Developing Expertise in the Professions:

Theoretical and Practical Concerns

Peter E. Doolittle

Frank R. Yekovich

The Catholic University of America

Developing Expertise in the Professions:

Theoretical and Practical Concerns

Expertise is the acquisition of a high level of cognitive skill and knowledge involving the development of two separate, yet inter-related cognitive structures. It has been demonstrated that experts possess a large, highly developed schema of domain-specific knowledge as well as the cognitive processes and procedures necessary to use this information effectively and efficiently (Anderson, 1983, Yekovich, 1993). For example, expert surgeons possess not only extensive knowledge of anatomy and physiology, but also comprehensive knowledge of a wide array of surgical procedures. This view of the development of expertise, as the acquisition of domain-specific factual, conceptual and procedural knowledge, raises several theoretical issues. The purpose of this paper is to identify three issues surrounding the development of expertise as described by Anderson (1983, 1990, 1993) and to discuss these issues in light of recent research. The remainder of this paper is divided into 5 sections. In the first section a framework is provided as to what constitutes expertise. In the second and third sections a theory of cognitive skill development (Anderson, 1983, 1990, 1993) and issues arising from this theory are discussed. The fourth section reviews a recent study concerning the development of expertise, while the final section examines how the study addresses the theoretical issues raised in section three.

What is Expertise?

While an exact definition as to what constitutes an expert is unclear, Glaser and Chi (1988) have posited seven general characteristics of expertise that have emerged from the expert-novice paradigm literature. These general attributes include (1) experts perceive large meaningful patterns within a problem space more readily than novices; for instance, when diagnosing a patient the expert surgeon will be able to integrate a greater number of symptoms more readily than a non-expert, (2) experts have superior short and long-term recall based on superior encoding and storage resulting from a more fully developed domain-specific knowledge base, that is, the knowledge of an experienced surgeon is more fully developed and better organized than that of a first year medical student which results in more efficient retrieval of desired information, (3) experts execute the basic skills of a domain more readily than novices, (4) expertise is domain specific, thus expertise in cardiac surgery does not insure expertise in neurology, (5) experts represent problems at a deeper, more principled, level than novices, (6) experts spend more time than novices evaluating the nature of a problem and determining its representation before attempting a solution, and (7) experts have stronger self-monitoring and meta-cognitive skills than novices, consequently, experienced surgeons will be more aware, than novices, when a treatment or diagnosis lies beyond their expertise and they will be better able to generate and evaluate potential alternatives.

These seven performance characteristics are the result of a continuous process of cognitive skill development within a specific domain. Anderson (1983, 1990, 1993) has proposed a theory of cognitive skill development that will be described here in an attempt to clarify the skill acquisition process. In addition, a running example of the development of expertise in surgery will be used to provide a more concrete example.

Briefly, Anderson's (1983, 1990, 1993) theory, previously called ACT*, now ACT-R, has a long term memory component that is comprised of two major types of knowledge, declarative knowledge and procedural knowledge. Declarative knowledge is conceptual and factual knowledge, procedural knowledge is knowledge of how to "do" something. Cognitive skill development first involves the acquisition of declarative knowledge, information about something. This declarative knowledge is initially used with general procedural knowledge to solve domain related problems. With further exposure to information and repeated use of these general procedures, more specific procedures emerge and are used. Eventually the declarative knowledge becomes very large and well organized while the procedural knowledge becomes more specialized and efficient. Let us turn briefly to how these knowledge forms develop.

A Theory of the Acquisition of Cognitive Skill

According to Anderson (1983, 1990, 1993) the acquisition of cognitive skill occurs in three continuous and overlapping stages, the declarative stage, the associative stage, and the autonomous stage.

The declarative stage is characterized by increases in declarative knowledge and the use of problem solving solutions based upon general strategies. The new declarative knowledge, facts and concepts about the domain, is stored in a semantic network where the facts form the nodes and the relationships between the nodes is established through their connections. During the declarative stage the amount of knowledge contained in the network is increasing but is not great and the relations formed by the links or connections are not intricate, well organized, or very strong.

For the future surgeon, the first two years of medical school are a case study in the acquisition of declarative knowledge. A course in gross human anatomy or biochemistry is filled with declarative knowledge of "what" and "where" and very little time, if any, is spent developing curative surgical techniques. In addition, due to the vast amounts of information that must be learned and the rate at which it must be learned the relationships or connections developed within this network of declarative knowledge are weak and simple.

Problem solving, in the declarative stage, is essentially the application of domain-general strategies. Since the problem solver has only limited domain-specific declarative knowledge and very few, if any, domain-specific problem solving strategies, the problem solver is left with applying general problem solving methods that have worked in other domains. These general across-domain problem solving methods are termed domain-general strategies or weak methods. The lack of a well developed and organized declarative knowledge network restricts the ability of the problem solver to discern meaningful patterns within the problem and only allows the problem solver to view the problem superficially.

A medical student presented with a patient's medical history and present symptoms is likely to analyze this information piecemeal. The medical student will lack the robust interconnectedness within their declarative network to discern larger more meaningful patterns among this wealth of information. Further, the process of arriving at a diagnosis will tend to be filled with large amounts of trial and error. The student may develop a diagnosis and then test it against the known medical history and current symptoms. If the diagnosis does not sufficiently satisfy the history and symptoms then another diagnosis is generated and the process begins anew. This problem solving strategy is a domain-general strategy and may be summed up, "If at first you don't succeed, try, try, again."

While the declarative stage is characterized by novice behavior, the associative stage begins the process of forming expert-like behavior. The associative stage, the next stage in skill development, involves both the refinement of the declarative knowledge network and the development of domain-specific procedural knowledge.

During the associative stage the addition of declarative knowledge to the network becomes easier due to the ability to relate new knowledge to knowledge already in the network. Also, as knowledge is repeatedly experienced, the links that connect concurrently experienced knowledge become stronger. This strengthening of connections between co-occurring groups of knowledge begins to shape and define the underlying structure of the domain network. These groupings of related knowledge will vary in size from smaller groups to larger groups. The organization of these groups will eventually produce an intricately organized representation of the learner's knowledge about the domain.

The development of declarative knowledge during the associative stage also facilitates the formation of domain-specific procedural knowledge. Procedural knowledge, the knowledge of how to "do" something, is composed of rules or productions in the form of IF <condition> THEN <action> statements. For example, consider the following production:

IF the goal is to review a patient's medical history
and the patient's medical file is not present
THEN set as a subgoal to find the patient's medical file
and then read the medical history forms

If the <condition> within the production is fully satisfied then the <action> will be executed. The relationship between declarative and procedural knowledge is that each <condition> and each <action> is composed of a declarative knowledge structure. Thus domain-specific procedural knowledge requires the use of domain-specific declarative knowledge.

Procedural knowledge is organized using a goal-subgoal structure, resulting in a production set or system. Productions are related, via their own goals and subgoals, in such a way as to accomplish a domain-specific processing goal. As the result of repeated exposures to domain-specific knowledge and their corresponding actions or mental processes domain-specific productions and production sets are developed. A fully developed production set provides a powerful and specialized mechanism for producing both cognitive and overt behavior within a domain.

Continuing our example, the student surgeon, now an intern working in a hospital, continues to develop their declarative knowledge network, both its knowledge content and its underlying structure. As the intern becomes exposed to more and more patients their knowledge of the interrelatedness among symptoms and conditions continues to develop. At the same time the student is developing procedures and productions to accomplish domain-specific goals. These goals or tasks may be as mundane as donning surgical garb or taking a medical history, or it may be a more complicated task such as performing a neurological examination or interpreting the results of an electrocardiogram (EKG). This declarative and procedural knowledge development will continue into the surgeon's residency, and beyond.

The development of fully functional production sets requires extensive practice and experience. Thus procedural knowledge is developed slowly and carefully. Within the associative stage one's performance matures from being very novice-like to being more like an exert. However, it would be presumptuous to state that one in the associative stage is an expert (Yekovich, Thompson, & Walker, 1991). Their declarative knowledge network is still not fully developed and their production sets still require a significant amount of cognitive and attentional resources.

The final stage, the autonomous stage, describes a continuous progression of improving the content and structure of the declarative knowledge network, as well as increasing the efficiency of the procedural knowledge productions. This final stage may sometimes involve a restructuring of declarative or procedural knowledge, but more likely it involves a continuous refinement.

The refinement of the declarative knowledge network involves increasing the intricacies of the interconnections. This increased interconnectedness allows for greater recognition of patterns within a problem space. The further development of declarative knowledge allows the learner to know more about the domain and to understand how all the aspects within a domain are related.

The refinement of procedural knowledge involves two processes. First, productions are "fine tuned" with regards to generalization and discrimination. Each production or production set is made more specific to the task it is designed to accomplish. This task specificity may involve allowing the production or production set to generalize to more stimulus conditions or it may involve a higher degree of discrimination among closely related stimuli.

Second, productions are made more efficient by automating their execution. Originally, productions are algorithmically based; they are performed by executing a series of instructions. This algorithmic execution is very cognitive resource intensive. During the autonomous stage these algorithms are automated such that little or no attentional and cognitive resources are needed. This gradual improvement in both declarative and procedural knowledge may continue almost indefinitely.

The surgeon, having completed residency and now working in a surgical group, continues to refine those production sets that were first developed in residency. The surgeon continues to learn the subtleties of surgery and is in the process of automating many previously learned productions. The developing expert surgeon has developed a more complete understanding of the body's systems and how they interrelate, as well as the surgical techniques necessary for successful surgery. However, this surgeon will need continued experience in both performing and observing surgery in order to develop a more mature level of expertise.

Issues Concerning the Acquisition of Cognitive Skill

This model of the acquisition of cognitive skill raises several fundamental questions. Here, we want to deal with three prominent ones. Firstly, "How does one define a 'domain?'" Secondly, "What types of problems typically occur within a domain?" And, thirdly, "How do individual differences impact upon the development of expertise?"

The first issue involves defining a domain. A domain of knowledge may loosely be defined as all the knowledge, both declarative and procedural, related to a particular topic. For some topics this may seem rather straight forward, for example, skeletal anatomy. The domain of "skeletal anatomy" may be fairly well mapped out and may include bone development and bone histology, as well as the identification of fossa, foramen, and bony protuberances. The domain of skeletal anatomy is fairly discrete or finite. These discrete or finite domains are generally referred to as well-structured. Not all domains, however, are well-structured.

Ill-structured domains, such as administration, teaching, or medicine, are less finite in their scope. The tasks involved in each of these are less easily enumerated and defined. Thus the boundaries of these domains are vague and fluid. As a result of this lack of precision in defining ill-structured domains less research has been undertaken with regards to the development of expertise within ill-structured domains.

The differences between developing expertise within a well-structured or ill-structured domain may be numerous. For instance, two possibilities may be, first, that the actual course of the development of expertise may be different. That is, one may develop expertise faster or slower within one domain versus another. A second possibility may be that regardless of the development process, the characteristics of the declarative and procedural knowledge of experts may be qualitatively different in well-structured versus ill-structured domains. For example, well-structured domains may produce more discrete, automated production sets than ill-structured domains, and ill-structured domains may produce more domain-specific heuristic strategies (i.e. - rules of thumb) than well-structure domains.

The second issue is related to the kinds of problems that typically occur within a specific domain. Some problems may be well-structured while others may not. In pharmacology, for example, a well-structured problem might be determining the correct dosage of a specific drug for a child or infant where only one correct answer exists. In contrast, computational neurobiologists, working at the outer edges of the domain, may spend a majority of their time and effort trying to solve ill-structured problems; that is, problems for which there is no single or necessarily correct solution. Again, most research involving expertise has involved well-structured problems within a well-structure domain. However, a question yet to be answered is how does expertise develop for ill-structured problems in an ill-structured domain?

A final issue concerns individual differences and the impact of those differences on the development of expertise. It could be assumed that all experts in a particular domain are alike. Indeed, the knowledge and performance characteristics of experts are highly homogeneous when confronted with well-structured problems in a well-structured domain. However, are the computational neurobiologists, working on ill-structured problems in ill-structured domains, all the same? Are individual differences in expertise the result of the expertise developmental process or do the individual differences cause differing developmental paths?

These are but a few of the issues that need to be addressed in order to better understand the development of expertise. In the next two sections, research conducted at Catholic University (Yekovich, Thompson, & Walker, 1991) is discussed in light of these three issues.

A Study of Expertise

In 1991, my colleagues and I conducted a study designed to investigate expertise (Yekovich, Thompson, & Walker, 1991). We were interested in comparing the knowledge states of experts and non-experts and in understanding how individuals who have been trained to perform certain tasks, yet lack the experience to be experts (Trained, Not Experts, TNEs), differ from true experts. In the study, both the experts and the TNEs recently completed 3 two-week training sessions on the topic of credit administration at a national bank management school. The difference between the groups was that the experts had been credit administrators in banks for an average of 9 years.

Theoretically, the TNEs, who have fairly extensive knowledge about their domain, but little experience, should fall somewhere in the associative stage. The TNEs should have a fairly large declarative knowledge network but only limited interconnections due to a lack of experience. This lack of experience would also lead to incomplete domain-specific procedural knowledge (productions). The productions may be lacking in coherent goal-subgoal structures resulting in incomplete or faulty production sets.

Subjects, both experts and TNEs, were asked to read a case study about a rapidly growing bank and then retell the case study indicating any concerns or insights regarding the health of the bank. In actuality, the bank was headed for trouble due to a number of problems, many of which were in the credit administration function. Following this retelling the subjects then read 24 statements and indicated whether each statement was true based on the case study and whether the statement actually occurred in the case study or if it was only implied by the case. Finally, each subject read 14 statements from the case study and was asked to indicate whether the statement represented a problem within the bank. For each affirmative response the subject was asked to elaborate on their reasoning.

The results indicated that the two groups, experts and TNEs, were very similar with regards to the content of their declarative knowledge network. The retelling task demonstrated that the TNEs were able to recall the same amount of explicit content from the case study as the experts. The recognition task, indicating whether each statement was true or false, also showed no difference. And finally, the problem indicator task showed that both groups were equally adept at identifying the more obvious and blatant problems.

While the content of the declarative knowledge network seemed very similar there was evidence that the knowledge within the network was constructed or structured differently. When performing the retelling task (free recall) it was noticed that each group tended to recall information that was consistent with their current work assignments. TNEs recalled more lending facts while the experts were more balanced in recalling both lending facts and management facts. The biased recall protocol of the TNEs and the relatively unbiased recall protocol of the experts may indicate a biased representation within the declarative knowledge network for the TNEs (see also Anderson & Pichert, 1978; Pichert & Anderson, 1977). This result suggests that the organization within the declarative knowledge network changes as one moves from a TNE to an expert.

In addition to the structural differences within the declarative knowledge network, the two groups appeared to differ significantly with regards to the development of domain-specific procedural knowledge (productions and production sets), as evidenced by large differences in their ability to make inferences. Inferencing is the process of integrating and synthesizing various facts, and it involves the use of both declarative and procedural knowledge.

In the retelling or recall task experts generated not only more inferences but more complex inferences. This may have been the result of the experts being more adept at identifying relevant and irrelevant information, being better able to establish relations between multiple facts, or having access to some inferences automatically. In addition, the recognition task showed that experts were better able to identify inferences as true statements within the case. In both instances, TNEs apparently lacked a robustly interconnected declarative network as compared to the experts.

Finally, the problem indicator task not only demonstrated that both groups could identify problem statements equally well, but also that the experts were significantly better at justifying their choices as to why certain statements represented potential problems. The TNEs lack of justification may be the result of a lack of domain-specific productions designed to recognize patterns of related facts as potential problems. This lack of pattern recognition could also be an indicator of a not yet fully developed and integrated declarative knowledge network.

Issues and Answers

How does the preceding research help address the three issues mentioned earlier? How do the expert/TNE results clarify the question as to what constitutes a domain? What types of problems confronted the experts and TNEs and did they responded similarly? How was the issue of individual differences addressed and what was its impact?

Most current research into problem solving involves well-structured domains and well-structured problems. The credit administration research is an example of ill-structured problems being solved in an ill-structured domain (see also Leithwood & Steinbach, 1993; Wagner, 1991, 1993). Each day doctors, lawyers, administrators, and executives spend a significant amount of their time in ill-structured domains. They are asked to analyze and evaluate situations in which there is no one correct solution. Research into ill-structured domains, such as the credit administration research, is needed in order to gain a better perspective as to how skill and expertise are developed.

For each of these professionals, doctors, lawyers, administrators, and executives, the types of problems that are typically encountered are often long term, ill-structured problems. Problems whose solution is not contingent upon a single decision, due to the dynamics of the problem continually changing with time. The credit administration case study was a snap-shot of one such problem. The bank did not develop its present state of crisis overnight. The situation at the bank developed over time and while the experts were more able to recognize meaningful patterns out of the complexity of information provided, and were able to generate more complex inferences, the solution to the problem would not be simple and would take time, even for the experts. Thus the types of problems encountered in ill-structured domains may sometimes require long term solutions developed in a changing environment.

The impact of individual differences on the development of expertise was not formally addressed in the credit administration research. However, future research that may be beneficial to the understanding of expertise, especially in ill-defined domains, may include the effects of general intelligence on the development of expertise, the effects of interpersonal style on the development of expertise, or how changes within the problem space effect the course of decision making. This type of research, individual differences, is but one area of the development of expertise that needs further investigation.

What does all this mean for educational instruction within the professions? Firstly, if the development of expertise is a primary goal of education within a profession, then it seems clear that this education must include substantial amounts of "real-life" and "hands-on" experiences. According to Anderson's (1983, 1990, 1993) ACT-R theory, expertise is dependent on not only the acquisition of declarative knowledge, but also the development of procedural knowledge. Thus education and training within a profession must include the opportunity for the student/employee to experience the types of problems and situations in which they are to be expert, in order for them to develop and automate relevant domain-specific procedures.

Secondly, with the increasing complexity in which the professions ply their trade, it is becoming apparent that professionals are being confronted more and more with ill-structured problems. If future employees and executives are to be successfully trained on how to be experts then there needs to be renewed interest in research that addresses the ideas of ill-structured domains and ill-structured problems.

References

Anderson, J.R. (1983). *The architecture of cognition*. Cambridge, MA: Harvard University Press.

Anderson, J.R. (1990). *The adaptive character of thought*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Anderson, J.R. (1993). *Rules of the mind*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Anderson, R.C., & Pichert, J.W. (1978). Recall of previous unrecallable information following a shift in perspective. *Journal of Verbal Learning and Verbal Behavior*, 17, 1-12.

Glaser, R., & Chi, M.T.H. (1988). Overview. In M.T.H. Chi, R. Glaser, and M.J. Farr (Eds.), *The nature of expertise* (pp.xv-xxviii). Hillsdale, NJ: Lawrence Erlbaum Associates.

Leithwood, K., & Steinbach, R. (1993). Processes used by school administrators to solve school improvement problems: Differences that matter. In P. Hallinger, K. Leithwood, and J. Murphy (Eds.) *A cognitive perspective on educational administration*. New York, NY: Teachers College Press.

Pichert, J.W., & Anderson, R.C. (1977). Taking different perspective on a story. *Journal of Educational Psychology*, 69, 309-315.

Wagner, R.K. (1991). Managerial problem solving. In R.J. Sternberg and P.A. Frensch (Eds.), *Complex problem solving:*

Principles and mechanism. Hillsdale, NJ: Lawrence Erlbaum Associates.

Wagner, R.K. (1993). Administrative expertise as practical problem solving. In P. Hallinger, K. Leithwood, and J. Murphy (Eds.) *A cognitive perspective on educational administration*. New York, NY: Teachers College Press.

Yekovich, F.R. (1993). A theoretical view of the development of expertise in credit administration. In P. Hallinger, K. Leithwood, and J. Murphy (Eds.) *A cognitive perspective on educational administration*. New York, NY: Teachers College Press.

Yekovich, F.R., Thompson, M.A., & Walker, C.H. (1991) Generation and verification of inferences by experts and trained nonexperts. *American Educational Research Journal*, 28, 189-209.