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ABSTRACT

To examine the characteristics of expertise, a study at the University of Minnesota cardiac clinic compared differences in diagnostic ability and strategies between novices (fourth year medical students) and experts (specialists in pediatric cardiology). The investigator presented a model for expertise based on knowledge of subject matter content and knowledge of reasoning procedures. Four medical students and four specialists diagnosed eight cases, four in a simulated clinic task and four in a consultant task. All sessions were audiotaped. The novices and experts made different diagnoses based on a varying knowledge of the subject matter content and the use of different reasoning procedures. For example, a student used the procedure of successive scanning (considering only one hypothesis at a time) when he was reasonably sure of his diagnosis, while a specialist used a focusing strategy (reducing the set of hypotheses already generated) to limit the possibilities. The conceptualization of expertise as a combination of knowledge of content and knowledge of procedures is particularly relevant to the adult educator. Since most adults have mastered general strategies of learning, they need to learn and apply the procedures unique to an area in order to develop expertise in that area. A careful investigation of the expert's strategies can be utilized for programs designed to develop that expertise. A bibliography and diagrams related to the study are included in the report. (LMS)

An Investigation of Expertise: Implications for Adult Educators

by

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Abstract

The majority of tasks that adults face in everyday activity involve decision making and problem solving skills. Tasks such as selecting a new plant site, categorizing a patient into a disease category, allocating resources for a project, or maneuvering a car from home to a meeting, all involve using information to analyze a problem and require the individual to reach a conclusion on the basis of that analysis. When someone successfully combines the skills of decision-making or problem solving for a particular area, he develops expertise in that area. Thus, one description of learning, for an adult, is that it is the development of expertise.

However, educators have only a rudimentary understanding of expertise. Often, it seems, once one becomes an expert, it is difficult to describe how one got there. Many educators conclude that the major component of expertise is more subject matter knowledge. Others conclude that the major component is experience and design master-apprentice programs which share experience informally. The paper discusses a model of expertise which includes knowledge of reasoning procedures as well as subject matter knowledge for the individual. Both the expert and novice have knowledge of problem solving procedures and knowledge of subject matter content to support the problem solving task. However, their knowledge is organized differently, which is reflected in their use of procedures during problem solving.

The paper presents an examination of this model of expertise in a naturalistic problem solving setting--diagnosis in medicine. Previous studies of expertise have used very constrained game tasks such as cryptarithmetic or chess (Newell and Simon, 1966) or have offered descriptions of the expert's behavior as multivariate regression or Bayesian procedures (Slovic, 1969; Warner et al., 1964). These descriptions do not capture the pattern matching capabilities nor the memory limitations of the individual problem solver. An experimental study is presented in which the differential use of reasoning procedures in a diagnostic problem solving task for subjects with different subject matter knowledge (novices who are medical students and experts who are physicians in the subspeciality of pediatric cardiology) is examined.

The implications of this understanding of expertise for training and retraining of adults are discussed. Applications of the results of the experimental study to educational programs directed toward adults are also discussed.

An Investigation of Expertise: Implications for the Adult Educators

Janice B. Mandernach

A qualitative difference in understanding between the advanced student and the expert has been noted in many fields. For instance, one who is an expert in a field is able to make judgments with information which are quicker and more insightful than those made by the non-expert. Faculty in professional schools such as law, medicine, and education comment that the student often starts "thinking" like a professional during his last year of school or during an internship. This suggests that when someone successfully combines the skills of decision-making or problem solving for a particular area, he develops expertise in that area.

However, educators have only a rudimentary understanding of expertise. Often, it seems, once one becomes an expert, it is difficult to describe how one got there. Many educators conclude that the major component of expertise is more subject matter knowledge and design programs which teach more and more facts. Others conclude that the major component of expertise is experience and design master-apprentice programs which share experience informally. Let's examine some of the characteristics of expert behavior.

Knowledge of the Subject Matter

A basic knowledge of the subject matter is certainly important in developing expertise. Investigations by information processing psychologists such as Newell and Simon (1972) and Gagné (1962) have demonstrated the contribution of subject matter knowledge to expert performance. One of the differences between the master and Class A player in chess is the number of chess patterns he has studied. Simon and Chase (1973) estimate that master and grandmaster players have a chess vocabulary between 10,000 and 50,000 patterns whereas the vocabulary for the Class A player is on the order of 1,000 to 5,000 patterns. This difference in quantity of patterns available to be used during problem solving surely is a major contributor to gradations in performance on chess tasks by grandmasters and Class A players.

A changed perception of relations specified by information in the environment also characterizes expert behavior. As one learns, perceived relations undergo transformation. Aspects of the environment which were of central importance at one level of expertise become incorporated into other relationships and take on peripheral importance at another level of expertise. Developmental studies show that children respond differentially to identical features of the environment at different ages (Suppes, 1966; Pufall, 1973). Pufall (1973) obtained a roughly curvilinear relationship between egocentrism and age with a peak at age six. Further experiments showed, however, that egocentrism does not appear and then disappear from the child's repertoire of behaviors around age six but is integrated with the child's level of cognitive functioning. As the child develops the ability to detect abstract relations between ages six and ten, his egocentric behavior reflects the new relations he perceives.

In Chase and Simon's study (1973), all pieces on the chess board were perceived individually by the novice chess player, while each piece was perceived in relation to other pieces on the board by the grandmaster and master. In a recall task, the grandmaster replaced up to 25 pieces on a board when the pieces were arranged in actual chess positions whereas novice players could replace only about 8 pieces. Players who were rated between grandmaster and novice in chess ability showed a gradation in recall performance as a function of their skill. On a second task, when pieces were arranged randomly on the board, all players from master to novice recalled only three or four pieces on the average. Thus, it is apparent that the relationship of chess pieces specified by the game situations carried information for the expert as a result of his increased knowledge.

Knowledge of Procedures

Knowledge of content which is stored in an individual's memory is of little value unless it is used. Thus, it is important for the learner to develop procedures which can use the content knowledge. Some procedures are more efficient than others (i.e., less time consuming or less costly) and result in variable performance among persons with identical factual knowledge. Resnick (1976) notes that there is a change in procedure use as one becomes more skilled in a task. Skilled performance is not only a matter of learning the routines and rules which are taught by an instructor but also of simplifying and organizing those rules into more efficient strategies. Some of these strategies are algorithmic--e.g., the addition of two numbers, others are heuristic--e.g., having a rule of thumb to drink orange juice before eating your cereal in order to enjoy the taste of each; some are general--e.g., always working from the general to the particular, whereas others are limited to a particular knowledge domain--e.g., determining the order of adding the butter, flour, and milk when making white sauce.

Novice and Expert Behavior

Since our concern is the development of skilled behavior, and skilled behavior encompasses both knowledge of content and knowledge of procedure, the first step in understanding expertise is to analyze expert performance within the task domain of interest. However, since we also have educational concerns, the investigation must include an analysis of novice performance as well as expert performance. It is the transformation of the individual's knowledge of content and procedural use from that of a novice to that of an expert which is the goal of instruction. That is to say, knowledge structures and procedural rules or heuristics which constitute expert behavior must evolve from a prior state of the individual. They cannot be presumed to have entered a *tabula rasa*. If the educator knows what that prior state encompasses, it is easier for him to design effective programs.

Resnick (1976) suggests a triangular relationship "between the structure of a task as defined by the subject matter, the performance of skilled individuals on a task, and a teaching or acquisition routine that helps novices learn the task." (p. 73) This relationship is depicted in Figure 1. He states that:

> "Analysis for instructional purposes cannot *just* describe the expert's performance (although such description will almost always be a part of such analyses). They must also describe performance characteristics of novices and attempt to discover or point to key differences between novices and experts, suggesting thereby ways of arranging the experiences that will help novices become experts. Instructional task analysis...should suggest ways of organizing knowledge to assist in acquisition, recognizing that this organization may differ from organizations that are most efficient for expert use of that knowledge." (p. 53)

Investigations of Expert Performance

Information processing psychologists have addressed the questions surrounding expert performance. Some studies have used very constrained game tasks such as cryptarithmetic or chess (Newell and Simon, 1972),some have forced the expert's behavior into a binary tree decision structure (Kleinmuntz, 1968), while still others have offered descriptions of the expert's behavior as multivariate regression or Bayesian procedures (Slovic, 1966; Warner, Toronto and Veasy, 1964). These descriptions do not capture the pattern matching capabilities nor the memory limitations of the individual problem solver.

Recently, studies of problem solving have extended to more complex areas such as physics (Johnson, Feltovich, and Swanson, 1975), psychophysics (Greeno, 1976), geometry (Resnick, 1976; Greeno, 1976), medical diagnosis (Rubin, 1975; Elstein, Shulman, and Sprafka, 1976), class inclusion (Wallace, 1972) and moral judgment development (Lawrence, 1977). These studies have attempted to incorporate the complexities of the task environment and in some instances have looked at several levels of expertise. The experimental study I will describe is a part of this tradition.

An Investigation of Expert Reasoning

The remainder of this paper describes an investigation of expertise in an applied complex task situation: medical diagnosis. The study was developed in conjunction with investigations of expert behavior by Johnson (Johnson, Feltovich, and Swanson, 1977; Swanson, Feltovich, and Johnson, 1977). The study investigates problem solving in a naturalistic environment since physicians are required to use problem solving skills in their daily clinical routine

Currently, physicians are taught diagnosis in a master-apprentice setting. This is both expensive and time consuming. Expert physicians have diagnostic skills which have been gained from clinical experience, but the composition of those skills is little understood. As I suggested above, the identification and description of strategies which facilitate clinical diagnosis is the first step toward designing a program in which diagnostic skills can be taught. By examining the process of diagnosis and identifying strategies and conditions of use of particular reasoning processes, the research also serves as an illustrative resource for those interested in developing programs which foster expertise in other cognitive skill areas.

In this study, diagnosis is considered to be an inductive reasoning process which entails the use of several component procedures by the physician. The physician's task in diagnosis is to recognize symptoms in a patient and identify a disease category for the patient--an inductive reasoning process--so that appropriate treatment measures can be taken. In order to perform the inductive reasoning task, the physician calls into use component procedures, However, the use of a relevant procedure is not restricted to an induction or deduction stage, but component procedures interact performing inductive or deductive functions as the physician gathers information from the patient. He may generate several hypotheses before trying to prove any of them, or he may generate a hypothesis while he is in the middle of disconfirming an alternative one. The use of any particular procedure by the physician is governed by his current data on the patient and its interaction with his knowledge of medicine.

Both the expert and novice physician have knowledge of diagnostic procedures and knowledge of medical content to support the diagnostic task. However, their knowledge may be organized differently, and this should be reflected in their use of procedures during diagnosis.

Knowledge

Pediatric cardiology was chosen as the medical area of investigation because physiological principles of the heart are known, and the relationship of symptoms to diseases is well documented in textbooks (Moller, 1973). Both the expert physician and the medical student possess anatomical knowledge. They also have knowledge of physiology which includes an understanding of the flow of blood through the system and an understanding of relative resistances at valves and vessels.

Knowledge may be organized as associations between many levels of the cardiac system. These associations may be represented in a causal network, if the associations are derived from disease to associated defects to associated hemodynamic consequences to physical changes to symptom patterns. However, the associations may also be in the reversed direction or they may be direct and not include some levels. Of course, the associations may be available to the physician without a causal organization based on pathophysiologic principles of flow, pressure, and enlargement relationships.

If the knowledge is organized in a causal network and the pathophysiologic principles which link one level of the network to the next are known, then the causal network need not be remembered by the physician but can be generated from the defect related to a particular disease and principles of pathophysiology of the heart. Thus, the physician who can use principles of physiology to organize his knowledge will not have to store as much intermediate knowledge during diagnosis but will have it available through generative procedures if he needs it. In fact, because the structure of the heart constrains the possible paths for blood, physiologic principles organize knowledge of possible hemodynamic states and physical changes across diseases.

Component Procedures

As I have indicated, the physician's task is to find a disease name to attach to the patient's symptoms. The expert physician perceives his task to include, in addition, a physiologic understanding of the patient's symptoms. The knowledge he has to guide him in this task has been described above. Now let's consider the procedures he has available to assist him in gathering information from the patient and reducing the set of disease hypotheses he is considering.

In order to generate either disease or hemodynamic hypotheses about the patient's current state, the physician must solicit information from the patient. The physician has knowledge about what information will be most helpful in determining whether the patient has a cardiac problem. This "important information" knowledge will have come from instructors, from texts, or from reflecting on personal experience. The physician can check this information and will generate the associated hypotheses if the symptom is found.

Another procedure the physician can use to generate hypotheses is pattern recognition. The characteristics of this procedure are similar to those described in Gibson (1966) which have been extensively investigated by psychologists. The physician can review conclusions about the patient in order to recognize a pattern which indicates a particular disease state of the patient. In the pattern recognition procedure, the physician considers the findings as a whole before generating hypotheses rather than generating hypotheses on the basis of individual associations between symptoms and diseases.

A procedure which can be used to reduce the set of hypotheses which have already been generated is similar to that described as a focusing strategy by Bruner, Goodnow & Austin (1956). The physician considers a set of hypotheses and generates findings or remembers conclusions associated with each hypothesis. He then compares the findings for each hypothesis and chooses a symptom test which differentiates the hypotheses. In the most efficient form of this strategy, the physician finds a symptom which splits the disease set in half, and then seeks the symptom data from the patient. When using a focusing procedure, the physician attempts to systematically eliminate hypotheses by seeking data from the patient.

Another procedure which can be used to reduce the set of hypotheses is called a scanning strategy by Bruner et al. (1956). While using it, the physician evaluates one or more hypotheses which have been generated previously. He identifies findings associated with it and seeks data from the patient to confirm or disconfirm the hypothesis. If he is actively considering only one hypothesis at a time, he is using a successive scanning approach. If he is considering several hypotheses, he is using a simultaneous scanning procedure. With the simultaneous scanning procedure, he carries along the hypotheses as he checks for data. He may or may not generate associated findings before asking for data, but he evaluates each hypothesis, in turn, as the data are collected. Thus, simultaneous scanning involves a reaction to data rather than an active solicitation of data.

Materials

Eight cases from the University of Minnesota cardiac clinic were used in the study. Four were very difficult to diagnose and four were moderately difficult to diagnose in order to obtain a wide range of behaviors from expert physicians.

Tasks

Two tasks were used in the study: a simulated clinical diagnosis and a consultant diagnosis. The use of simulated clinic patient rather than an actual patient was desirable from an experimental point of view since such extraneous factors as emergencies, returning cases, fussy children and so on could be controlled. Furthermore, the inductive reasoning behavior of many physicians, all of whom receive the same data, could be compared using a simulated case whereas such control would not have been possible with a real patient because of time and treatment constraints. In the simulated clinic task, the physicians were required to request items of information from the experimenter as he would in the clinic. Verbal protocol was recorded as the physician performed the task and all sessions were audiotaped. The physician was not restricted other than requiring him to solicit all information as he would solicit it in the clinic.

The consultant diagnostic task provided a converging measure of the physician's use of component procedures since it is presumed that when serving both as the initial diagnostician and as the consulting physician, the individual taps the same underlying organization of subject matter knowledge to support his inductive reasoning process. If the physician uses component procedures similarly in both clinical and consultant tasks, then we have greater assurance that those procedures are an integral part of the physician's reasoning processes. In the consultant task, the physician could ask the experimenter for data in any order; he was not restricted to the clinic order of symptom data collection (history, physical examination, X-ray, and EKG). The physician gave verbal protocol throughout the task which was audiotaped.

Subjects

Subject groups were chosen on the basis of their knowledge of the subject matter in order to separate the way knowledge of principles of pathophysiology and knowledge of direct symptom-disease associations contributed to the expert pediatric cardiologist's use of component procedures during the inductive reasoning process. Two groups of subjects were examined:

(a) The first group was composed of expert pediatric cardiologists who had detailed knowledge of the anatomic, physiologic, and specific manifestations of congenital heart diseases. For the expert pediatric cardiologist, physiology integrates knowledge across diseases and across defects. The expert physician could generate findings from principles of pathophysiology if needed which allowed him to organize his diagnostic activity at the hemodynamic level rather than the disease level.

(b) The second group consisted of final year medical students taking the pediatric cardiology elective who were assumed to have general knowledge of the anatomy and physiology of the heart and to have learned some specific symptoms relating to congenital heart disease, but did not use principles of pathophysiology to organize their diagnostic activity.

Experimental Design

The experimental design is presented in Figure 2. Four pediatric cardiologists and four medical students served as subjects. Each subject diagnosed all eight cases, four in a simulated clinic task and four in a consultant task. Within each task, two cases were difficult and two were moderately difficult. Cases were counterbalanced across subjects and tasks. Order of presentation was randomly assigned.

Data Analysis

Tapes were transcribed and scored by the investigator. Since data are still in the process of being collected and analyzed, only a preliminary analysis will be presented here.

Differences in Knowledge of Content

The protocol contains instances of different conclusions by the physician groups based on a difference in knowledge of the subject matter content. In most cases this reflects a refinement in the expert's knowledge, i.e., he knows exceptions to the rule and they inhibit him from reaching prototypical conclusions which are incorrect.

The following two passages provide examples of the effect of differences in knowledge of content on physician behavior. In both instances, the subject has asked to palpate or touch the chest for information about thrills. Prototypically, a thrill at the base of the heart indicates the disease aortic stenosis and aortic insufficiency. This is the conclusion that students reach:

The subject's words are unbracketed. The experimenter's words are bracketed.

> Palpation of the precordium as to heaves and thrills, activity of the precordium?
>
> {The heart seems very active and there is a mild precordial bulge.}
>
> Heaves or thrills?
>
> {There are systolic and diastolic thrills palpable.}
>
> In the neck, apex?
>
> {Over the base of the heart.}
>
> Over the base. Okay. That again is a little bit of an indication of aortic insufficiency or stenosis.

All the students diagnosed this case as aortic stenosis-aortic insufficiency with a high degree of conficence: "I was almost 100% sure of my diagnosis", "I am pretty comfortable with my diagnosis. It's a fairly straightforward case."

For the expert subject, however, the magnitude of the chest activity indicated that aortic insufficiency was not an adequate explanation. Although AI produces thrills in the chest, they are usually not as turbulent as those presented in this case. The expert knew he must consider other pathophysiological reasons for the patient's symptoms:

{Palpation of precordium, you feel both systolic and diastolic thrills at the base.}

Where? At the base?

{Yes.}

The quicksand is getting deeper and deeper. Systolic and diastolic thrills at the base of the heart. Is there a thrill at the suprasternal notch?

{Yes.}

Is there a thrill at the apex?

{No.}

The thrill seems to be localized to the base. Great vessels and base of the heart. I'm thinking of things which give systolic/diastolic thrills or real turbulent types of things, like a huge ductus, some fistulus connections between arteries and veins or aorta and pulmonary artery. A normally growing 10 year old boy, I'm not thinking of A-V fistula in the head, not present since birth anyway. Something big in the great vessel area at the base of the heart.

Although the expert had hypothesized aortic stenosis previously, upon receiving information about the thrills he kept his thinking at a very general level: "Something big at the base of the heart."

At the conclusion of the case, he reported to the experimenter that one reason for moving away from a simple aortic stenosis-aortic insufficiency was the presence of "the thrill , a palpable thrill and a grade IV-V/VI diastolic murmur. With the thrill, I'm away from AS-AI. With this amount of activity, I'm leaning toward something like ruptured Sinus of valsalva or LV tunnel. At ten years of age, I wouldn't think there'd be this much AI, especially with congenital AS. I'm moving into things that are suggested by the natural history at ten years of age."

Another example of the effect of differences in the subject's knowledge involves a case determined at catheterization to be a truncus: a disease where only one large vessel leaves the heart instead of two. Normally, two vessels, the aorta and pulmonary artery leave the heart. Prototypically, in patients who have the truncus lesion, a single second heart sound is heard. Twenty-five percent of all truncus patients also show a right aortic arch on the X-ray. The truncus case chosen for the study has two second heart sounds. Because the second heart sound is split, the students discarded truncus as a potential diagnosis. The expert pediatric cardiologist placed more weight on the right aortic arch than the split second heart sound and correctly diagnosed the case.

Differences in Use of Procedures

The second major component of expertise discussed above was the use of reasoning procedures. The use of reasoning procedures interacts, of course, with content knowledge. If the physician is fairly certain of his diagnosis, he uses a successive scanning procedure to confirm his expectations for the patient. If he is not as certain of which disease the information is leading toward, he uses other procedures such as the check procedure to collect routine data or the focusing or simultaneous scanning procedures to decide among alternative diagnoses.

The student, whose protocol is presented below, had already decided on AS-AI as the diagnosis by the time this section of protocol was produced. The experimenter asked the student what he expected to see on the X-ray.

> You might expect to possibly see, although there is no evidence for it at this point, you might expect to see some dilatation of the left ventricle and possibly some left atrial enlargement, although there is no evidence for that on physical exam. But the thing I would also be watching for if there is a jet lesion, you know an AS lesion, you would expect to see dilatation of the ascending aorta. So that would be the main thing I would be looking for on the chest X-ray.
>
> {You sound pretty much like you are working towards one diagnosis, is that correct?}
>
> Um yeah. And, again, the other thing on physical findings that suggest that, would be the prominent precordial bulge. That tends to strengthen the diagnosis, too.

The features the student planned to attend to on the X-ray all follow from the disease AS-AI, indicating that he was using a successive scanning strategy.

The expert, on the other hand, had not yet reached a definitive diagnosis before viewing the X-ray. He had a hemodynamic level representation of the child's problem: aortic runoff. The procedure he planned to use was a focusing procedure which would help him narrow the problem to either the right or left side of the heart.

> "I'm still going to stick with a volume runoff from the aorta most likely. Back into the left ventricle or perhaps the pulmonary artery or right side. On the X-ray, I would expect a big heart. If the vascularity is increased, then something back into the right side of the heart. If the vascularity is normal, then I'll be able to keep it on the left side of the heart."

Educational Implications

"What does research of this sort tell us as educators?" First, it admonishes us to attend: (1) to the reasoning skills and procedures inherent in any task domain, (2) to the organization of the content knowledge by both novice and expert, as well as (3) to the relationship between the use of the knowledge and the reasoning procedures available for the individual. Some programs have been designed to explicitly teach reasoning procedures to novices in order to facilitate their development toward expertise.

Gordon (1973) designed a program to teach heuristics to medical students. Although there was great variability between individuals which made his results somewhat tentative, he found that heuristic instruction tended to increase the probability that the student would consider the correct diagnosis. This suggests two things: (1) students may not just pick up heuristics during master-apprentice teaching, and (2) explicit teaching of procedures encourages their use during problem solving.

Resnick describes a study by Schadler and Pellegrino (1974) which "has shown that requiring the subject to verbalize the goals of the problem and his or her strategies for solving it before making overt moves toward solution greatly enhances the likelihood of invention" (p. 79). This study suggests that one of the reasons individuals are unsuccessful in solving problems is their inability to consider alternative procedures to use with a problem. They may never have learned the procedures or they may simply not recognize that the task allows a particular procedure to be used.

In order to teach the novice procedures which are relevant to particular task demands, educators must understand the ways in which knowledge of content and knowledge of procedure guide the problem solving efforts of the expert, i.e., they must study the expert. In addition, they must determine the knowledge of content and knowledge of procedures available to the novice during problem solving. A conceptualization of expertise as a combination of knowledge of content and knowledge of procedure is particularly relevant to the adult educator. Most adults have mastered general strategies of learning. In order to develop expertise in an unfamiliar area, they need to learn and apply the procedures unique to that area. Time and energy which are spent on teaching procedures that the adult learner already has available are wasted resources. By analyzing the task domain and the expert, the educator documents the knowledge and procedures needed for success in that domain. By analyzing the novice, the educator documents the resources available for developing the expertise.

This paper presents a model of expertise which includes knowledge of subject matter content and knowledge of reasoning procedures. It examines the differences in problem solving knowledge and procedures used by novices and experts in the complex task of medical diagnosis. It suggests that a careful investigation of the expert's strategies can be utilized for programs which are designed to develop that expertise.

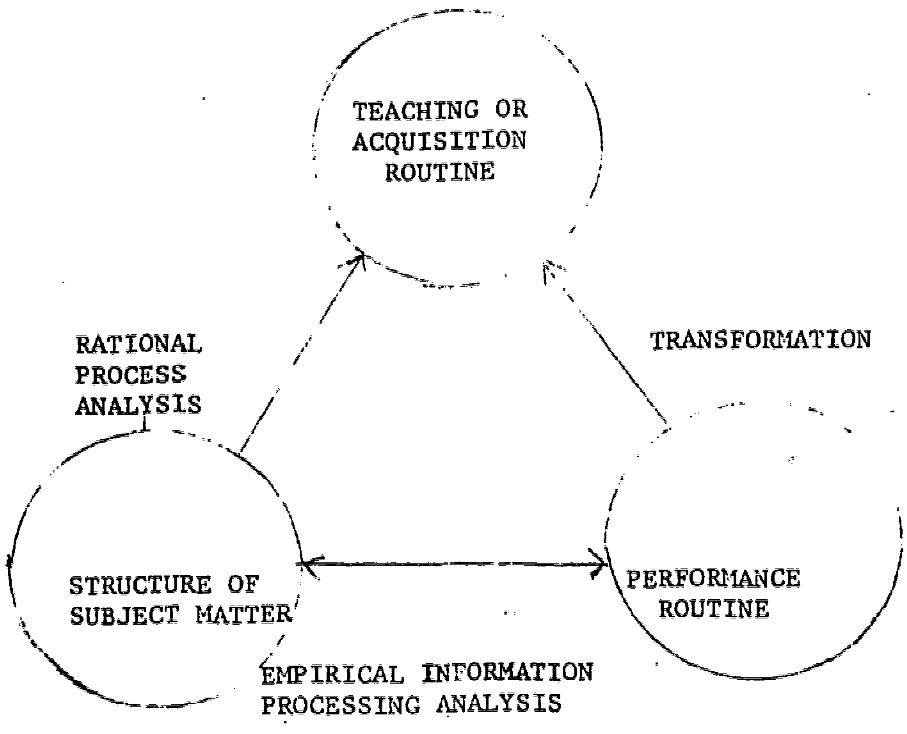

Figure 1: Relations between teaching routines, performance routines, and structure of subject matter.

(taken from Resnick, 1976)

Tasks / Subjects	Expert N=4		Novice N=4	
	Difficult	Moderately Difficult	Difficult	Moderately Difficult
Consultant	2	2	2	2
Simulated Clinic	2	2	2	2

Figure 2: Experimental Design for a study of expert and novice behavior in medical diagnosis.

BIBLIOGRAPHY

Bruner, J., J. Goodnow, and G. Austin (1956). A study of thinking, John Wiley, New York.

Chase, W.G. and H.A. Simon, 1973. Perception in chess. Cognitive Psychology 4: 55-81.

Elstein, A., L. Shulman, and S. Sprafka (1976). An analysis of medical inquiry processes. Final report. Office of Medical Research and Development, Michigan State University, East Lansing, Michigan. October, 1976.

Gagne, R.M. (1962) The acquisition of knowledge. Psychological Review 69, No. 4 355-365. July, 1962.

Gordon, M.J. (1973) Heuristic training for diagnostic problem solving among advanced medical students. Unpublished doctoral dissertation. Michigan State University. Discussed in Elstein et al, 1976. Chapter XII.

Greeno, J. (1976) Cognitive objectives of instruction: theory of knowledge for solving problems and answering questions, in D. Klahr (ed.) Cognition and Instruction, Hillside, N.J., Lawrence Erlbaum Assoc.

Johnson, P. Feltovich, P., and Swanson, D. (1975) A model of knowledge for understanding selected problems in introductory college physics. Unpublished manuscript, University of Minnesota.

Johnson, P., Feltovich, P., and Swanson, D. (1977) A theory of expertise for problem solving in medical diagnosis, Center for Research in Human Learning, University of Minnesota.

Kleinmuntz, B. (1968) The processing of clinical information by man and machine in B. Kleinmuntz (ed.) Formal Representation in Human Judgment, John Wiley, New York.

Lawrence, J. (1977) The processes of moral judgment making using the DIT. dissertation in preparation, University of Minnesota.

Moller, J. (1973) Essentials of pediatric cardiology, F.A. Davis Company, Philadelphia.

Newell, A., and H.A. Simon (1972) Human Problem Solving, Prentice-Hall, Inc., Englewood Cliffs,NJ.

Pufall, Peter (1973) Developmental relations between egocentrism and coordinate reference systems. Unpublished manuscript.

Resnick, L.B. (1976) Task analysis in instructional design: some cases from mathematics, in D.Klahr (ed.) Cognition and Instruction, New York, Lawrence Erlbaum Assoc. pp. 51-80.

Rubin, A.D. (1975) Hypothesis formation and evaluation in medical diagnosis AI-TR-316. MIT Artificial Intelligence Lab, Cambridge, Mass.

Schadler, M., and J.W. Pellegrino. Maximizing performance in a problem solving task. Unpublished manuscript, University of Pittsburgh, Learning Research and Development Center, 1974.

Simon, H.A. and Chase, W.G. (1973) Skill in chess. American Scientist pp. 394-403 July-August.

Slovic, P. (1969) Analyzing the expert judge. Journal of Applied Psychology, 53, No. 4, 255-263.

Suppes, P. (1966) Mathematical concept formation in children. American Psychologist, 21: 139-50.

Swanson, D., Feltovich, P., and Johnson P. (1977) Are information processing theories relevant to instructional psychology? Paper presented at AERA, New York City, April, 1977.

Wallace, J.G. (1972) The adaptation of instruction to individual differences: an information processing approach. Paper presented at American Psychological Association, Honolulu, Hawaii, September, 1972.

Warner, H.R., Toronto, A.F. and Veasy, L.G., (1964) Experience with Bayes' Theorem for computer diagnosis of congenital heart disease. Anns. N.Y. Acad. Sci. 115, 558-567.