DOCUMENT RESUME

ED 171 804 TM 009 517

AUTHOR Eylon, Bat-Sheva; Reif, F.
TITLE Effects of Internal Knowledge Organization on Task Performance.
PUB DATE Apr 79
NOTE 45p.; Paper presented at the Annual Meeting of the American Educational Research Association (63rd, San Francisco, California, April 8-12, 1979)

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS *Cognitive Processes; Higher Education; Knowledge Level; *Learning Processes; Models; *Organization; *Problem Solving; *Recall (Psychological); Senior High Schools

ABSTRACT

A study was designed to investigate forms of human internal knowledge organization that facilitate the recall of information or its use for complex problem solving tasks. Three experiments, using college and high school physics students, were performed. The effects were studied by: (1) formulating explicit models of organization; (2) using extensive treatments to induce subjects to acquire specified organization; and (3) testing subjects' subsequent performance on recall and problem-solving tasks. A prescriptive model of hierarchical organization, was specified, designed to facilitate selective information retrieval, constructed by successive elaborations of a few top-level ideas most important for a specified task domain. Subjects with such a hierarchical organization performed appreciably better compared to subjects with a single-level organization of the same knowledge. Subjects also performed better on those tasks involving information included at higher levels of the subjects' internal hierarchical organization. In general, subjects of higher ability seemed better able to assimilate and exploit hierarchical organization. Various observations indicated that training methods used were quite effective in inducing a specified internal knowledge organization. (Author/MH)

Expanded version of a paper presented at the annual meeting of the American Educational Research Association, April 1979.

EFFECTS OF INTERNAL KNOWLEDGE ORGANIZATION ON TASK PERFORMANCE

Bat-Sheva Eylon and F. Reif*

University of California, Berkeley

*Address: Physics Department and Group in Science/Math Education, University of California, Berkeley, California 94720.

ABSTRACT

The effects of human internal knowledge organization were studied by (1) formulating explicit models of organization, (2) using extensive treatments to induce subjects to acquire specified organizations, and (3) testing subjects' subsequent performance on recall and problem-solving tasks. In particular, we specified a prescriptive model of hierarchical organization, designed to facilitate selective information retrieval, constructed by successive elaborations of a few top-level ideas most important for a specific task domain. In our experiments subjects with such a hierarchical organization performed appreciably better compared to subjects with a simpler organization of the same knowledge. As expected, subjects also performed better on those tasks involving information included at higher levels of the subjects' internal hierarchical organization. In general, subjects of higher ability seemed better able to assimilate and exploit hierarchical organization. Various observations indicated that our training methods were quite effective in inducing a specified internal knowledge organization.

INTRODUCTION

Theoretical considerations and empirical data both suggest that the organization of a person's knowledge affects crucially his or her ability to use such knowledge effectively. Accordingly, the study described in this paper was specifically designed to investigate forms of human knowledge organization that facilitate the recall of information or its use for realistically complex problem-solving tasks.

A study of this kind is clearly relevant to basic research on human information processing. Moreover, because of its emphasis on information-processing models designed to improve human performance, such work is also directly germane to practical instruction.

Our work deals with complex knowledge and tasks representative of practical educational or scientific concerns. Previous studies of certain organizational aspects of human knowledge have been described by Kintsch and Keenan (1974), Meyer (1975), Ausubel (1968), Shavelson (1972, 1974), Mayer and Greeno (1972), Postman (1972), and others.

The basic presupposition of our work is that the observable and diverse intellectual performance of persons can be explained economically in terms of postulated properties of the "internal knowledge" inside a person's mind. This theoretical stance leads one to formulate models of specific forms of internal knowledge, including <u>prescriptive</u> models designed to enhance human performance on certain intellectual tasks. Controlled experiments and detailed observations are then used to test particular features of these models and to suggest revisions in them.

In the following pages we first discuss the theoretical construct of human "internal knowledge" and then describe a model specifying a hierarchical knowledge organization expected to facilitate complex information-retrieval tasks. Next we point out some research questions suggested by the model and propose an experimental approach for studying these questions. Then we report on three specific experiments designed (1) to examine the effectiveness of such a hierarchical knowledge organization compared to a single-level organization, (2) to study the appropriate matching of a hierarchical organization to the intended task domain, and (3) to assess the efficacy of our experimental methods for inducing human subjects to acquire specified forms of internal knowledge organization. Finally, we discuss some implications of this work for research on human information processing and for practical educational applications.

BASIC ISSUES AND METHODS

A person's "internal knowledge" is a theoretical construct useful to the extent that it allows one to relate and predict a wide range of directly observable phenomena. Conversely, the properties of such internal knowledge are ultimately deduced from mutually consistent inferences derived from observable phenomena.

The postulated internal knowledge of a person can be characterized by the content of its information, by its organization, and by its symbolic representation. In addition, the internal knowledge includes procedures for acting on the preceding information (e.g., procedures for retrieving data efficiently from a given organization of information, or procedures for reorganizing information into more useful forms). As mentioned previously, our study focuses its attention specifically on the organization of such internal knowledge.

By using the theoretical c[illegible]str t of internal knowledge, a person's information-processing behavior can be analyzed into three subprocesses: (1) Input processes whereby observable information outside the person is transformed into internal knowledge. (2) Internal processes (not directly observable) whereby such internal knowledge may be further transformed. (3) Output processes whereby the internal knowledge is transformed into the person's behavior observable i[illegible] the outside world. (These input and output processes are usually l[illegible] and sequential, while the postulated internal knowledge is some comp[illegible] multidimensional structure.)

There are then two analyt[illegible]ly separable questions which can be asked about internal knowledge [illegible] organization) and directly observable processes: (1) What is the relation between input processes and the resulting organization of internal knowledge? (2) What is the relation between the organiza[illegible] of internal knowledge and the resulting output processes?

In the present study we are primar[illegible] interested in the second (or "output") question. In other words, our central aim is to study the effects of given forms of in[illegible]owledge organization on the performance of various recall and [illegible]ving tasks. Thus we are only secondarily interested in in[illegible] the processes whereby a given internal knowledge organizatio[illegible]lly acquired.

The preceding emphasis has [illegible] of decomposing a complex problem into two distinct quest[illegible]ich may be studied separately in greater detail. Furthermore [illegible]r study of useful internal knowledge organizations should facilit[illegible]equent efforts to study or promote the acquisition of practically u[illegible] ms of internal knowledge organization.

achieve our goal of studying the effects of a given internal knowledge organizati[illegible] we adopted the following approach: (1) Formulate [illegible]ome models of interna[illegible] knowledge organization, including a prescriptive model designed t[illegible] fac[illegible]tate optimally human performance on certain tasks. [illegible]) Create controlled experimental conditions to assure that a human subject acquires [illegible] internal knowledge organization. (3) Perform [illegible]perimental tests to observe how well such a subject performs on various [illegible]s.

By choosing this manipulative approach, we hoped to gain the advantage of studying particular features of a model under controlled conditions. Furthermore we hoped that the prescriptive aspects of this approach would yield models and procedures of potential relevance to educational applications.

The actual implementation of such a manipulative approach (somewhat akin to work in artificial intelligence) is clearly more difficult in the case of a human information processor than of a computer. In particular, it is impossible to manipulate or observe directly human internal knowledge. Furthermore, to focus on internal organization requires one to separate its effects from those of other aspects of internal knowledge. We shall describe later the specific experimental methods whereby we sought to minimize these difficulties.

HIERARCHICAL TASK-ADAPTED KNOWLEDGE ORGANIZATION

If a person is to use a substantial amount of internal knowledge for performing flexibly a variety of tasks, this knowledge must be effectively organized to facilitate the selective retrieval of any particular information

Hence it is of interest to formulate a prescriptive model explicitly designed to facilitate such retrieval.

An efficient retrieval process can be achieved by using a "top-down" procedure of successive refinements to narrow the domain of search in geometrically progressive fashion. This is accomplished by decomposing the retrieval process hierarchically into successive steps each of which involves decisions about only a few major alternatives, in such a way that decisions at earlier steps facilitate more detailed decisions at later steps.

Evidence from several domains suggests the utility of a hierarchical organization for information-processing tasks. Such evidence comes from psychological studies on hierarchical organization and recall (Kintsch & Keenan, 1972; Meyer, 1975), from work in artificial intelligence (Sacerdoti, 1977), from studies on human problem solving in physics (Larkin, 1978; Larkin & Reif, 1979), and from recent developments in computer programming (Hughes & Michton, 1977).

The previous considerations led us to formulate the following specific features of a prescriptive model of human knowledge organization designed to facilitate selective information retrieval:[1]

(1) Hierarchical structure: The knowledge is subdivided into knowledge units related in such a way that a few information items in any unit are elaborated by further description through "subordinate" knowledge units. The result of such successive elaborations is a multi-level description hierarchically organized in the fashion illustrated in Fig. 1. Explicit cross-references or "pointers" help to link subordinate units to superordinate ones. In addition, there are some pointers providing connections to help retrieve information "laterally" (i.e., not merely along superordinate-subordinate connections).[2]

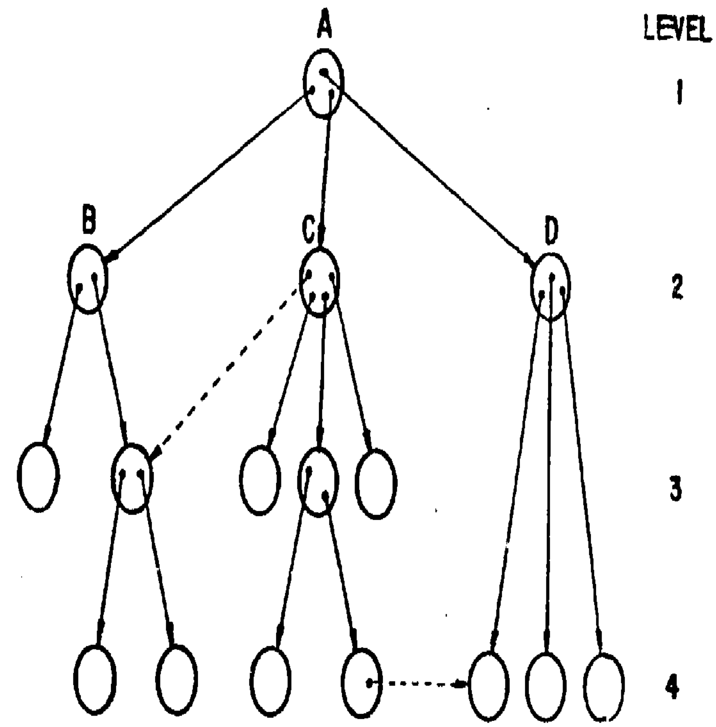


Fig. 1: Schematic diagram of a hierarchical knowledge organization.

(2) Adaptation to task domain: To adapt the preceding hierarchical knowledge organization to the domain of tasks for which this knowledge is to be used, superordinate knowledge units incorporate information more "important" for the task domain than subordinate units. (The information ranked as most important is that which is most frequently used for tasks in the domain, or which is most useful for retrieving other information most frequently used.) In this way, the total number of steps in a top-down retrieval process can usually be kept small.

(3) Adaptation to human capabilities: The knowledge organization of Fig. 1 is adapted to the limited processing and short-term memory capacities of human subjects. Hence the amount of information in each knowledge unit is kept small enough to be easily processed, but large enough to keep the total number of knowledge units small. Furthermore, each knowledge unit is only elaborated into a few (≤ 5) subordinate units (so that only very few alternatives need be considered at any decision step of a retrieval process).

Theoretically we expect that knowledge organized in the hierarchical task-adapted fashion just described, when used in conjunction with a top-down retrieval procedure, should facilitate efficient flexible performance of many tasks. In particular, we expect that recall of information should be facilitated because high-level information in a few superordinate knowledge units facilitates the retrieval of more extensive detailed information in subordinate knowledge units. We also expect that various problem-solving tasks should be facilitated. For example, finding a mistake ("debugging") should be facilitated because one can more easily isolate one of the few superordinate knowledge units affected by a mistake, and can then trace down successively to find the specific locus of the mistake.

Similarly, a task of modification or generalization should be facilitated because one can quickly identify which superordinate knowledge units are affected or left invariant, and can then readily make more detailed modifications in the affected unit.

RESEARCH QUESTIONS AND EXPERIMENTAL APPROACH

QUESTIONS FOR INVESTIGATION

The preceding theoretical model suggests the following specific questions for experimental investigation:

(1) How effective is an internal hierarchical knowledge organization (of the kind described in the preceding paragraphs) for facilitating performance on various recall and problem-solving tasks? In particular, we shall try to answer experimentally the following questions: (a) Is a hierarchical organization more effective than a single-level organization? (b) Is a hierarchical organization indeed more useful for those tasks which match information in its higher levels, than for those tasks which match information at its lower levels?

(2) How effectively can one induce human subjects to acquire a specified form of internal knowledge? In particular, we shall try to answer the following questions: (a) What are some methods for inducing a desired form of internal knowledge organization? (b) What evidence can be provided to ascertain the nature of such an internal organization?

This second major question is important because our method for studying the effects of internal knowledge organization is predicated on the assumption that we can induce a specified organization in human experimental subjects. More generally, this question may also help to

reveal to what extent it is possible, for either research or educational purposes, to deliberately influence a person's internal knowledge.

EXPERIMENTAL APPROACH

The following sections describe three specific experiments designed to answer jointly the preceding questions. Experiment 1 addresses primarily question 1a about the comparative effectiveness of a hierarchical and a single-level organization. Experiment 2 addresses primarily question 1b about the importance of appropriately matching a hierarchical organization to the intended task domain. Both of these experiments also yield some information about question 2 concerning the acquisition of internal organization. However, experiment 3 is especially designed to explore this latter question.

To carry out these experiments, it was necessary to devise methods which can overcome or minimize the following difficulties involved in studying human internal knowledge.

(1) It is impossible to manipulate directly internal knowledge or its organization. To minimize this difficulty in the face of possible previously existing internal knowledge, we used "strong" input treatments which maximally structured the acquisition process to assure that a subject acquire information in a specified form. This was done by using information unfamiliar to the subject, by carefully controlling the form of the information presented to the subject, by engaging the subject in special processing tasks designed to reenforce the acquisition of a specified form of knowledge, and by limiting opportunities for internal reorganization of this acquired knowledge.

(2) It is impossible to observe directly whether a particular internal knowledge organization exists or has been acquired. To minimize this difficulty, we monitored the subject's performance on some special tasks which collectively allowed inferences about the nature of the subject's internal knowledge organization. This monitoring included (a) some "acquisition tasks" given during the instruction to assure that the desired organization was being incorporated; (b) observations of some qualitative differences in performance on the final testing tasks; and (c) detailed analysis of some subjects' recall protocols.

(3) For purposes of our study, the effects of internal organization must be separated from those of other aspects of internal knowledge. To achieve this aim, the content and symbolic representation of the knowledge acquired by subjects was kept constant throughout an experiment. Furthermore, the experiments tried to assure that subjects use their internal knowledge with a particular retrieval process. This was done by presenting the input information in a way exhibiting such a process, and by monitoring indirectly whether subjects themselves actually used this process.

The preceding considerations were embodied in an experimental procedure which involved the following main steps: (1) Choose a particular knowledge domain and a particular set of recall and problem-solving tasks to which this knowledge is applied. (2) Specify alternative organizations of this knowledge (including a hierarchical organization according to the prescriptive model). (3) Use strong input procedures to assure that different subjects acquire the specified alternative forms of internal knowledge organization. (4) Test the performance of the subjects on a common set of tasks.

EXPERIMENT 1

Experiment 1 addressed the following question: Is a hierarchical internal knowledge organization indeed more effective than a single-level organization for performing various recall and problem-solving tasks?

DESIGN

To achieve such a comparison, the experiment used treatments whereby subjects would acquire either a hierarchical or a single-level organization. The particular design involved three groups of subjects who were exposed to the three treatments illustrated in Fig. 2. The "H-treatment" presented a hierarchical organization of some knowledge; the "S_1 - treatment" presented a single-level organization of the same knowledge; and the "S_2 - treatment" presented this single-level organization twice in succession. (This last treatment was merely used to compare a single presentation, of an essentially two-level hierarchical organization, with two presentations of a single-level organization.) Each treatment involved appropriately organized materials, as well as acquisition tasks designed to assure the incorporation of the specified organization. After these various treatments, all subjects were given the same performance test.

The subjects participating in the experiment were 36 paid volunteers recruited among students in an introductory college-level physics course. These subjects were subdivided into three blocks of different ability (high, medium, and low) determined by the subjects' performance on a prior physics test in their course. The subjects in each ability block were then randomly assigned to three groups which were then randomly assigned to the three treatments. Thus each treatment included 12 subjects, 4 for each ability level.

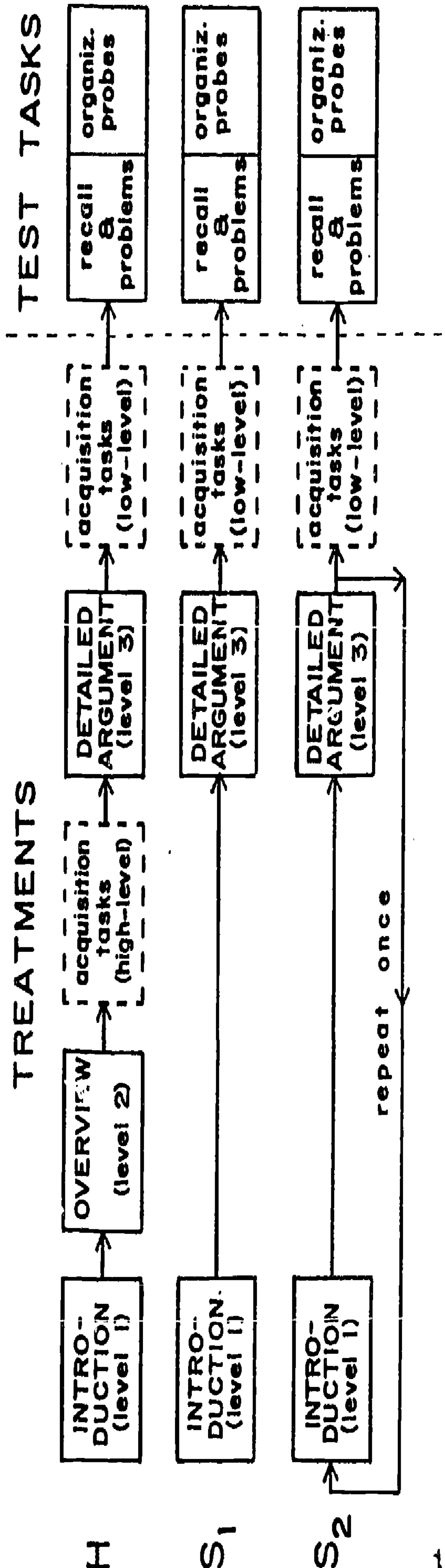


Fig. 2: Design of experiment 1 comparing the effects of hierarchical and single-level knowledge organizations (H and S).

METHOD

Knowledge domain and tasks

The knowledge selected for this experiment consisted of an argument using given premises to derive a desired result. The argument, taken from the field of physics, was typical of similar arguments commonly encountered in other college-level science courses. It involved a derivation using physics principles and algebraic operations to express a desired quantity in terms of measurable quantities.

A knowledge of this kind of argument can be used to carry out various recall and problem-solving tasks. Such tasks were then included in the performance test described later.

Alternative organizations and materials

The argument was organized in a hierarchical or single-level form, each described in a written version of materials. In the hierarchical or H-version, the argument was organized hierarchically at several levels. The first or highest level consisted mainly of a statement describing the purpose of the argument and the quantities to be related by it. The second level provided an overview expressing the argument in terms of four major steps (e.g., "find the gravitational acceleration g from the initial motion by using the general relation $h = \frac{1}{2}gt^2$"). The third level consisted of the complete argument described in terms of a sequence of detailed mathematical steps.

Several means were used to make the hierarchical structure explicit within the constraints of a linear prose presentation. For example, the presentation traversed the hierarchy systematically in a top-down fashion (from level 1 to level 3). It emphasized the underlying structure by

graphical aids such as titles and subtitles, indentations, etc. It explicitly pointed out what parts of the argument were elaborations of steps encountered at higher levels. And it made connections between levels apparent by using titles referring back to the preceding higher level.

The S-version of the materials, designed to approximate a single-level organization of the argument, differed from the H-version by omitting the second "overview" level, while retaining the third level (with the same wording, but without the interspersed titles connecting this level back to the higher second level). The top first level was also retained. Thus the S version was designed to simulate closely a good conventional class-room presentation which states the basic goal of an argument and then launches directly into a logically tight detailed argument.

Treatments

The treatments using the preceding materials are illustrated in Fig. 2. (Each of these treatments lasted about an hour.) In the H-treatment, the subjects first read levels 1 and 2 of the presentation. Then they performed some "high-level" written acquisition tasks designed to assure the acquisition of information at levels 1 and 2. (These tasks asked subjects questions about the purpose of the argument, about major steps needed in the argument, or about the function of some of these major steps.) Then subjects read through level 3 of the argument. Finally, they performed some "low-level" written acquisition tasks designed to assure that a subject had the "local" knowledge necessary to interpret every individual detailed step of the argument (e.g., to apply such a step to specific numerical examples).

In the S_1-treatment, the subjects read the S-version once and then did the previously described low-level acquisition tasks. In the S_2-treatment, the subjects read the S-version twice before doing these low-level acquisition tasks.

After doing either the high or low-level acquisition tasks, the subjects were given the correct answers and were then asked to redo any questions which they had failed to answer correctly. This procedure was repeated until the subjects could answer all questions correctly. Thus the acquisition tasks served to monitor that specified aspects of the knowledge had, in fact, been assimilated.

To minimize chances of internal reorganization of acquired knowledge, subjects were not allowed to take any notes, were allowed to read through the versions only the prescribed number of times, and were not given any excess time beyond that required for such reading.

Performance tests

After a subject had completed the preceding treatment, he or she relinquished the instructional materials and was given a test consisting of several performance tasks. These tasks were given in an order likely to minimize undesirable interaction between tasks (e.g., recall tasks were given before problem-solving tasks that might cue such recall).

Five of the tasks tested were "complex" in the sense that each of them required information about several parts of the argument. (Such tasks were thus expected to be facilitated by the hierarchical organization which provided higher-level connections between detailed steps of the argument.) These tasks included free recall (reproducing the entire argument unaided); cued recall (e.g., given a certain part of the argument, what is the next step in the argument?); "debugging" (e.g., diagnosing the effects of a mistake in a similar argument); and two modification tasks (carrying out a similar argument with changed premises).

A few other tasks were "local", i.e., they relied only on information about individual detailed steps of the argument (and involved thus questions similar to those used in the low-level acquisition tasks).

Finally, some additional test tasks, described later, were designed to probe the subjects' internal knowledge organization.

RESULTS

Performance on "complex" and "local" tasks

Fig. 3 shows, for each of the three treatments, the mean scores of the subjects on each of the five "complex" tasks described above. Consistently, subjects in the H-treatment performed better than subjects in the S_2-treatment, who performed better than (or equivalently to) subjects in the S_1-treatment. For each subject, the scores on all these tasks can be combined into a composite score for complex tasks. The mean value of this score, averaged for each treatment, is also shown in Fig. 3. A two-way analysis of variance (treatment x ability), performed on the composite scores for complex tasks, shows statistically significant effects of the three different treatments [$F(2,27) = 10.84$, $p < 0.001$] as well as of the subjects' three different ability levels [$F(2,27) = 8.5$[illegible], $p < 0.01$]. More specifically, a-priori one-tail t-tests, comparing pairs of treatments on these scores, show that subjects in the H-treatment performed significantly better on the complex tasks than subjects in the S_2-treatment [$t = 2.68$, $df = 27$, $p < 0.01$], and that

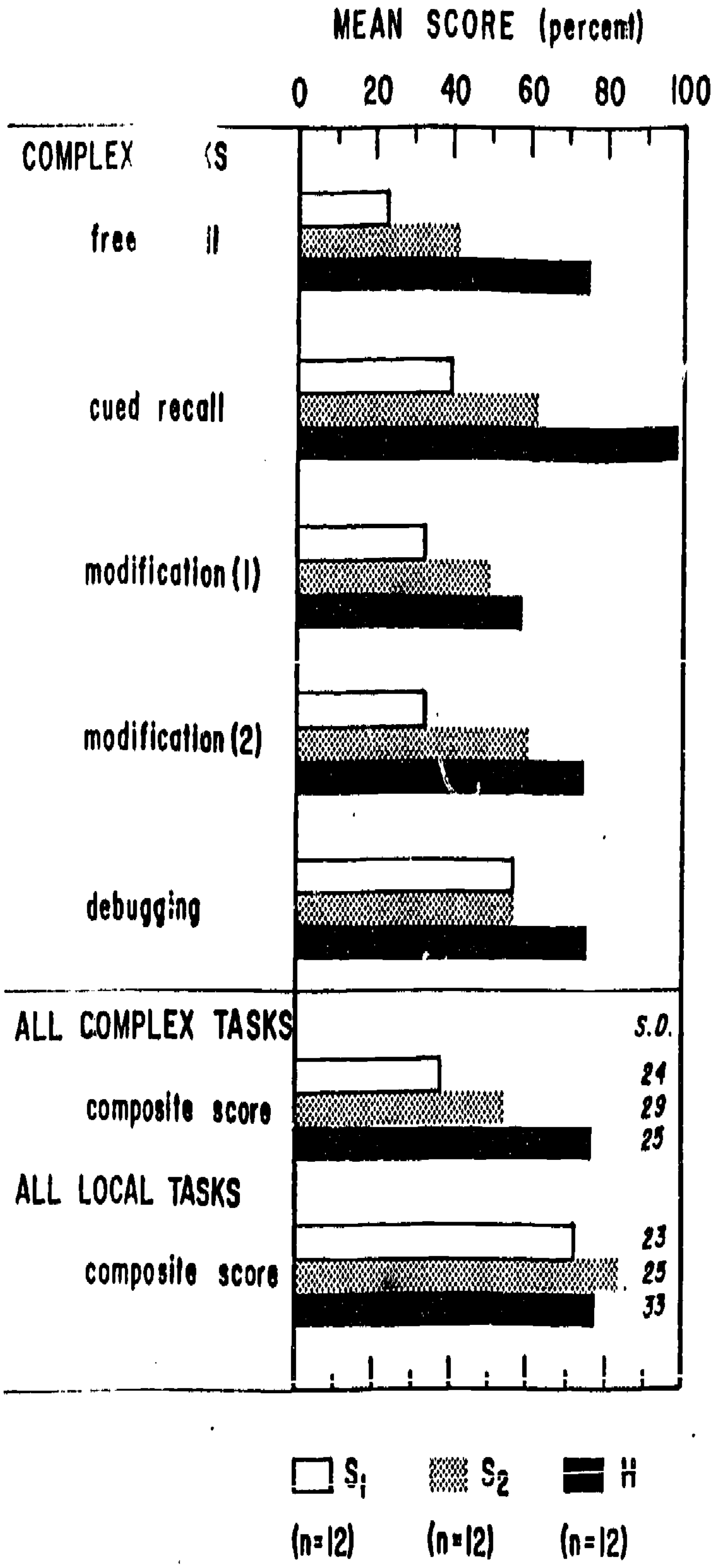


Fig. 3: Scores on various test tasks performed by subjects receiving S_1, S_2, and H treatments in experiment 1. (S.D. = standard deviation.)

subjects in the S_2-treatment performed significantly better than subjects in the S_1-treatment ($t = 1.96$, $df = 27$, $p < 0.05$).

Fig. 3 also shows the mean composite scores on all the "local" tasks. The application of t-tests indicates that these scores do not differ significantly between the different treatments.

The preceding results thus confirm the expectation that a hierarchical organization should facilitate performance on complex tasks involving appreciable information retrieval, but not on tasks which are merely local.

Evidence about internal knowledge organization

As previously mentioned, the last three test tasks were intended to provide some evidence about the nature of the subjects' internal knowledge organization. Two of these tasks probed for the existence of high-level information. (One of these tasks asked subjects to use only a few statements to summarize the argument. The other task asked them to order a scrambled list of such summary statements into a sequential description of the argument.) If the S_1 and S_2 subjects did indeed acquire an internal knowledge structure which is merely locally connected, they would be expected to have difficulty with these tasks. This was actually the case. Thus the H subjects were consistently found to perform better than the S_2 subjects, who were better than the S_1 subjects.

In the last test task, all subjects were given a high-level overview of the argument (the same overview as that contained in the H-version) and were then asked to derive the complete detailed argument. Nearly all subjects could perform this task, with about 90% perfect performance for all subjects irrespective of treatment. This result contrasts strikingly with the widely differing performances exhibited by differently treated subjects in the prior free-recall task where subjects had to recall the argument unaided (see Fig. 3). The fact that the mere provision of an external high-level description improved the performance of the S_1 and S_2 subjects so markedly suggests that the internal knowledge organization of these subjects lacked such a high-level description.

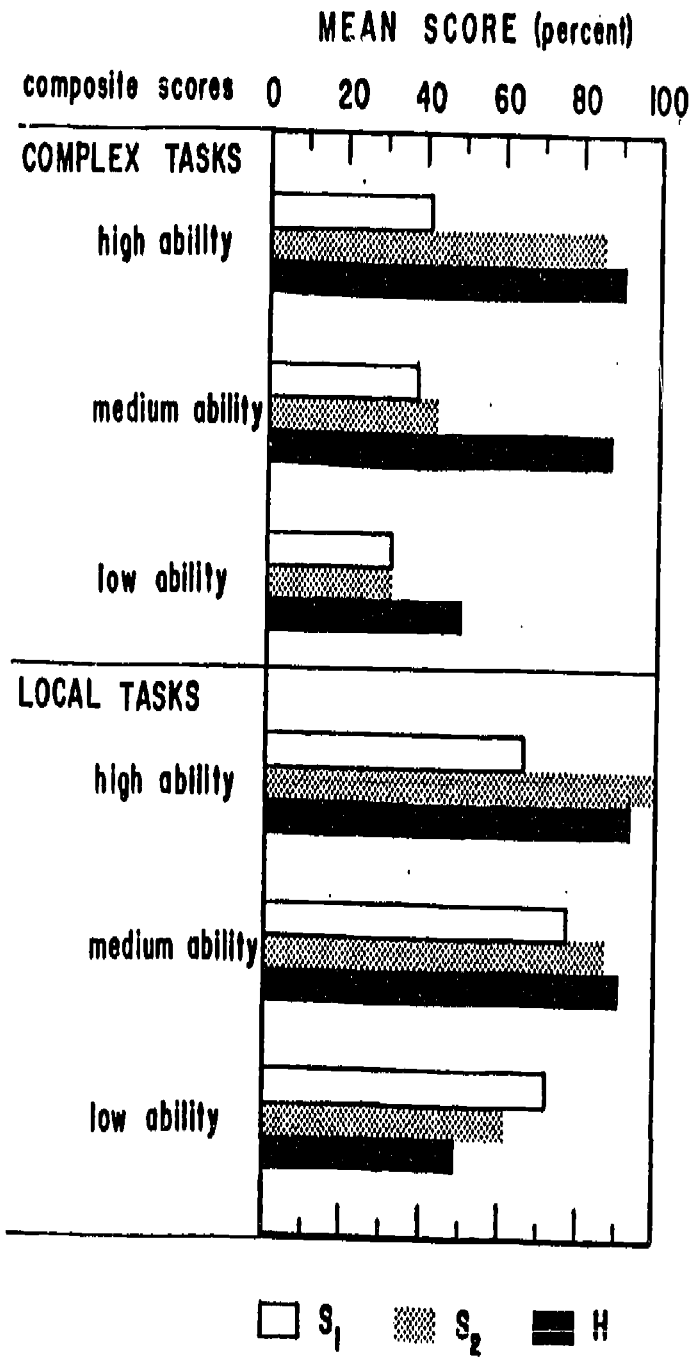
Qualitative differences in the performance on the various recall tasks provided additional evidence about internal knowledge organization. An internal knowledge organization which is merely locally connected would be expected to result in the recall of only detailed steps of the argument. On the other hand, a hierarchical organization would be expected to result in the spontaneous recall of some higher-level information which would, in turn, facilitate the recall of greater amounts of detailed information. In fact, in the "cued-recall" task (cued by the question "what is the next step in the argument" after a given step) all 12 H subjects answered the question, and 7 of them responded with a sequence of steps or an overview of such a sequence. By contrast, only 5 S_1 subjects and 8 S_2 subjects responded to this question, and all of them gave as an answer an immediate consecutive step of the argument. Furthermore, of those subjects who recalled the first step of the argument in the "free-recall" task, most H subjects (9 out of 11) could complete the argument; but very few of the S_1 subjects (1 out of 8) or of the S_2 subjects (3 out of 10) could complete it.

Individual differences

As already mentioned, a two-way analysis of variance on the composite scores for the complex tasks showed a significant effect ($p < 0.01$) of subjects' ability, as measured by performance in a physics class. Fig. 4 exhibits these individual differences in greater detail. Comparison of the treatment groups, by Scheffe's method of a-posteriori contrasts, yields the following results for the test scores on complex tasks: Among the high-ability subjects, there was no significant difference between the mean scores of the H and S_2 subjects; but the combined mean score of these subjects was significantly higher ($p < 0.01$) than the mean score of the S_1 subjects. Among the medium-ability subjects, there was no significant difference between the mean scores of the S_1 and S_2 subjects; but the mean score of the H subjects was significantly higher ($p < 0.01$) than the combined mean score of the S_1 and S_2 subjects. Among the low-ability subjects, there was no significant difference between any of the mean scores.

These results suggest the following possible interpretation. The fact that the low-ability H subjects did not perform better than S_1 or S_2 subjects may indicate that they either did not acquire the hierarchical organization, or did not have the ability to use it effectively. Similarly, the fact that two readings of the single-level organization were quite useful for high-ability S_2 subjects, but not for low or medium-ability S_2 subjects, may indicate that the high-ability S_2 subjects possessed skills for effectively reorganizing information and exploited these skills in the second reading.

The preceding results are consistent with those obtained by Meyer (1978) who found that higher-ability subjects are better at acquiring the organization of input information, and are also better able to recall and use such information.



<u>Fig. 4</u>: Scores of subjects of different ability on test tasks in experiment 1. (Score differences less than about 25 percent are statistically not significant.)

<u>EXPERIMENT 2</u>

The primary goal of experiment 2 was to assess the importance of properly adapting a hierarchical internal knowledge organization to a desired set of tasks. Accordingly, the experiment compared the relative effectiveness of two hierarchical organizations which contained the same knowledge, but were adapted to different tasks.

In addition, the experiment sought to examine more closely the acquisition of internal knowledge organization. It also compared the effectiveness of two different treatments for inducing a specified internal organization.

<u>DESIGN</u>

We chose a knowledge domain and specified two distinct types of tasks (type "<u>a</u>" and type "<u>b</u>"). We then constructed two hierarchical organizations of the same knowledge units: organization A adapted to the tasks of type <u>a</u>, and organization B adapted to the tasks of type <u>b</u>. (Thus organization A included in its high levels information most important for tasks of type <u>a</u>, and in its lower levels information most important for tasks of type <u>b</u>. The reverse was true for organization B.) By means of treatments of the kind indicated in Fig. 5, subjects were trained to internalize one of these alternative organizations. After two weeks (a time deemed long enough for subjects to forget superficial features of the mode of presentation), the subjects were then tested on <u>both</u> types of tasks (<u>a</u> and <u>b</u>).

Each treatment included some written materials, either A or B version, presenting the knowledge in the corresponding organization. The treatment included also several acquisition tasks designed to assure the

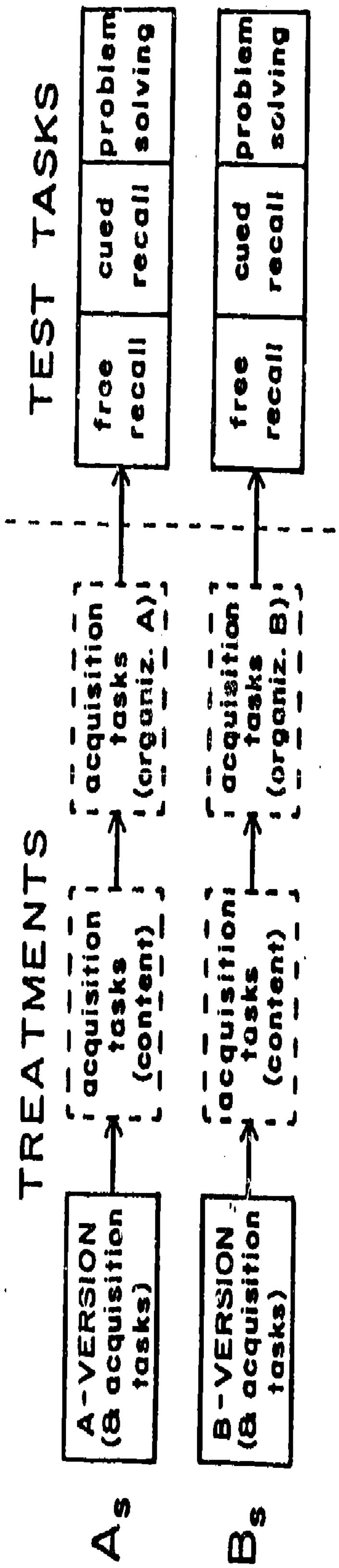


Fig. 5: Design of experiment 2 comparing hierarchical organizations A and B adapted to different tasks. The design is shown for the strong treatments A_s and B_s. (In the weak treatments A_w and B_w, the acquisition tasks, indicated in the dashed boxes, are replaced by the writing of a summary.)

incorporation of the desired organization. In the "strong" treatments A_s and B_s, the acquisition tasks were extensive (similar to those in experiment 1). To assess the adequacy of less extensive acquisition tasks used with the same materials, the experiment included also two "weak" treatments A_w and B_w. The design of the experiment included thus two factors, i.e., different input versions (A and B) and different acquisition tasks (strong and weak).

The subjects (20 students enrolled in an advanced high-school physics class) were assigned to five blocks of different ability (four subjects per block) on the basis of their grades in the physics class. The subjects in each block were then randomly assigned to the four different treatments.

METHOD

Knowledge domain and tasks

To provide realistically complex knowledge unfamiliar to the subjects, the knowledge used in the experiment described a fictitious universe of nuclear particles, but simulated the actual physical world. The knowledge thus included fictitious experimental observations, fictitious theoretical models explaining these observations, and a fictitious history of the development of theoretical concepts and experimental observations.

The tasks for which this knowledge can be used consist of recall and problem-solving tasks which are either of type _a_ ("deductive") or of type _b_ ("historical"). Such tasks were included in a performance test described later.

Alternative organizations and materials

The preceding fictitious knowledge was organized in two alternative hierarchical ways. Each organization included the same knowledge units, but the relationships between these units was different. These units included "deductive" information about the assumptions and predictions of the most comprehensive physical model, and "historical" information about various periods of theoretical or experimental progress. In organization A, adapted to the "deductive" or "a" tasks, the deductive information was placed in the higher levels of the hierarchy, while historical information was pl· ·d in the lower levels of the hierarchy. Conversely, in organization B ..dapted to the "historical" or "b" tasks, the assignment of information to levels was reversed.

To convey the hierarchical organization, each of the A or B versions of the materials presented the information by systematically traversing the respective hierarchy top-down from higher to lower levels. In addition, the versions emphasized the hierarchical organization by using titles at various levels, overviews, boxes surrounding important information, organizational charts, and other aids.

Treatments

Each of the treatments, illustrated in Fig. 5, lasted about 90 minutes. Each subject read the previously described versions (either A or B) and performed various acquisition tasks. In the strong treatments A_s and B_s, the following procedure was used: (1) After reading each of the four sections of the written version, the subject had to answer questions about the factual content of that section and to mark on an organizational chart the items that had been discussed in that section.

(2) After reading the entire written version, the subject performed the following two acquisition tasks: (a) A "content" task which asked questions about various facts presented in the entire version, and which again asked the subject to mark his or her answers on an organizational chart. (b) An "organization" task in which the subject, when given individual information items in random order, was asked to arrange them in an organizational chart (like that previously presented in the instructional materials).

After each of the preceding acquisition tasks, the subject was given correct written answers and then had to repeat those tasks which were inadequately completed. This procedure was repeated until the subject could perform all the acquisition tasks correctly.

[In the weak treatments A_w and B_w, the interspersed acquisition tasks were also used. However, instead of performing the second set of acquisition tasks, the subject was merely asked to write a summary of what he had read (with instructions to structure the summary so that about five major ideas should be elaborated in turn).]

Performance tests

At the end of the treatment, the subjects were told to return two weeks later to engage in similar activities. When the subjects returned, they were actually given a test (lasting about 90 minutes) consisting of various tasks performed in the following order: (1) A "free-recall" task in which the subject was asked to write a summary of the information he had read. (This summary was to be structured in the form of about five major ideas which were then to be successively elaborated). (2) Several "cued-recall" tasks in which the subject was asked specific questions requiring him or her to recall particular deductive or historical facts. (3) Some problem-solving tasks which required the subject to make some inferences on the basis of given facts. These problem-solving tasks were both "deductive" (e.g., asking the subject to generalize the given theoretical model of nuclear particles to a slightly more complex situation) and "historical" (e.g., asking the subject how a change in the sequence of experimental discoveries would have affected the formulation of new theoretical concepts).

RESULTS

Adaptation of organization to tasks

For each subject, a composite score was computed for all cued-recall and also for all problem-solving tasks of type a (deductive) and of type b (historical). Fig. 6 shows the means of these scores for subjects in the A and B treatments (both strong and weak). As predicted, subjects with the A organization performed consistently better on tasks of type a, while subjects with the B organization performed consistently better on tasks of type b. (Indeed, the individual scores on any one cued-recall or problem-solving task exhibit the same consistent pattern.)

The observed differences can be exhibited more clearly by considering for each subject a "difference score" $C_a - C_b$, where C_a is the composite score for all a tasks and C_b is the composite score for all b tasks. Fig. 6 also shows the means of these difference scores. An analysis of variance (input version x acquisition tasks, blocked by 5 levels of ability) shows that this difference score depends significantly on the input version A or B [$F(1,12) = 6.45$, $p < 0.03$], but not significantly on either the nature of the acquisition tasks used in the

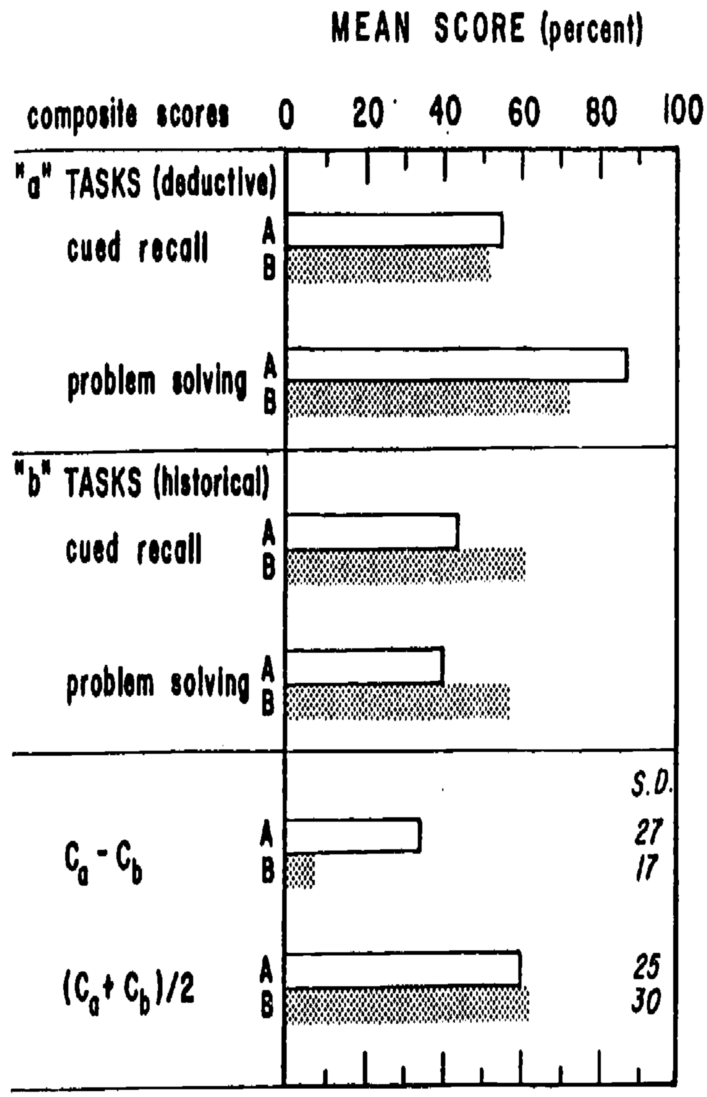


Fig. 6: Mean scores in experiment 2, on tasks of type a or b, obtained by subjects with knowledge organizations A or B. (The scores C_a and C_b are composite scores on all tasks, of type a or b respectively.)

strong or weak treatments, nor on the subjects' abilities.

The summaries resulting from the free-recall tasks can be analysed (in the fashion described in the next section) to obtain scores indicating the proportion of knowledge units recalled at every level of a postulated organization. The data consistently indicate that information at the higher levels was recalled better than information at the lower levels. They also show the expected differential effects of acquired organization on the ability to recall information of different types. For example, among subjects acquiring the A organization with deductive information at its higher levels, the recall score was 50% for the first or highest level, 50% for the second level, 27% for the third level, and about 5% for the lowest level including historical information. (Indeed, only 3 out of 10 subjects mentioned historical information at all.) Similarly, among subjects acquiring the B organization with historical information at its higher levels, the recall score was 65% for the first or highest level, 47% for the second level, and 44% for the third level containing predominantly deductive information.

In conclusion, even with our small number of subjects, the observed differences in performance are consistent and large enough to indicate the importance of appropriately adapting a hierarchical organization to the intended tasks. Thus no hierarchical organization is universally superior for all tasks. (Indeed, as shown in Fig. 6, the overall performance of subjects with A or B organizations is about equally good on the combined set of tasks of type a and b.)

Acquisition of organization

The free-recall summaries written by subjects two weeks after the treatment were used to make some inferences about their acquired internal knowledge organization. To do this, each summary was interpreted as being a systematic linear traversal of some underlying internal knowledge organization. The analysis consisted then of trying to map this observed linear sequence upon the particular organization presumably acquired by the subject in the prior treatment (the A organization for a subject in the A_S or A_W treatments, or the B organization for a subject in the B_S or B_W treatments). To implement this analysis, we sequentially numbered the statements in a subject's summary, and then attached these numbers to the organizational structure presumably acquired by the subject. These sequential numbers indicated then a retrieval path within the subject's hypothesized organization.

Most of the observed paths were indeed consistent with a subject's systematic traversal, top-down and in depth, of the particular organization supposedly acquired in the prior treatment. Fig. 7 summarizes the data compactly by indicating, on a simplified A (deductive) organization, the "average retrieval path" of all 10 subjects who had read the A version in their treatment. (This average path was obtained by averaging the numbers indicating the serial positions of the knowledge units recalled by the individual subjects.) The retrieval paths can also be described in greater detail by specifying the observed deviations of the paths from a top-down path. (This can be done by simply computing the proportion of subordinate units recalled before their superordinate units.) Among the 10 subjects who had read the A version, 9 had no such deviations, and 1 had 25% such deviations. Among the subjects who had read the

B version, 6 had no such deviations, 1 had 33% deviations, 1 had 25% deviations, 1 completely reorganized the information into the A organization, and 1 completely misinterpreted the information.[3]

The preceding results indicate that our treatment methods were quite effective in inducing subjects to incorporate the presented organization. These results are consistent with some previous work by Shavelson (1973) whose experiments showed a good correspondence between the organization of instructional materials ("content structures") and the resulting organization of well-internalized knowledge ("cognitive structures").

Effects of different acquisition tasks

The overall performance of subjects in the "strong" treatments was significantly better than that of subjects in the "weak" treatments. In particular, a two-way analysis of variance (input version x acquisition tasks), performed on the sum of the composite scores of all a and b tasks, showed explicitly that the different acquisition tasks had significant effects [$F(1,12) = 5.96$, $p < 0.05$].

These results indicate that appropriate acquisition tasks are important for assuring that a particular knowledge organization is internalized. In our experiments, those subjects who had engaged in acquisition tasks explicating the organization through a visual representation performed better than those subjects who had merely been asked to write a well-structured summary. This performance difference existed despite the fact that all subjects had studied the same well-organized written materials and had devoted equal time to acquiring the organization.

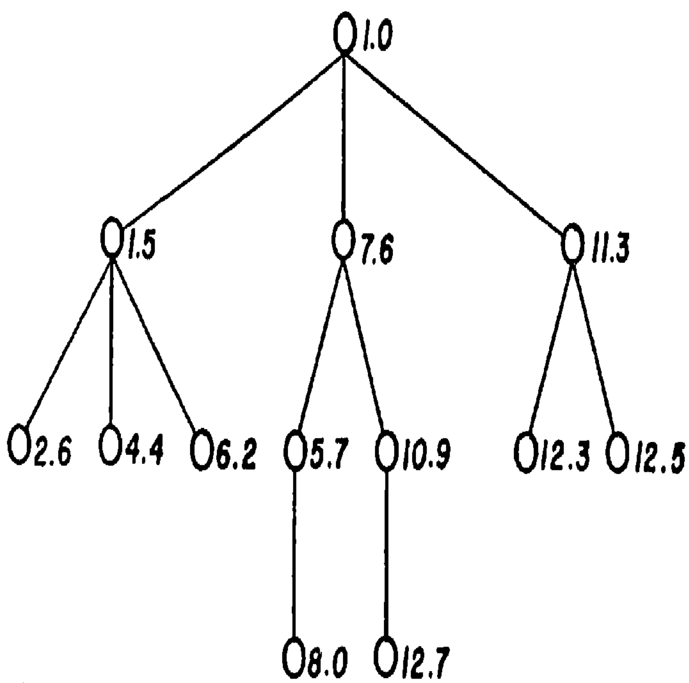


Fig. 7: A simplified A organization with numbers showing the average retrieval path of the ten A_s and A_w subjects.

EXPERIMENT 3

The purpose of experiment 3 was to study in greater detail the process whereby an internal organization is acquired. This experiment used the same materials as those of experiment 2. The acquisition tasks were also similar, but with some important modifications. Thus the experiment dealt with subjects individually to carry out the acquisition process under more controlled conditions. Furthermore, the final performance of individual subjects was observed more unobtrusively and was then subjected to more detailed analysis.

METHOD

The A and B treatments used in this experiment were similar to the strong A_s and B_s treatments in experiment 2. (See Fig. 5.) They used the same materials and were designed to have subjects acquire either the A (deductive) or B (historical) organization. However each treatment, lasting about 90 minutes, was carried out with individual subjects. Correspondingly, one could monitor more closely that each subject read the materials and carried out the acquisition tasks in the prescribed sequence, and could also provide subjects with oral corrective feedback on their acquisition tasks.

After the treatment, each subject was told to come back after two weeks to engage in similar activities. When the subject returned, he (or she) was asked to tell orally everything he could remember about what he had learned in the first session. (This "free-recall" task, unlike that in experiment 2, was completely unstructured and did not provide the subject with any instructions about the manner of retrieving the information.) The subject's recall was then tape-recorded and subsequently transcribed

into the form of a protocol.

The eight subjects participating in this experiment were paid volunteers obtained among students in an introductory college-level physics course. These subjects were matched into pairs of comparable ability on the basis of their prior performance in their physics course. The two members of each pair were then randomly assigned to the two treatments.

RESULTS

The oral-recall protocols were analyzed in a manner similar to that used for analyzing the recall summaries in experiment 2. The analysis of each subject's protocol led thus to a retrieval path within the subject's presumed internal knowledge organization. The detailed analysis and some case studies are described in Eylon (1979). Here we only summarize the major results without detailing the evidence:

(1) The internal knowledge organization, inferred from the protocols, corresponded well to the organization presented in each subject's treatment. Indeed, six out of the eight protocols could be mapped into a systematic top-down retrieval path within the appropriate input organization.

(2) Subjects recalled the information in different orders. Thus, of the subjects using top-down retrieval, some traversed the hierarchical organization in breadth, some in depth, and some used a combination of both procedures. This variety of traversals indicates that subjects did not merely recall the information in the sequence in which it was originally presented. Instead, they extracted an underlying structure which they subsequently traversed according to their own preference. Thus the underlying knowledge organization is more fundamental than the sequential

procedure of presenting or using this knowledge.

(3) Higher levels of the hierarchical organization were usually recalled better than lower levels. For example, in the deductive organization, the average proportion of knowledge units recalled was 63% from the first or highest level, 45% from the second level, and 9% from the third level. Similarly, in the historical organization, the average proportion recalled was 75% from the first level, 36% from the second level, and 43% from the third level. (When subjects were prompted to provide more information, they added mostly information from the lower levels.)

(4) The retrieval paths of two subjects could not be mapped upon the organization of their treatment. These subjects recalled very little information and also did not seem to exhibit any appreciable organization of their underlying knowledge. These two subjects were also the two subjects of lowest ability (as determined by performance in their physics class). This correlation of performance with ability was also more generally apparent. Thus the four subjects of highest ability recalled on the average about 57% of all the knowledge units, while the four subjects of lowest ability recalled on the average only about 20% of all these knowledge units.

DISCUSSION

MAIN CONCLUSIONS

This study formulated a particular prescriptive model of a useful internal knowledge organization and tested selected aspects of this model under controlled experimental conditions. The main conclusions

emerging from this work are the following:

(1) An internal knowledge organization, which describes information hierarchically at several levels and is appropriately adapted to the intended task domain, can appreciably enhance a person's performance on recall and problem-solving tasks. Performance is facilitated most for tasks utilizing information at the highest levels of the hierarchical organization.

(2) By using sufficiently controlled experimental conditions, it is possible to induce a person to acquire a specified form of internal knowledge organization. Weaker experimental conditions are partially effective. (However, our experiments did not seek to determine optimally efficient procedures for promoting the acquisition of given forms of internal knowledge.)

(3) The persons studied in our experiments exhibited individual differences on task performance, differences which correlated positively with prior performance in a physics course. Experiments 2 and 3 suggest that some of these differences were due to differing abilities to acquire a given hierarchical knowledge organization; experiment 1 suggests that some of these differences were also due to differing abilities to reorganize acquired information.

IMPLICATIONS

The work discussed in this paper has also some implications beyond the preceding specific findings. From the point of view of research on human information processing, the work points out the interest of studying the effects of knowledge organization on various problem-solving tasks more complex than recall tasks. Furthermore, it suggests some specific methods for inducing specified forms of internal knowledge and for obtaining evidence about the nature of such knowledge.

From a broader perspective, the work illustrates the utility of an approach which strives to formulate prescriptive information-processing models for enhancing human performance. The effectiveness of such models can then be studied in experiments where human subjects are deliberately induced to act in accordance with the models. [The virtues of such an approach are discussed in (Reif, 1979).] Such an approach can be useful for research purposes since it allows one to study selected aspects of a model under well-controlled manipulable conditions. Furthermore, the approach can be usefully extended to design instruction by combining well-validated prescriptive models of human performance with specific instructional models.

From the point of view of practical education, our work indicates that the organization of the knowledge acquired by a student, and not just its content, is of crucial importance in determining the student's ability to use this knowledge effectively. Pragmatic instructional efforts could thus benefit significantly by paying more attention to the organization of knowledge to be taught. Our work indicates specifically that a hierarchical task-adapted knowledge organization can be broadly useful for facilitating many recall and problem-solving tasks. Furthermore, our work suggests how usefully-organized knowledge can be taught by suitably structured teaching materials (e.g., containing explicit indications of hierarchical multi-level organization, explicit connections between levels of description, systematic order of traversal of the hierarchy) and by carefully designed teaching methods (e.g., using active student processing for incorporating organizational aspects).(4)

LIMITATIONS AND EXTENSIONS

Several aspects of the model of hierarchical knowledge organization have not been studied in our work and might usefully be explored. For example, can one specify an optimum amount of information per knowledge unit? Or how might different levels of description profit by using appropriately different symbolic representations?

It would also be of interest to extend our prescriptive approach to study the effectiveness of a hierarchical knowledge organization for larger and more complex knowledge domains (e.g., for the solution of problems in physics).

We dealt with the acquisition process merely to assure that a specified form of internal knowledge is actually acquired. However, the input process by which a person acquires various forms of internal knowledge is worthy of study in its own right. For example, how can a linear sequential input process (such as reading prose) efficiently convey the information necessary to construct a complex multi-dimensional structure of internal knowledge? Such a question might also usefully be studied by formulating prescriptive theoretical models of such an acquisition process (e.g., models specifying optimal mappings of a hierarchical organization upon a linear structure that can be traversed sequentially). Particular features of such models could then again be studied under well-controlled conditions where the acquisition process is known to occur in a manner specified by the model. Studies of this kind would also be directly relevant to practical instruction which is obviously interested in designing procedures for promoting the efficient acquisition of internal knowledge.

Finally, our work leads naturally to some more far-reaching questions. How do individuals acquire the important cognitive skill of reorganizing information into more efficient forms? And, given our evidence about the effectiveness of a hierarchical organization, how could one teach students the skill of independently organizing information into such a useful hierarchical form? Such questions deal with an interesting cognitive processing skill, and are also directly germane to the central educational aim of making persons better independent learners.

FOOTNOTES

(1) A fuller discussion of this model, and of the experiments described in this paper, can be found in an unpublished thesis by Eylon (1979). Some copies of this thesis can be obtained, at cost, from the author.

(2) The structure in Fig. 1 is thus a network or graph, rather than a simple tree. It may also be useful to characterize the knowledge units in Fig. 1 by distinct levels of importance (so that retrieval can be pursued only down to a particular level). Then it is admissible that elaboration of two knowledge units at the same level (such as C and D in Fig. 1) may lead to knowledge units at different levels of importance.

(3) Throughout experiment 2, subjects performed relatively worse on historical tasks and seemed to incorporate the historical organization less well. One possible reason may be the prior mental set whereby subjects, used to studying physics, are inclined to ignore historical information.

(4) Indeed, the utility of such ideas has been successfully exploited in the design and implementation of practical physics laboratory instruction (Reif and St. John, 1979).

REFERENCES

Ausubel, D.P. Educational Psychology: A Cognitive View. New York: Holt, Rinehart, and Winston, 1968.

Eylon, B.S. Effects of Knowledge Organization on Task Performance. (Unpublished Ph.D. Dissertation, University of California, Berkeley, 1979.)

Hughes, J.K., and Michton, J.I. A Structured Approach to Programming. Englewood Cliffs, N.J.: Prentice Hall, 1977.

Kintsch, W., and Keenan, J.M. Recall of propositions as a function of their position in the hierarchical structure. In W. Kintsch (Ed.), The Representation of Meaning in Memory. Hillsdale, N.J.: Lawrence Erlbaum Associates, 1974.

Larkin, J.H. Skilled problem solving in physics: a hierarchical planning model. (Working paper, Group in Science and Mathematics Education, University of California, Berkeley, 1978).

Larkin, J.H., and Reif, F. Understanding and teaching problem solving in physics. European Journal of Science Education, 1979.

Mayer, R.E., and Greeno, J.G. Structural differences between learning outcomes produced by different instructional methods. Journal of Educational Psychology, 1972, 63, 165-173.

Meyer, B.J.F. The Organization of Prose and Its Effects on Memory. Amsterdam: North-Holland, 1975.

Meyer, B.J.F., Brandt, D.M., and Bluth, G.J. Use of author's textual schema: key for ninth grader's comprehension. (Paper presented at the American Educational Research Association Convention, March 1978.)

Postman, L. A pragmatic view of organization theory. In E. Tulving and W. Donaldson, Organization of Memory. New York: Academic Press, 1972.

Reif, F. Theoretical and educational concerns with problem solving: Bridging the gaps with human cognitive engineering. In D.T. Tuma and F. Reif (Eds.), Problem Solving and Education: Issues in Teaching and Research. Hillsdale, N.J.: Lawrence Erlbaum Associates, 1979.

Reif, F. and St. John, M. Teaching physicists' thinking skills in the laboratory. (Submitted to the American Journal of Physics, 1979.)

Sacerdoti, E. A Structure for Plans and Behavior. New York: Elsevier North-Holland, 1977.

Shavelson, R.J. Some aspects of correspondence between content structure and cognitive structure in physics instruction. Journal of Educational Psychology, 1972, 63, 225-234.

Shavelson, R.J. Methods for examining representations of a subject-matter structure in a student's memory. Journal of Research in Science Teaching, 1974, 11, 231-249.