of the schoolchildren who participated in our study, we found that all children were required to carry out certain classroom chores on a regular basis. The children were familiar with a list of chores (e.g. washing the blackboards, watering the plants) and the actions involved in doing each one, but the task was made novel by asking children to organize a plan to accomplish the set of chores so that they could be carried out by one person efficiently. Since we wished to see now children engaged in revisions, we utilized a method in which they were encouraged to develop and improve upon their plans over the course of an experimental session. The term "microgenesis" (cf. Flavell & Draguns, 1957; Werner, 1956) is derived from the rich but little known developmental studies of the organization of thought processes in the first half of the twentieth century. The term refers to the sequence of cognitive events which unfold over the brief time between initial contact with a stimulus and a relatively stable cognitive response -- in our case, the child's final plan. We view the microgenesis of a plan through successive revisions as revealing important features of planning processes that have general developmental significance. This microgenetic method allows us to closely observe the revisionary processes involved in a planning task.

In addition to the analyses of planning processes, we were interested in how certain mental representational abilities may impact on children's approaches to the planning situation. Sophisticated planners must simulate actions mentally, observe their consequences, and consider alternatives. Planning is usually thought about as a fully internalized symbolic process which requires mental, symbolic representation and mental operation upon the symbols. For this reason, we were interested in understanding how individual differences in memory capacity and cognitive style (specifically, field dependence-independence) might contribute to effective plan construction. A successful planning effort for a complex situation is memory-intensive, requiring children to remember complex sequences of actions. Effective planning also requires facility in seeing how potential parts of a plan interrelate with the effectiveness of the plan alternative considered as a whole. We therefore felt it was important to collect information about children's memory capacity and their facility in thinking about part-whole relations. In order to understand how these abilities may relate to planning skills, all children in the study were given a variant of the WAIS forward digit-span task (as a measure of memory capacity) and the WISC Block Design Subtest (as a measure of field dependence-independence), as we discuss below.

In constructing our planning situation, we also took into account the practice of planning as it occurs in everyday situations. The complex symbolic manipulations involved in planning often necessitates externalizing the representation of the planning space in some way. Planning activities often occur in contexts where the planning process is supported by various sorts of representational "tools" or aids, developed especially to assist in planning for a particular type of activity. Specialized planning tools may be found in a number of professional contexts (e.g. business, education, medicine). For example, designers such as architects and interior designers may construct planning spaces in which they can physically try out alternate arrangements as part of the planning process. And in writing, sophisticated word processors allow for easily created simultaneous comparison of different options for planned text organizational schemas. Likewise, designers may make use of specialized drawing devices and conventions to facilitate both the planning process and its execution, such as computer-aided design and manufacturing systems (CAD/CAM) for computer microcircuits.

These planning supports appear to have at least two functions: to relieve the memory burden required for the representation of complex plans; and as a "symbolic" space in which to try out alternate formulations of a plan before actual execution (e.g. a model for the design of a kitchen). In this sense, "epistemic planning," much like "epistemic writing" (Bereiter, 1980), serves to externalize thought and enable transcendence of human information processing limitations. At these high levels, planning becomes an externalized tool of thought which can be transformed as an object of perception and reflection.

The planning task used in this research takes into account this feature of planning in "real" contexts: a classroom map was designed as an external representational model to support the planning process. This tool enabled children to reveal their planning processes to observers as they constructed their plans.

In the following sections, we present details of the experimental materials used, the task description, experimental procedure, participant characteristics, systems for data analysis, and then the results of our study.

The Chore Scheduling Task and Experimental Method

Materials

A transparent plexiglass map (22" by 30", scale 1" to 15") of a fictitious classroom was developed (see Figure 1) for the task.

(Insert Figure 1 here)

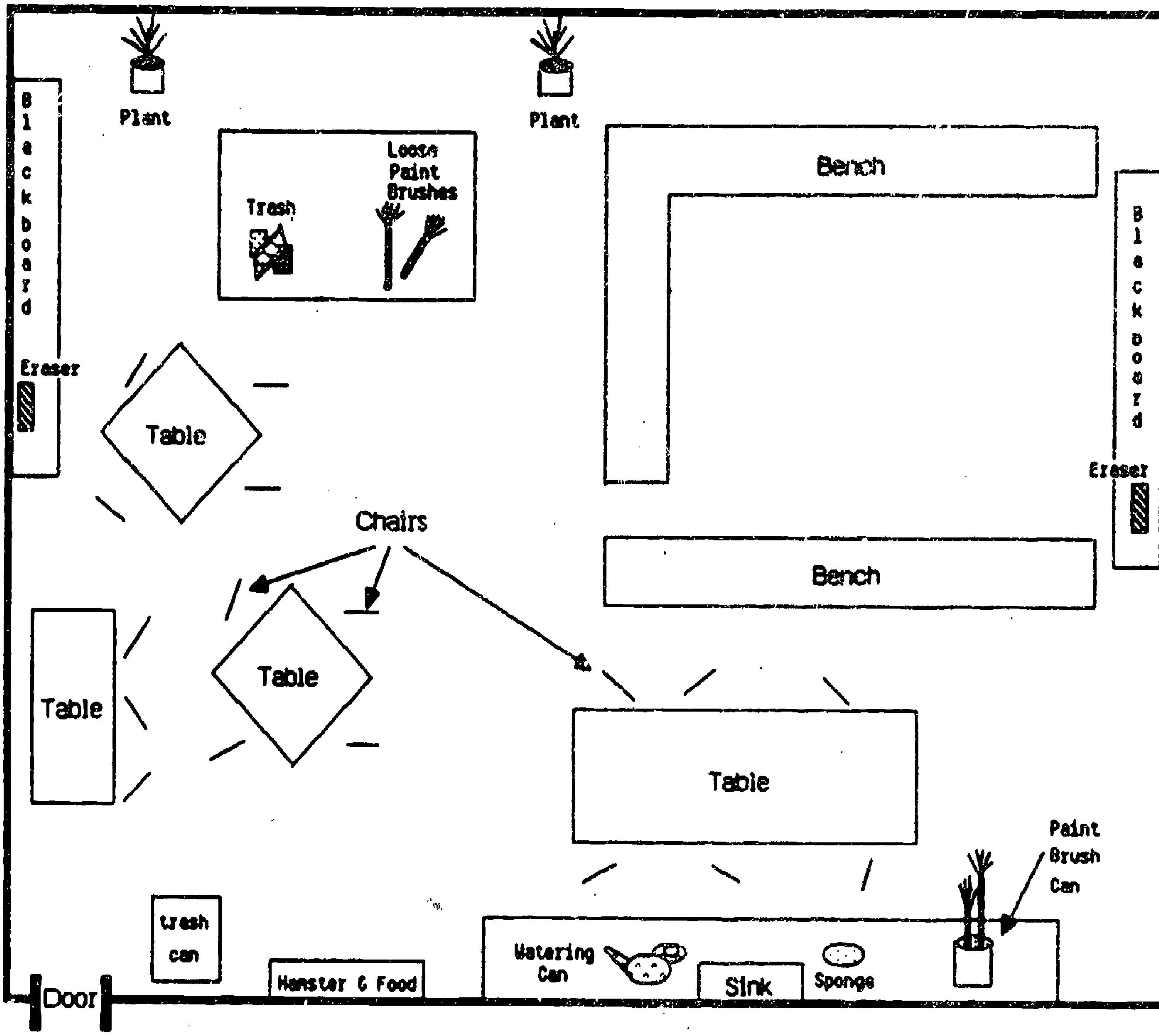
The chore list consisted of six major chores to be done after first entering through the classroom door: (1) watering (two) plants; (2) erasing and washing (two) blackboards; (3) feeding a hamster; (4) putting (seventeen) chairs under their adjacent tables; (5) washing (five) tables; and (6) putting away objects (returning and washing out paintbrushes; disposing of trash paper) lying on the art table. The final "chore act" is to leave through the classroom door. These six major chores and their closing act may be accomplished with a minimum of 39 distinct component chore acts, some of which are instrumentally necessary to accomplish others (i.e. watercan is needed to water plants; sponge is necessary to wash tables and blackboards). Finding the optimal sequencing of these chore acts is thus a challenging task.

Participants

Thirty-two students in a private school in Manhattan participated in the study. Half of the children were 8 and 9 year-olds, the other half were 11 and 12 year-olds. These two age groups were not selected for specific reasons of developmental theory, but because their teachers were willing to participate in the intensive longitudinal

Figure 1

Diagram of Classroom Map



studies of Logo computer programming and planning development that we had planned; this age range was chosen since it is representative of children learning Logo programming in American schools. We nonetheless anticipated substantial development of planning skills across the age period of early to late concrete operational thinking represented by these ages.

The 32 children came from four different classrooms. Four boys and four girls of each age formed an experimental group who were learning Logo computer programming, and four boys and four girls of each age constituted a control group not receiving the treatment. Since the Logo programmers did not significantly differ from controls in their planning performances as described below, we have collapsed the experimental and control groups into a single group for current purposes. The relations between these groupings and planning results are detailed in Pea & Kurland (1984), but will not concern us here. But a year of Logo programming did not help children become more effective planners, at least as indexed in the task described.

Participant selection was not random. For the experimental groups, participants were selected on the basis of two criteria: a large quantity of time spent working at the classroom microcomputers during their first two months of use, and teacher-assessed reflectiveness and talkativeness so that rich think-aloud protocols during the task might be provided. For the control groups, only the second criterion was used.

Other tasks administered were a digit span task and the WISC Block Design subtest. The former measure was chosen to assess whether the size of a basic processing capacity affects planning performances during this task. The latter measure was selected as a task for determining an individual's cognitive style in terms of their field-dependence or field-independence. The rationale and procedure for both tasks is discussed below. Table 1 provides a summary of WISC and Digit Span scores for the two age groups.

Table 1. WISC Block Design (BD) and Digit Span Scores

	Digit Span		Standardized WISC BD Scores	
Age Group	Mean	s.d.	Mean	s.d.
Younger Group	5.3	(1.3)	13.4	(2.6)
Older Group	6.2	(1.5)	13.3	(2.8)

Experimental design

The planning task was administered early in the school year. Between participant grouping variables for current purposes were: (1) age (younger, older); and (2) sex (male, female). Other between participant variables were: (4) Wechsler Intelligence Scale for Children (WISC) Block Design Score, and (5) Digit span. The key within participant variables were mean scores across all plans, and scores for first and last plans.

Procedure

Classroom Chore-Scheduling Task

Each child was taken individually from his or her classroom to a filming room, and seated at a table upon which the plexiglass map stood. The map was oriented upright on an attached stand 6" in front of the child, and tilted back 6° from the vertical plane. A videocamera was located approximately 8' from the map, and filmed each session through the map.

The experimenter then slowly read the following instructions to the child:

> This is a map of a classroom. Today I'd like you to play a game for me. In this game, pretend it is the afternoon, just before school is over. Your classmates have left early, and your job is to make a plan to do the classroom chores I will tell you about.
>
> You have to water the PLANTS (point) near the window. You have to erase and wash the two BLACKBOARDS in the room (point). The HAMSTER in his cage needs to be fed (point to cage and food). The CHAIRS are out of place

> around the tables, and each should be put under the tables neatly. All the TABLES in the room also need to be washed (point to each). There are a few things to do at the ART TABLE (point). The PAINTBRUSHES there (point) need to be washed, and put in the brush can next to the sink (point). The TRASHPAPER (point) on the art table should be put in the trashcan (point).
>
> There are a lot of chores to do here. You can plan for as long as you want to do the list of chores (point to child's list of chores) in any order you want. Some ways of doing the chores are ones where you have to walk farther to do them. You want to find the shortest way of doing the chores. The shortest way is the best way. [The experimenter then demonstrated the contrast of shorter versus longer spatial paths by walking straight toward the child (shortest path) versus around the room and then to the child (longer path).]
>
> Now you can practice by trying out different plans until you are ready to show me the best plan you can think of. It is real important that you think out loud all the time you work on this game. Tell me everything you think about as you are doing it, like if you are making decisions about what to do in your plan. Use the [foot-long wooden] pointer to show the path you would take in your plans to do the chores.
>
> I also have something you can use to help you in getting the best plan. There is a pencil and paper for making notes if you want to.
>
> There are a couple of other things. The SPONGE does not need to be rinsed. It is good for all the chores that need to be done. And the WATERCAN has enough water in it for both plants.

After a child completed each plan by moving their pointer to the exit door on the map, the experimenter asked whether he or she had done all the chores they wanted to, in order to prompt the noticing of any omitted chore acts. If the child did not notice chore acts that had been omitted, E asked: "Can you make up a shorter plan?" If the child answered "yes", the session continued with the formulation of another plan; sessions terminated when the child believed he or she had arrived at the shortest plan he or she was able to formulate.

Digit Span Task

Since the symbolic planning activities that one may use in working on the classroom problem are memory- ntensive, we utilized a digit span measure of short term memory capacity. As a child plans aloud and constructs a path to achieve the task goal, many different chore acts are named in sequence. It is reasonable to assume that remembering one's plan so that it may be improved through revisions in a subsequent plan would be facilitated through greater span capacity.

Within two weeks of the experimental session, the children were individually presented with a variation of the Digits Forward task of the Wechsler Adult Intelligence Scale (WAIS) Digit Span subtest. Numbers were displayed visually[1] by microcomputer so that presentation rate could be tightly controlled.

Each number appeared for one second and then vanished as the next digit on the list replaced it. When the presentation of each list was complete, a cursor appeared, instructing the child to start the next list by pressing a specific key. Before pressing the key, children attempted to reproduce orally the numbers in the list in the correct order.

During the task, five lists of each length (from 4 to 11 digits) were given so as to provide reliable measures of span size. Responses were only considered correct if all the numbers in the list were recalled in correct order. Children received lists of increasing length until they reproduced none of the five lists of that length correctly. The cumulative partial scoring method advocated by Brener (1940) and Lyon (1977) was used, according to which one's span size is counted as the sum of: (1) the longest list length for which all five lists were recalled correctly, and (2) the proportion of lists reproduced correctly at each of the longer list lengths.

The mean digit span for the younger group according to this method was 5.31, for the older group 6.23, but this difference was not significant. However, age was significantly correlated with digit span ($r = .35$, $p = .029$).

<u>WISC Block Design Task</u>

Field dependence-independence is a robust cognitive style variable developed by Witkin and associates (Witkin et al., 1954; Witkin et al., 1962), and refers to a self-consistent pattern of functioning with respect to separating an item from its background context (field), to confronting a situation analytically, and to preserving an active orientation to the environment. Since planning involves distancing of self from the task, the dimension of field dependence/independence may be linked to planning insofar as planning requires self-task distancing and a corresponding strategy-seeking attitude. A rational analysis of the classroom map problem suggests that it is a task environment in which such distancing from the task is less likely to occur with field dependency than independency. One would thus expect superior performance by individuals who are relatively field independent. Each plan has a large number of components whose interrelationships are important to consider in improving one's plan. Disembedding proposed plan moves within their field context and reconstructing move sequences in formulating a new plan should be facilitated by field independent cognitive style. A related interpretation of direct relevance for the classroom problem is suggested by Case's (1974, p. 549) discussion of this cognitive style variable: "field dependent subjects are assumed to...assign higher weight to perceptual cues than to cues provided by task instructions, in situations where these two sets of cues suggest conflicting executive schemes."

The WISC Block Design task was selected for determining field-dependence or field-independence since Case & Globerson (1974), among others, found that WISC blocks show a high loading on factors defined by Witkin's Rod and Frame Test for assessing cognitive style. The WISC blocks are also easy to present and score.

The WISC Block Design task is comprised of eleven timed design reproduction problems, and a child's score is contingent on the speed with which they can copy accurately the examiner's reference design block arrangement with their own set of blocks. The task was administered by a clinical psychologist qualified as a WISC examiner in approximately 10-15 minute individual sessions. Scores for this task are given in terms of the national age norms specified in Wechsler (1974).

The mean WISC score for the younger group was 13.4 (s.d. 2.6), for the older group, 13.3 (s.d. 2.8). The overall mean for the group of 32 participants was 13.34, well above the national average of 10.

Results

Three principle types of analysis were performed. In the first section, we review analyses of plans considered as products, with the principle focus on the shortness or efficiency of plans that children produced. In the second section, we consider the types of revisions that children made in their plans. What were the qualitative features of plans that contributed to plan improvement? In the third section, we examine planning processes, specifically in terms of the types and levels of abstraction of decisions made during the planning process. In addition, we discuss the decision choice flexibility that was revealed in individuals' formulation of plans. In the final section, we integrate findings for these analyses, examining the extent to which a child's processes of plan formulation contribute to the quality of their plans.

1. Product Analyses

Data reduction from the videotaped sessions took place in three main phases. Videotapes were carefully transcribed, with sequential notations made of utterances, pointing, and other gesturing. For subsequent analyses of the plans as products, the sequence of chore acts (moves) for each plan created was then determined from the transcripts. As in related research by Goldin & Hayes-Roth (1980), we used the final, child-revised version of each plan for our plan distance measurements. We then measured the distances on our map between pairs of chore act locations and for each plan we calculated the total distance that would be traversed if the plan were to be executed.

Furthermore, a child would sometimes omit a chore act, rendering their plan incomplete. To compare the length of plans for children and groups, we needed a full plan; otherwise plan distance comparisons would be distortive in the sense that they would favor incomplete plans. To make the total distance of each plan comparable from one child to the next, an adjustment method was used to build up each partial plan to a "full plan," i.e. one accomplishing every chore act in the task. This conservative adjustment consisted of calculating for each plan for each individual the "median length of moves" (more meaningful than the mean since interchore act distances were sometimes very small or very large). To derive "total plan distance" we then added to the child's partial-plan distance the product of the number of omitted acts and their value for median move length[2].

The data created as each child produced multiple plans allows many comparisons within and between individuals. We analyzed the distances of the individuals' plans, and their efficiency relative to the "ideal plan", which would accomplish the chores in the shortest distance. F statistics are significant for alpha less than .01 unless otherwise specified. Several preliminary summary statistics set the stage for plan efficiency result presentation.

Number of plans

The mean number of plans per child was 3.94 (s.d. 1.48), and there were no significant age differences. The number of plans an individual produced was also not related to the efficiency of an individual's best plan.

Effects of sex, WISC score and digit span

In general there were few significant relationships between WISC score or Digit Span score and any of the product measures. However, those significant relationships, reported in the relevant sections below, were in the predicted direction, i.e., higher WISC scores or higher Digit Span scores were positively correlated with more highly developed planning behaviors. There were no sex differences revealed at all, so in subsequent analyses we will not distinguish boys from girls.

Plan efficiency

For each child for each plan, the key variable for efficiency analyses is "plan route efficiency," calculated as a score (Goldin & Hayes-Roth, 1980):

$$\text{Route efficiency} = 100 - \frac{(\text{Total distance} - \text{Optimal distance}) * 100}{\text{Optimal distance}}$$

We believe that this route efficiency score represents the single most straightforward index of the effectiveness of an individual's planning efforts in this task. Since not all children formulated the same number of plans, we used a child's first and last plan efficiency scores for analyses. Number of plans was not a good index of planning skill since it is possible to make many bad plans, or just a few very good ones.

The efficiency of plans significantly increased with age and from first to last plan. We found that from first to last plan, the mean efficiency score (out of 100 possible) rose significantly from 52.7 to 69.2. A better sense for the improvement of scores may be gleaned from the two-score sequence for each age group from first to last plan. For the young group, we find improvements from 39.5 to 58.4; for the older group, from 65.9 to 88.3. A comparable analysis of the shortest plan overall reveals that the older group produced significantly shorter overall shortest plans, and had shorter overall longest plans.

2. Qualitative analysis of plan improvements through revisions

We have shown that each age group improves in plan efficiency from first to last plan, but how did plan revisions led to improvements? We would like to know what kinds of plan revisions were made, so we need fine-grained observations that point to concrete features that vary across plans, rather than, in the case of strategy analyses, descriptions of general task approaches which may map somewhat indirectly onto concrete plan features. We will refer to this approach as a featural analysis.

Our aim is not to examine all types of plan revisions, but those accounting for the bulk of progress made across plans. We derived such a set by observing many plans, and noting major changes in plan structure that led to improvements. For the most part, we can characterize the substantive revisions of structure children made in improving their plan as resulting from "seeing" the chores differently over time. These phenomenological shifts, whereby the task and its elements come to be understood differently from plan to plan are characteristic of human problem solving efforts, and an aspect of problem solving skill one might expect to be improved by learning to program. The general importance of such "reseeings" in thinking has been extensively documented by Gestalt psychologists (Wertheimer, 1961) and recent studies of problem solving in cognitive science (e.g. Bamberger & Schon, 1982; DiSessa, 1983; Heller & Greeno, 1979).

More specifically, the initial formulation of our task as the doing of a set of named chores (e.g. clean tables, wash blackboards, push in chairs) is a frame for problem understanding that must be broken for the task to be effectively accomplished. Doing each named thing, in whatever order, is not an effective plan. Each chore must be decomposed into its component chore acts, and the parts must be reconstructed and sequenced into an effective whole plan. The child's understanding of part-whole relations for the task is thus transformed during plan revisions. To move toward the optimal solution of this planning problem, a child must reconfigure the chore "chunks" in terms of their spatial distribution on the classroom map. Major breakthroughs in plan structuring occur through discovering spatial clusters of chore acts. Progress in plan structure is thus made through restructuring the "chunks" of activities to be accomplished -- from a list of named chores to a list of spatial clusters of chore acts.

What kinds of changes children made are better understood in this context. There are two major types of plan features, and we have assigned 1 point for each of 14 plan features present. There are 9 "chore act clusters," and 5 plan features that involve "movables" (such as brushes, watercan, sponge). In all cases, the plan feature eliminates redundancies in travel that arise when an area in the classroom is visited twice to do different chore acts that could be accomplished in one trip. Below we illustrate the types with one example of each; details are provided in Appendix 1. For example, for one "chore act cluster," an improved plan occurred when each of the tables with chairs was only visited once, at which time the table was washed <u>and</u> the chairs at that table were pushed in, rather than separate trips being made.

In addition, for one of the cluster types involving "movables", major improvements in plan structure occurred when, in one trip to the sink, <u>both</u> instruments (sponge and watercan) needed in a sweep around the room were picked up. Likewise, improvement occurred when the sink was returned to only when all three movable things (sponge, watercan, paintbrushes) were returned simultaneously, i.e. were needed for nothing else.

<u>Qualitative featural analysis: First and last plan comparisons</u>

Thus, children's plans were analyzed in terms of the way they organized the chore acts into efficient clusters of actions. The mean plan cluster score, with a maximum of 14 points, significantly improved for each of the age groups from first to last plan. For all children combined, the scores for first and last plans were 6.2 and 8.4. The mean score for the younger group improved from 4.8 to 6.6, for the older children changed from 7.6 to 10.2. Thus, children reorganized their plans into more efficient clusters over the course of revising their plans.

What accounted for these improvements? The plan clusters can be divided into two groups: those for which mean scores were relatively high (over 0.5) in children's first plan attempts and therefore accomplished efficiently by the majority of children, and those which less than half the children recognized in their first plan. Of the 14 possible plan clusters, the following 5 had high mean scores for both age groups in the first as well as last plan: (1, 2) getting each of two instruments only once; (3, 4) doing the erasing and washing together at each blackboard; (5) doing 3 of the 5 separate chore acts at the art table (few children received the additional points for doing 4 or 5 of these 5 chores). There were no significant age differences in mean scores for any of these first plan features. In contrast, children received relatively low scores on the remaining nine plan clusters for their first plan.

Improvement in plan feature scores beyond the first plan

After the experience of creating their first plan in this task environment, children improved significantly in incorporating the remaining 9 plan features. For the 4 table activity clusters, there were significant improvements from first to last plan, and significantly higher feature scores for the older children. For the 3 activity clusters, one involving getting the sponge and the watercan together, the other two involving returning either 2 or 3 of the 3 objects to the sink area in sequence, there were also significant improvements from first to last plan and significantly higher feature scores for the older children. The remaining 2 clusters involve doing either all 5 of the 5 chore acts near the art table in sequence, or 4 of them. For the former, most efficient cluster, there were significant improvements by plan; on the latter, there were not. There were no age differences for either of these two feature scores. Nonetheless, it is striking that whereas for the first plan nearly none of the young <u>or</u> old children recognized the 5-act cluster, by the last plan, fully half of the older group, but only one-quarter of the younger group, had plans revealing this feature.

These analyses illustrate that children tended to group the chore acts more efficiently after the first plan in terms of spatial arrangements, to "break the set" evident in the first plans of completely carrying out one named chore or repeating the same chore actions successively regardless of spatial location (e.g., getting the watercan, crossing the room to water the plants and again crossing the room to return the watercan). Overall, children revised their plans into more efficient organizations. This finding corresponds to the general model of planning specifying that the planning process oscillates between constructing plan elements, simulating the plan's execution, and revising it to incorporate improvements that are recognized.

Relationships among common kinds of plan features

Another indication of the nature of changes children made when revising their plans is to examine the relationship between plan clusters including similar kinds of actions. Did children's responses indicate that they recognized similarities among chore act groups, and used this knowledge in constructing more effective plans? It would be best to develop a strategy for accomplishing groups of actions efficiently, and to then generalize this strategy to other types of actions in the plan. Such relationships among plan features may be analyzed at two levels of abstraction. For the first, more concrete-level identical chore act sequences such as "clean table - push in its chairs" could be extended to a new location. Feature scores on these 4 table-chair consolidation clusters were highly correlated: from r = .67 to .85 for the first plan, and from r = .75 to .88 for the last plan. For the two blackboard cluster sequences involving consolidating erasing and washing, r values ranged from .73

to .93 for all plans. Thus, within a plan children tended to use the same strategy for identical chore act sequences.

For the second type of relationship among plan features, clusters may be grouped according to a more abstract, general principle. Efficient accomplishment of chore groups requires consolidation of actions within a contiguous spatial area. Children have to break their natural tendency or "set" to do all chores of the same kind (such as table washing) at the same time, and instead organize their plan in terms of dissimilar acts that are close to one another spatially. This general "principle" of spatial clustering, which crosscuts the two most advanced clusters of the plan feature analysis -- the 5-chore act group by the art table, and the sequential return of all 3 sink objects -- was not initially apparent for many children, for there was not a significant correlation among scores for these two types of cluster for the first plan. This would have required a more general understanding of efficiency in terms of spatial location. However, for the last plan, children's performance on these major consolidations was significantly related.

Analogously, two other related clusters involved consolidating instrument use, i.e., simultaneously picking up all instruments from the origin that would be needed in the chore circuit, and returning them together without separate trips. Children's scores for these two plan features were not significantly related for the first plan, but were for the final plan. At this higher level, children thus evolved "higher order" strategies of spatial arrangement and instrument consolidation through their revisionary efforts. Children's recognitions of clusters were at first "local" insights, rather than principled groupings of powerful generality, which they came to recognize through revising their plans.

Relations between plan feature scores and plan efficiency

An analysis of the relationship between mean cluster scores and the plan efficiency scores discussed earlier determined that the scores were highly and significantly correlated for first plan (r = .72), and last plan (r = .66). The qualitative analysis of the plan clusters was thus related to the quantitative analysis of overall plan distance: more efficient organization of chore acts into clusters was highly related to shorter plan distance.

3. Process Analyses

Each child's think-aloud protocol was divided into segments of talk assumed to represent individual planning decisions. Each segment was then categorized according to its type and its level of abstraction as specified in the coding system below. The mean number of segments for all plans produced was 44.2, not significantly different for the two age groups (8-9 year-olds; 11-12 year-olds), nor for first and last plan.

In discussing the process by which children generated their plans, our central concerns have to do with whether efficient plans get created differently than inefficient plans. The planning studies of Hayes-Roth and colleagues (described elsewhere in this volume) have developed a detailed system for coding the types of planning decisions, and for characterizing the levels of abstractness of planning decisions made by adults as they think-aloud while constructing plans to carry out a set of errands in an imaginary small town. Our categories are a subset of those used by Goldin & Hayes-Roth (1980) and Hayes-Roth & Hayes-Roth (1979) in categorizing planning decisions made by adults in this task, supplemented by categories that emerged for this classroom environment. In the final phase of our analyses, we examined the process of plan construction by categorizing each segment of the children's think-aloud protocols in terms of the type of planning decision being made and its level of abstraction. The aspects of the system germane to our current analytic purposes will now be briefly reviewed.

The "type" categories of analysis specify different conceptual categories of decisions made during the planning process. The first three categories of decisions choose plan features, the other two are more "strategic" in nature, determining features of the planning process.

(1) Plan. Represent specific actions the planner intends to take in the world (e.g. "go to wash the art table this way" while tracing out a path).

(2) Plan abstraction. Select desired attributes of potential plan decisions, noting kinds of actions that might be useful without specifying the actual actions (e.g. "go to closest chore next" or "organize plan around bunches of chores").

(3) World knowledge. Assess data (e.g. of chore or instrument locations, distance, or time) concerning relationships in the task environment that might affect the planning process (e.g. "the hamster is next to the door" or "the chores are all in a circle").

(4) Executive. Determine allotment of cognitive resources during planning, such as what kinds of decisions to make first, or what part of the plan to develop next (e.g. "I'll decide what order to do the chores before figuring out how to walk").

(5) Metaplan. Reflect the planner's approach to the planning problem, methods they intend to apply to it, or establish criteria to be used for making up and evaluating prospective plans.

Planning decisions analyzed according to these five categories, or types of decision-making can be further analyzed in terms of the level of abstraction employed within each category. For the "abstractness level" categories of analysis, the general idea is that decisions at each more specific, or concrete level specify a more detailed plan than those at the higher level of abstraction. Levels for all the types but the "metaplan" type are hierarchically organized (see Appendix 2 for details). Goldin & Hayes-Roth (1980) found that good planners in a similar task moved flexibly among both types and levels of abstraction while constructing a plan. Here we present the levels of analysis for the "plan" type described above, moving from abstract to concrete down the list:

Level	Definition
1A: Outcome	Determine which chores will be accomplished when plan is executed (e.g. "I'll definitely do the hamster and the plants, because they'll die")
1B: Design	Determine specific spatiotemporal approach to planned activities (e.g. "I'll do the chores by going in a circle")
1C: Procedures	Determine specific sequences of gross actions (e.g. "I would do the hamst... and then get the sponge," without noting pat...)
1D: Operations	Determine specific sequences of minute actions (e.g. noting the details of the path for a sequence of gross actions in the plan)

The process analysis addresses the question of whether the organization of the planning process in terms of the types and levels of planning decisions made by the children is different for efficient than inefficient plans.

First we present some general statistics about the process data. We then survey findings on: (1) frequencies of different types and levels of planning decisions, (2) decision choice flexibility, (3) relationships between the amount of "executive" and "metaplanning" activity during the planning process and decision choice flexibility, and (4) whether scores on cognitive style and processing capacity measures distinguish different planning process profiles.

Frequencies of planning decisions in terms of types

Five types of planning decisions were distinguished. The first three types: Plan, Plan Abstraction, and World Knowledge, which we will refer to globally as "low level" types, have to do with the specific details of planning. The latter two, Executive and Metaplan, which we will designate as "high level" types, pertain to higher level executive or metacognitive aspects of planning decision-making.

Most of the planning decisions children made were on the Plan type (95.7%). The overall frequencies of decisions on other types were Plan Abstraction (0.6%), World Knowledge (1.6%), Executive (1.7%), and Metaplan (0.4%). "High level" type planning decisions overall thus constituted only about two percent of all the planning decisions the children expressed. Nonetheless, we find some interesting differences in when and by whom such higher level decisions were made.

As for differences in the types of planning decisions made for first versus last plans by the 32 children, we find that children made significantly more high level decisions in their first plans than in their last plans (3.5 versus 1.0), and 11-12 year-olds produced more high level decisions (3.0) than did 8-9 year-olds (1.4).

Decision choice flexibility

How flexible was a child's decision making during the planning process? We may address this question from two perspectives (Goldin & Hayes-Roth, 1980). The first looks at the number of transitions a child makes between different types of plan decision making while creating a plan, a second involves the number of transitions a child makes between levels of plan decision making irrespective of the type of that decision making. We may note that the mean number of type transitions per plan is highly correlated with the mean number of level transitions per plan.

The mean number of type transitions for the group of 32 children was 2.8. Although more type transitions were made in the first (3.8) than in the last plan (2.4), this difference was not significant. Age differences in type transitions were striking. Older children made significantly more (4.0) type transitions per plan than did younger (1.5) children.

The mean number of "level" transitions for the group of 32 children was 2.7. As in the case of type transitions, although children made more level transitions in their first than in their last plan (3.1 versus 2.3), this difference was not significant. Older children made significantly more (4.1) level transitions per plan than did younger (1.2) children.

High level planning decisions and decision flexibility

Do children who engage in more high level decision-making during planning (i.e. Types 4 and 5) also display more flexible decision-making by shifting opportunistically between different decision types and levels? We addressed this question by looking at the correlations between frequencies of high level decision-making and both the number of transitions between types and levels of decision-making, and found that high level decision-making during planning was significantly correlated with both the number of type and level transitions overall.

High level planning processes, WISC, and digit span

It is of some interest to see whether cognitive style (as indicated by WISC score) and processing capacity (as indicated by digit span) are related to the features of high level planning processes previously defined. We find that digit span and WISC scores were not significantly correlated with the frequency of high level (Types 4 and 5) planning decisions. And although the mean number of type transitions was significantly correlated with digit span, there were nonsignificant correlations of .3 to .4 between digit span and mean number of level transitions. WISC score did not significantly correlate with either mean number of type or level transitions per plan.

4. Relating plan as product and as process

How related are the decision-making processes that go into the formulation of a plan to the effectiveness of the plan as a product? We found that, at least for this task, the process and product measures are weakly related. Neither the plan efficiency mean score for all plans produced nor the distance of the shortest plan a child created correlated significantly with any of the high level plan process measures, i.e., mean number of type transitions per plan, mean number of level transitions per plan, or frequency of high level (Types 4 and 5) planning decisions.

We also tested for a relationship between the frequency of metaplanning decisions and the mean cluster scores from the feature analysis. Few significant relationships were apparent, indicating that children revise their plans to accomplish the acts more efficiently without necessarily using (verbally explicit) metaplanning resources. Only for the last plan of the younger children are these variables significantly correlated ($r = .65$).

Conclusions

In our study, the development of planning skills was examined in two different ways: by comparing the planning skills displayed by children of two different age groups, and by tracing the development of a plan over the course of its repeated revisions within a planning session. The general model of planning adopted in this work considers planning to be essentially revisionary. Good planners, whether they are adults or children, appear to engage in cycles of plan revision in order to consider different and increasingly efficient plan organizations. They reveal different types and levels of decision making in formulating their plans (Goldin & Hayes-Roth, 1980).

The chore-scheduling task we used was designed to engage children in planning a novel sequence of events within a familiar environment. The task provided an external planning aid, characteristic of many functional planning situations. This classroom map aid also enabled us to closely observe the sequence of children's actions and decisions as they created plans.

In focusing on qualitative aspects of planning processes, we were driven to change traditional experimental methods and modes of interpretation. As noted above, we used a microgenetic method (Flavell & Draguns, 1957) in order to make public and protracted the cycles of revisionary work that characterize highly developed planning. We examined children's abilities to formulate alternative plan organizations by providing them with opportunities for improving the effectiveness of their plans. And unlike the Hayes-Roth work on planning, we explicitly conveyed to our participants the goal of the task -- children were specifically asked to construct the shortest-distance plan so that the effectiveness of their planning would be assessed relative to that goal. In contrast, developmental comparisons have often ignored the goal-relative nature of the developmental level of a performance in terms of what the person thinks he or she is doing.

Furthermore, in terms of the four components of the planning process described in the introduction, our analyses focused on how children displayed the second component of the planning process, the construction of a plan, in a situation in which the goal state, initial state, and operators for transforming the problem space were well-defined.

Our findings demonstrate that both older (11-12 year-old) and younger (8-9 year-old) children engage in complex revisionary processes over the course of the planning session. While older children produced significantly better plans than younger children according to a variety of measures, the performance of both groups improved significantly from first to last plans within a session. This improvement can be characterized in several ways. First, plans improved in terms of route efficiency over plan attempts. Children revised their plans to produce shorter, more efficient means of accomplishing the set of chores. Second, children became increasingly sensitive to the constraints of this particular planning situation, and adapted their plans accordingly. In the case of the chore-scheduling task, many children shifted their approach from one where they performed all chore acts of the same type together (e.g. wash all tables, regardless of where they were located), to one where they discovered the importance of spatial location and consolidation of actions (e.g. performing all chores in the same area together, regardless of chore category). This major change required a significant reconfiguring of the situation, so that children could incorporate this "reseeing" into the plan construction process.

In terms of cognitive variables related to the character of children's planning, we found only weak relationships between WISC block-design task performance and effective planning. Since our rational analysis of the cognitive demands of this task leads to a prediction of a strong relationship between these variables, this finding may appear surprising. Nonetheless, we are hesitant to dismiss the field independence/dependence dimension as germane to studies of planning skill since virtually all of the participants in the study scored highly on the WISC subtask. Case (1974) classified children who scored one deviation above the mean on national norms as field-independent, those who scored one deviation below the mean on national norms as field-dependent. By this criterion, only one of our 32 children is classified as field-dependent. In future work, we would recommend that WISC block-design task scores serve as a grouping variable, with clearly defined field-dependent and field-independent groups for a stronger test of our hypothesis.

We also found only weak relationships between digit-span and effective planning. Apparently, span size does not figure prominently in distinguishing more from less effective planners. One likely reason for this is that children can use visual as well as kinaesthetic feedback in remembering their planned route, and do not need to rely entirely upon mental representations of their plan. With versions of the task in which either the visual or kinaesthetic feedback could be blocked, we might find digit span to play a more significant role in planning performances.

Finally, with respect to the decision-making process, we found that there were differences in types and levels of planning decisions for individual children within planning sessions, and between the two age groups. Both older (11 and 12 year-olds) and younger children (8 and 9 year-olds) made more high level and metaplanning decisions in their first plan as compared with their last plan. The older children made more high level and metaplanning decisions than did younger children. Older children also demonstrated more flexibility in their plan construction process, since they more frequently made type and level transitions than did younger planners. And just as Goldin & Hayes-Roth (1980) found for adults, high level decision-making was associated with planning flexibility.

However, the overall infrequency with which children of any age engaged in executive (1.7%) or metaplanning decisions (0.4%) is noteworthy. Most of their planning decisions concerned concrete plan type acts. Further, in their performances on this task, the frequency of such higher level planning decisions was unrelated to plan efficiency (product) scores. There are several possible reasons for this finding. The first is that children of these ages may in general infrequently engage in this form of higher level decision-making in planning situations, preferring to make decisions in terms of specific, concrete actions. A second, alternative reason is that the content of the chore-scheduling task may have influenced the relative frequency of decision-types. As noted earlier, in order to focus on developmental processes of plan construction, the chore-scheduling task offered a well-formed planning problem to the children, built around familiar subtasks. The task may be too familiar for the children, and not viewed as challenging enough to require planning, even with the time constraints set out in the task instructions. Perhaps we would find more reflective processing if the planning task exemplified many of the vagaries of everyday planning (Pea, 1982), such as conflicting goals (Wilensky, 1981), absence of prestatable goal criteria (Scriven 1980), an open rather than closed set of operators for the problem space (Dorner, 1983), and known operators whose consequences of application are unknown (Schutz, 1973).

Although there may be some validity to this second account, independent evidence on planning during the writing process with children in this age range supports the "concreteness" interpretation. Scardamalia & Bereiter (1984) have reviewed findings from various studies that show how "composition planning in children starts out more like rehearsal [which refers to working through a task at approximately the same level of concreteness as will eventually be used] and gradually comes to be carried on at levels more remote from the level of text production" (ms., p. 36). Burtis et al. (1983) note how think-aloud protocols from 11 to 13 year-olds start to reveal evidence of a more abstract level of planning than the "rehearsal" of younger children's text production. Our older group of 11 and 12 year-olds also began to show higher level decision-making during planning, such as giving verbal accounts of their major reorganizations of action-sequences in plans subsequent to their first plan.

It may be that to develop planning skills, children will require instructional support and practice in activities that focus on each component of the planning process. Certainly our planning process results indicate how rarely children engaged in revisions where they "stepped back" and redefined the planning situation after beginning to construct a plan. The finding that high level decision-making decreased from first to last plan among the children further suggests that children's planning efforts consisted of refining an initial conception, rather than considering top-level reorganization of the plan.

We expect these results may be useful to educators who wish to promote planning, and to developmental psychologists and cognitive scientists investigating planning processes. Our findings reveal significant capabilities among even 8 year-old children to plan and improve their plans through revisions in a familiar task environment with a clearly defined goal. This finding stands in contrast to young children's revisions in writing tasks, which rarely improve the quality of the written text, a contrast likely due to the difficulty of defining goals in writing. Since even the young children generally improve their chore-scheduling task performance across plans, it appears that it is not that they lack the capability of making progressive revisions in writing, but that the goals are not as apparent in the writing environment as they are in our chore-scheduling task.

Footnotes

* This research was supported by a grant from the Spencer Foundation. D. Midian Kurland made continuing conceptual and technical contributions to the project. We are particularly grateful to Sally MacKain and Moni Hamolsky for their careful work in coding videotapes, datafile work, and help with experimental sessions. Jeff Aron provided assistance with early sessions and videotape analyses. Portions of this paper were presented at the 1983 Biennial Meetings of the Society for Research in Child Development in Detroit.

[1] Although WAIS subscales are standardized for an auditory-verbal sequence of input-response rather than our visual-verbal, this is not problematic, for two reasons. First, we are not referencing standardized norms from WAIS procedures, but using the span task as is commonly done in psychological studies as a way of insuring the comparability of experimental and control groups, and because different span tasks are often used as measures of mental processing capacity, which as Case, Kurland and Goldberg (1982; also see Hunt, 1978) indicate, relate in theoretically interesting ways to a number of different high level cognitive tasks. Secondly, it is well known that memory span values are highly correlated for different modalities of stimulus presentation and recall.

[2] Washing the paintbrushes was a chore act forgotten by almost everyone, and many children forgot to erase the blackboards before washing them. Extensive forgetting of chore acts was rare, and there were neither age differences nor group (programming versus non-programming) differences in number of omitted chores. Number of omitted chores was also unrelated to the efficiency of plans.

References

Bamberger, J. & Schon, D. Learning as reflective conversation with materials: Notes from work in progress. (Working Paper No. 17). Massachusetts Institute of Technology, Division for Study and Research in Education, December 1982.

Bereiter, C. Development in writing. In L. W. Gregg & E. R. Steinberg (Eds.), Cognitive processes in writing. Hillsdale, N. J.: Lawrence Erlbaum Associates, 1980.

Brener, R. An experimental investigation of memory span. J. Experimental Psychology, 1940, 26, 467-482.

Burtis, P. J., Bereiter, C., Scardamalia, M. & Tetroe, J. The development of planning in writing. In C. G. Wells & B. Kroll (Eds.), Exploration of children's development in writing. Chicester, England: John Wiley & Sons, 1983, in press.

Case, R. Structures and strictures: Some functional limitations on the course of cognitive growth. Cognitive Psychology, 1974, 6, 544-573.

Case, R. & Globerson, T. Field independence and central computing space. Child Development, 1974, 45, 772-778.

Case, R., Kurland, D. M. & Goldberg, J. Operational efficiency and the growth of short-term memory span. J. Experimental Child Psychology, 1982, 33, 386-404.

DiSessa, A. Phenomenology and the evolution of intuition. In D. Gentner & A. L. Stevens (Eds.), Mental models. Hillsdale, NJ: Lawrence Erlbaum Associates, 1983.

Dorner, D. Heuristics and cognition in complex systems. In R. Groner, M. Groner & W. F. Bischof (Eds.), Methods of heuristics. Hillsdale, NJ: Lawrence Erlbaum Associates, 1983.

Flavell, J. & Draguns, J. A microgenetic approach to perception and thought. Psychological Bulletin, 1957, 54, 197-217.

Flower, L. & Hayes, J. R. A cognitive process theory of writing. College Composition and Communication, 1981, 32, 365-387.

Goldin, S. E. & Hayes-Roth, B. Individual differences in planning processes. Rand Corporation Note N-1488-ONR, June 1980.

Hayes-Roth, B. Estimation of time requirements during planning: The interactions between motivation and cognition. Rand Corporation Note N-1581-ONR, November 1980.

Hayes-Roth, B. & Hayes-Roth, F. A cognitive model of planning. Cognitive Science, 1979, 3, 275-310.

Heller, J. & Greeno, J. G. Information processing analyses of mathematical problem solving. In Tyler, R. W. & White, S. H. (Eds.), Testing, Teaching and Learning. Washington, D. C.: National Institute of Education, 1979.

Hunt, E. Mechanics of verbal ability. Psychological Review, 1978, 85, 109-130.

Lyons, D. R. Individual differences in immediate serial recall: A matter of mneumonics? Cognitive Psychology, 1977, 9, 403-411.

Pea, R. D. What is planning development the development of? In D. Forbes & M. Greenberg (Eds.), New Directions in Child Development: The Development of Planful Behavior in Children. San Francisco: Jossey-Bass, Fall 1982.

Pea, R. D. & Kurland, D. M. Logo programming and the development of planning skills. Technical Report No. 16, Bank Street College, Center for Children and Technology, February 1984.

Rogoff, B. & Gardner, W. P. Developing cognitive skills in social interaction. In B. Rogoff & J. Lave (Eds.), Everyday cognition: Its development in social context. Cambridge, Mass.: Harvard University Press, 1983, in press.

Scardamalia, M. & Bereiter, C. Written composition. In Handbook of Research on Teaching. 1984, in press.

Schutz, A. Choosing among projects of action. In Collected papers, Vol. I: The problem of social reality. The Hague, Netherlands: Martinus Nijhoff, 1973.

Scriven, M. Prescriptive and descriptive approaches to problem solving. In D. T. Tuma & F. Reif (Eds.), Problems solving and education: Issues in teaching and research. Hillsdale, NJ: Lawrence Erlbaum Associates, 1980.

Stefik, M. Planning and constraints (MOLGEN: Part 2). Artificial Intelligence, 1981(a), 16, 111-140.

Stefik, M. Planning and metaplanning (MOLGEN: Part 2). Artificial Intelligence, 1981(b), 16, 141-170.

Wechsler, D. Manual for the Wechsler Intelligence Scale for Children. New York: The Psychology Corporation, 1974.

Werner, H. Microgenesis and aphasia. J. Abnormal & Social Psychology, 1956, 52, 347-353.

Wertheimer, M. Productive thinking. Enlarged edition. London: Tavistock, 1961.

Wilensky, R. Meta-planning: Representing and using knowledge about planning in problem solving and natural language understanding. Cognitive Science, 1981, 5, 197-233.

Witkin, H. A., Lewis, H. B., Hertzman, M., Machover, K., Meissner, P. B. & Wapner, S. Personality through perception. New York: Harper, 1954.

Witkin, H. A., Dyk, R. B., Faterson, H. F., Goodenough, D. R. & Kark, S. A. Psychological differentiation. New York: Wiley, 1962.

Appendix 1: Scoring System for Featural Analysis

The fourteen plan features were: 9 different "chore act clusters," and 5 features involving "movables" (such as brushes, watercan, sponge). For the chore act clusters, improvements in plan structure occurred when:

(1) Clusters 1 to 4. Each of the four tables with chairs was only visited once, at which time the table was washed and the chairs at that table were pushed in.

(2) Clusters 5 to 7. During the only visit to the art table, five componen acts were dealt with in a cluster: the table was washed, the trashpaper and paintbrushes were picked up, and the two nearby plants were watered (Cluster 7). Cluster 6 included any four of these acts; Cluster 5 any three of them.

(3) Clusters 8 to 9. Each of the two blackboards was only visited once, at which time it was erased and washed (Cluster 8 for one blackboard, Cluster 9 for the other).

For features of plans involving "movables," improvements in plan structure occurred when:

(4) Cluster 10. Going to the sink, both instruments (sponge, watercan) that would be needed during a sweep around the room were picked up.

(5) Clusters 11 and 12. The sink was only returned to when all three movable things that must be returned there (sponge, watercan, paintbrushes) were needed for no other component chore acts (Cluster 12). Cluster 11 was returning any two of these three movables at once.

(6) Clusters 13 and 14. Instruments at the sink (sponge, watercan) were only picked up once, rather than for each time they were needed (e.g. getting the sponge once to sponge the blackboard, returning it, getting it another time to wash the tables). Although not literally a cluster of acts, we designate getting the sponge only once as Cluster 13, and getting the watercan only once as Cluster 14.

Appendix 2: Coding categories and definitions for process analyses

A. Decision Type Categories

The coding categories have been slightly modified from Hayes-Roth & Hayes-Roth (1979) and Goldin & Hayes-Roth (1980), but are on most points comparable. The type categories of analysis specify different conceptual categories of decisions made during the planning process. The first three cate ries of decisions choose plan features, the other two are more "st tegic" in nature, determining features of the planning process.

(1) Plan. Represent specific actions the planner intends to take in the world (e.g. "go to wash the art table this way" while tracing out a path).

(2) Plan abstraction. Select desired attributes of potential plan decisions, noting kinds of actions that might be useful without specifying the actual actions (e.g. "go to closest chore next" or "organize plan around spatial clusters of chores").

(3) World knowledge. Assess data (e.g. of chore or instrument locations, distance, or time) concerning relationships in the task environment that might affect the planning process (e.g. "the hamster is next to the door" or "the chores are all in a circle").

(4) Executive. Determine allotment of cognitive resources during planning, such as what kinds of decisions to make first, or what part of the plan to develop next (e.g. "I'll decide wh t order to do the chores before figuring out a path").

(5) Metaplan. Reflect planner's approach to the planning problem, methods they intend to apply to it, or establish criteria to be used for making up and evaluating prospective plans.

B. Abstractness "Level" (within type) categories

For the "abstractness level" categories of analysis, decisions at each more specific, or concrete level specify a more detailed plan than those at the higher level of abstraction. Levels for all the types but the "metaplan" type are hierarchically organized. Level stratification moves in the definition charts from abstract to concrete down the list:

1. PLAN TYPE

Level	Definition
1A: Outcome	Determine which chores will be accomplished when plan is executed (e.g. "I'll definitely do the hamster and the plants")
1B: Design	Determine specific spatiotemporal approach to planned activities (e.g. "I'll do the chores by going in a circle")
1C: Procedures	Determine specific sequences of gross actions (e.g. "I would do the hamster, and then get the sponge" without noting path)

Level		Definition
1D:	Operations	Determine specific sequences of minute actions (e.g. noting the details of the path for a sequence of gross actions in the plan)

2. PLAN-ABSTRACTION TYPE

Level		Definition
2A:	Outcome (Intentions)	Determine which kinds of chores are desirable to accomplish when plan is executed (e.g. "Do all the important chores")
2B:	Design (Scheme)	Determine kinds of desirable spatiotemporal organizations of planned activities to achieve outcomes (e.g. "I'll organize a plan around clusters of chores")
2C:	Procedures (Strategy)	Determine characteristics of desirable kinds of sequencing of gross level individual chore acts (e.g. "I'll do the closest chore next")
2D:	Operations (Tactic)	Determine characteristics of desirable kinds of sequencing of the specifics of individual chore acts (e.g. "I'll take the shortest route to the next chore")

3. WORLD-KNOWLEDGE TYPE

World knowledge type decisions suggest decisions at the corresponding plan abstraction level, or instantiate decisions at the corresponding plan level.

Level		Definition
3A:	Outcome (Chores)	Note facts or values regarding specific chores to be accomplished (e.g. "feeding the hamster is the most important chore" or "washing blackboards takes a long time")
3B:	Design (Layout)	Note facts of spatiotemporal organization of a group of planned activities (e.g. "there are a lot of things to do by the sink")
3C:	Procedures (Neighbors or Instruments)	Note facts regarding the world of the chores relevant to ordering individual chore acts (e.g. "the closest chore to where I am now is watering Plant 1"; "Oh, I have to go get the sponge first")
3D:	Operations (Routes or Chore Act Details)	Note facts that relate to the specifics of performing specific chore acts or travelling from one chore act to another (e.g. "through the benches is the shortest way to get to the blackboard" or "I can hold the watercan in my hand while I'm doing that chore")

4. EXECUTIVE TYPE

Level		Definition
4A:	Priority	Establish principles for allocating cognitive resources during the entire planning process (e.g. "I'll decide what to do before deciding when to do things")
4B:	Focus	Indicate what kind of decisions to make at a particular point in the planning process (e.g. "Now I'll figure out the shortest way to get over to the trashcan")
4C:	Scheduling	Resolve any remaining conflicts between competing decisions that have been made, choosing one to execute next in the plan of action.

5. METAPLAN TYPE

Level		Definition
5A:	Problem Definition	Define the planner's representation of the task and its goals, resources, and constraints.
5B:	Problem Solving Model	Define the general strategy the planner takes in making up a solution to the planning problem.
5C:	Policies	Note a set of global constraints and desirable features for the developing plan.
5D:	Evaluation Criteria	Define a set of dimensions against which tentative plans may be evaluated.