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ABSTRACT

A two-part study examined the relationship between technical troubleshooting behavior and the level of expertise of service technicians who diagnose faulty equipment. The first investigation addressed the differences in the knowledge base that troubleshooters bring to a problem. A group of five novice troubleshooters and five experts was given electric generator sets to repair. The results showed that experts have a much greater depth of understanding of the basic principles and concepts that underlie the operation of generator sets. Experts can also comprehend the function and operation of the generator system, whereas the novices seem to lack an accurate mental model of the operation of the technical systems they repair daily. The second investigation attempted to identify differences in the actual troubleshooting performance of the expert and novice service technicians. In this test, the subjects were instructed to "think aloud" as they worked through a problem with either a faulty fuel pump or an open wire. The primary difference between the troubleshooting performance of the experts and the novices was that the experts were able to select better information and generate better hypotheses, probably because they have more knowledge and their knowledge is organized more effectively. The results of this study can be used to design training programs to reduce the differences between expert and novice technical troubleshooters. (KC)

Knowledge and Skill Differences Between Expert and Novice Service Technicians on Technical Troubleshooting Tasks

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The diagnosis of malfunctioning equipment and machinery is an important facet in our industrial economy. This nation's quality of life is dependent upon the ability of our workforce to identify and solve technical problems. The service sector of the nation's economy which has been steadily growing provides one example of the need for problem solving abilities in the workforce. As technology has advanced so has the complexity of most equipment. As a result, it is becoming increasingly difficult for people to know all there is to know about repairing equipment and machinery. The knowledge and cognitive process skills that are needed for troubleshooting and repair are becoming increasingly valuable. The problem, however, lies in our lack of understanding of the knowledge and skills that are required to perform the complex task of troubleshooting faulty equipment.

The major focus of this study was to examine the relationship between technical troubleshooting behavior and the level of expertise of service technicians who diagnose faulty equipment. This investigation provided insight into the nature of expertise through a comparison of the cognitive and performance activities of expert and novice troubleshooters as they attempt to locate faults in technical systems. This study was divided into two investigations. The first investigation addressed the differences in the knowledge base that troubleshooters bring to a problem. The second investigation examined performance differences between expert and novice troubleshooters.

Literature Review

Cognitive Task Analysis

Once a greater understanding of the knowledge, skills, and cognitive process differences that are required to solve complex, technical problems is obtained, effective training programs can be developed. Currently, most training programs are developed based on incomplete task analysis models.

This research study was based on a cognitive task analysis and results in a deeper and more complete understanding of both directly observable and indirectly observable behaviors. Gott (1986) described three arguments for the use of cognitive task analysis over either behavioral or rational methods. First, cognitive task analysis can capture more of the substructure of complex technical skills. Secondly, cognitive task analysis can provide an "ideal" model to guide the development of technical instruction. Thirdly, the use of cognitive task analysis concerns the adaptiveness of instruction to the needs of the learner.

Knowledge Organization

Current theory suggests that an expert's knowledge is organized much differently than that of a novice. Verbal protocols of experts and novices who were solving elementary physics problems showed that both groups have rich knowledge bases related to physical configurations and properties although the experts have additional knowledge related to the problem solution based on major laws and principles (Chi, Glaser, & Rees, 1982). Egan and Schwartz (1979) conducted a similar study of expert and novice knowledge structures and their influence on the subject's ability to recall symbolic drawings. Their study suggests that the memory of expert electronic technicians was structured based on "conceptual" chunks. Therefore, experts were able to recall portions of the drawings as chunks of information (i.e., amplifier circuit, tuner circuit, etc.) rather than as individual components.

Cognitive structures have also been looked at as forms of schemata or mental models. Schema theories suggest that the knowledge structure or schema of the individual may be used to help people recall information by allowing them to mentally trace through the cognitive structure (Anderson, Spiro, & Anderson, 1978). Other studies have looked at mental models as organizing factors for knowledge.

Investigation 1

Common sense tells us that expert troubleshooters certainly know more about the equipment they work on than novices. Because experts are able to bring more knowledge to their troubleshooting situations, they are able to work more efficiently and effectively. The purpose of this first investigation was to specifically identify the knowledge differences between expert and novice technical troubleshooters.

Subjects. The subjects selected for this investigation were classified as either expert or novice based on their amount of relevant education, years of experience on the job, and supervisor ratings. Five novice subjects were selected from a group of service technicians that were enrolled in the Small Products Training courses delivered by the Onan Service Training School in the winter of 1987. The novice subjects were service technicians who diagnose and repair faulty generator sets as a major portion of their work. These technicians had several years of experience with mechanical and electrical equipment although they only averaged 1/2 year of experience repairing generators.

The expert group consisted of five factory service representatives who were involved with the manufacturing and repair of generators at the factory level. These expert technicians averaged over ten years of experience with electrical, mechanical, and generator systems.

Apparatus. The equipment used for this investigation was electric generator sets. A generator set is a technical piece of equipment that requires service technicians to have very specialized knowledge and skills in the electrical, mechanical, and magnetic domains.

Procedure. The purpose of the investigation was to identify the knowledge differences that expert and novice technical troubleshooters bring to a problem situation. Two measures were developed to identify these differences. Each of these measures was developed with the assistance of subject matter experts and were pilot tested to achieve satisfactory levels of reliability and validity. The first measure, the Basic Principles Exam, was used to quantify the subject's knowledge of the basic principles that underlie the operation of a generator set. This involved asking the subjects questions about the basic electrical, mechanical, and magnetic principles and concepts that relate to the operation of generators. A second measure was used to quantify the subject's understanding of generator systems. The subjects were asked to identify system parts, describe their operation and function, and describe the relation of each part to the system as a whole.

Several measures were used to identify differences in the ability of the service technicians to perform the basic operations that are commonly performed by service technicians. These involved measuring each subject's ability to make technical tests, use technical manuals, read schematic and wiring diagrams, and use mathematical formulas.

Results

The data collected in this investigation show clear differences in the amount of knowledge the expert and novice troubleshooters bring to a problem situation. Basically, the results show that the experts knew more about the mechanical, magnetic, and electrical principles and theories that underlie the operation of generators than the novices. Based on the results of the 50 item Basic Principles Exam, significant differences between the expert and novice groups were found for the mechanical, magnetic, and electrical domains of knowledge.

It was also found that the experts had a much greater and more detailed understanding of generator systems. On the 20 item System Understanding Exam the experts answered significantly more questions correctly than the novices. In addition to the System Understanding Exam, an interview was conducted with each of the subjects. This interview involved asking each subject to identify system parts, to explain their operation and function, and to describe the part's relation to the entire system. While both groups were able to identify most of the generator parts and were able to provide a description of the function and operation of the parts, the novice descriptions were not as specific and detailed as were the expert descriptions. The novices were able to talk about how switches and starters work in general while the experts talked specifically about the particular switch or starter on a particular type of generator. Differences in the depth of system understanding were also shown by the data. When asked to describe the operation of the generator as a whole system, the novices provided scanty accounts from rote memory about the generation of electricity in a generator. In contrast, the experts delivered lengthy and detailed accounts about how generators produce electricity. Several of the experts went beyond the requested information and described how design modifications in the various parts and assemblies have affected the operation and efficiency of the generator.

In addition to identifying differences in the system knowledge of the experts and novices, this investigation also sought to identify differences in the procedural skills that troubleshooters bring to a problem. These skills include the ability to obtain information from technical documents, to perform mathematical calculations, and to trace current flow on schematic drawings.

No difference was found in the ability of the two groups to obtain information from technical documents. When asked to obtain various pieces of information from service and parts manuals, both groups obtained the requested information with similar success.

Significant differences were found in the ability to solve technical problems using mathematical formulas. Each subject was given ten generator related word problems to solve. The experts were able to solve 96% of the problems while the novices were only able to solve 34% of the problems. Even after the novices were given the appropriate formulas to use they were only able to solve 62% of the problems.

Technical troubleshooters often need to trace current flow on schematic drawings as they attempt to find problem faults within a technical system. In order to accurately trace current flow on schematic diagrams, subjects must understand the function and operation of the individual parts within the system and their relation to the system as a whole. They must also be able to differentiate between the various types of circuits on the schematic drawing itself. To measure for this ability, each subject was given a schematic drawing for a generator set and was asked to separately trace the circuits that carry battery current, ground, and alternating current while the unit is running. Of the lines that were drawn, the experts were significantly more likely to have drawn them in the correct places. This fact held true for all three types of current carrying circuits.

<u>Summary</u>

The results from this investigation show the differences in the knowledge and procedural skills that expert and novice technical troubleshooters bring to a problem situation. Experts have a much greater depth of understanding of the basic principles and concepts that underlie the operation of generator sets. Experts can also comprehend the function and operation of the generator system. Based on the system understanding and the schematic tracing task data, the novices seem to lack an accurate "mental model" of the operation of the technical systems they repair daily. It appears that a key to the development of technical troubleshooting expertise is in the troubleshooter's depth of system understanding. To further investigate the nature of technical troubleshooting expertise, Investigation 2 was conducted.

Investigation 2

The purpose of this second investigation was to identify differences in the actual troubleshooting performance of the expert and novice service technicians. For this study, troubleshooting performance was defined as the ability to effectively acquire and interpret information and to generate, evaluate, and accept appropriate hypotheses. This involved investigating both directly observable performance and indirectly observable performance.

<u>Technical Preparation</u>

In order to provide a thorough study of troubleshooting behavior, the Problem Solving Behavior Research Model was used to structure these investigations (Johnson, in press). This research model requires that three components be thoroughly examined; the problem, the problem solver, and the problem solving process. An understanding of each of these components is necessary in order to achieve an accurate description of problem solving behavior.

<u>The problem</u>. A cognitive task analysis approach was used to identify potential faults that could be installed into the generator sets. After a careful review of the various types of potential faults, two problems were selected that occur infrequently and are hard to diagnose. These problems were selected because their unfamiliarity and difficulty require the troubleshooters to invoke cognitive processes that access a deeper level of knowledge than with problems that occur frequently or are easy to diagnose. The two selected problems would be caused by either a faulty fuel pump or an open wire between a printed circuit board and the starter solenoid.

<u>The problem solver</u>. As described in the literature review, the knowledge base of the expert is organized much differently than the novice. Newell and Simon (1972) recognized that a major limitation in the problem solving ability

of individuals was their limited memory capacity that affected the quantity of data they could effectively manage during problem solving. The novice is aware of all the facts and procedures that are required to solve a problem and, because of their limited short term memory capacity, is only able to focus on specific, individual components of the problem. In contrast, the expert, through chunking of information, is able to free up the short term memory and thereby operate more efficiently and effectively.

The organization of expert knowledge is an important factor in the problem solving performance of troubleshooters. Current theory suggests that human memory consists of two parts; (a) knowledge bits, and (b) the organization of those knowledge bits (West, Fensham, & Garrard, 1985). To better understand the cognitive structure of the troubleshooting subjects in this study, a cognitive map was developed through the cognitive task analysis. The cognitive map represents the expert's knowledge of the generator system and shows the physical and conceptual components within a generator as well as the relationships between the components. This cognitive map was used to aid in the analysis of the troubleshooter's behaviors as they worked to identify the generator faults.

__The problem solving process__. In many types of problem solving the final solution is apparent and specific which results in the problem solver using one of several common problem solving methods. However, in problems such as troubleshooting where the final solution is not apparent or specific, the problem solver is more likely to use a hypothesis testing method (Sweller & Levine, 1982). Other research on troubleshooting technical systems support this thought (Bouwman, 1983; Elstein, Shulman, & Sprafka, 1978). Through a synthesis of these and other studies found in the problem solving literature, a Technical Troubleshooting Model was developed (Johnson, 1987). As shown in Figure 1, this model describes the troubleshooting process from the acquisition of the initial symptoms through the generation and evaluation of potential hypotheses to the identification of the fault.

__Method__

Verbal protocols were used to analyze technical troubleshooting performance. Subjects were instructed to "think aloud" as they worked through a problem. These verbalizations were recorded using an audio cassette recorder and were later transcribed for analysis. Prior to the actual collection of the protocols, each subject was given several practice exercises to help them become comfortable with the thinking aloud process (Ericsson & Simon, 1984). Following the practice exercises, each subject was individually presented with two generator sets that had either a faulty fuel pump or an open wire installed. The subjects had available to them all the necessary equipment and materials needed to solve the problem including schematic and wiring diagrams, test equipment, and technical manuals.

__Results__

The investigation of technical troubleshooting performance involved the collection of both directly observable performance data and indirectly observable performance data. The directly observable data included the variables of success rates, time to solution, and procedural skill performance. All of the experts were able to find the faults in both generator sets. The novices were not as successful in finding faults. Only three of the five novices were able to find the fault in the fuel pump problem while only two

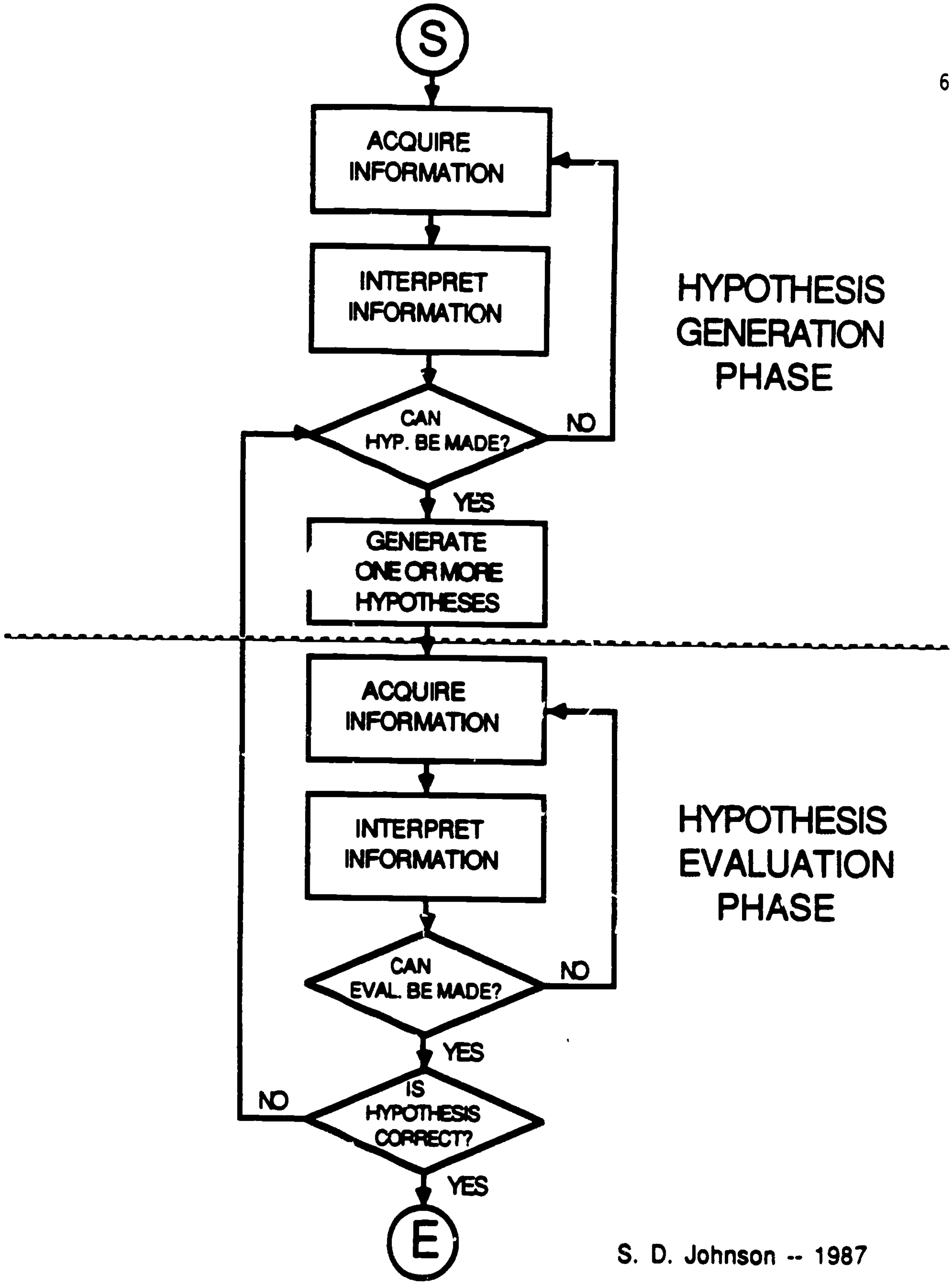

Figure 1. Technical troubleshooting model.

were able to find the open wire. The novices were allowed to continue searching for the fault until they felt it was useless to continue or until a 45 minute time limit had been reached. In only one of the five unsuccessful attempts was the time limit reached.

The time to solution data shows that the problem type is an important factor in the performance of technical troubleshooters. On the fuel pump problem, which was mechanically based, the novices who solved the problem were able to complete the task faster than the experts. However, on the wire problem, which was electrically oriented, the experts were able to solve the problem almost five times faster than the novices. The amount of novice knowledge and experience in the mechanical domain seemed to be an important factor in the successful completion of the faulty fuel pump troubleshooting task.

The procedural skill variable concerned the ability of the subjects to accurately perform various procedural measures. These measures included both mechanical and electrical procedural tests. It was found that the experts were more likely to rely on test procedures than the novice. However, there appeared to be no difference in the ability of the subjects to accurately perform the procedural tests they selected.

A summary of the quantitative analysis of the protocol data highlights the differences between expert and novice troubleshooting performance. Basically, the experts were very purposeful in their troubleshooting behavior. They knew what specific types of information was needed for them to find the fault and they were most likely to obtain their information through some form of technical test. Virtually all of the information the experts obtained was relevant to the problem. From this information, the experts were able to generate logical and relevant hypotheses which could be checked through additional technical tests.

In contrast, the novices appeared to exhibit somewhat of a trial and error approach to troubleshooting. They typically sought general types of information primarily through sensory checks (i.e., sight, sound, smell, touch). Seldom did the information they obtained serve to reduce the size of the problem and therefore, did not help them generate potentially accurate hypotheses.

The above quantitative analysis of the cognitive processes of the experts and novices clearly shows definite differences between the groups. Beyond the quantitative description of these processes, it is valuable to analyze the troubleshooting protocols qualitatively. A clearer understanding of the troubleshooting activities of the experts and novices was gained through a qualitative analysis of the subject's initial problem formulation, the development of the problem space representation, and an examination of the subject's sequence through the problem space.

Problem formulation. One of the first steps in the problem solving process is the initial problem formulation. Following the identification of the initial problem symptoms, the troubleshooter can determine what additional information is needed and what the potential fault might be. In this technical troubleshooting study, the subjects varied in the amount of information they were able to gather regarding the initial conditions of the problem. The protocol data suggest that the expert troubleshooters were able to gain much more information from the initial problem symptoms than were the novices. For example, following an initial attempt to start the faulty generator, Expert 1 states:

"I can feel the fuel pump pumping so I know that I do have voltage to my fuel pump. Therefore, that means my circuit board is good, am applying voltage, at this time I know that the fuse is good, and it gives me a pretty good indication that I do have battery power. At this time I don't know if its enough because of the fact that the fuel pump draws less current than the starter does."

From the initial symptom of the fuel pump clicking on the wire problem, this expert was able to determine that there was battery power going to the printed circuit board and the fuel pump and that the fuse and battery were likely in working condition. Contrast the above protocol with that of Novice 1:

"We'll push the start button. Ah. I get nothing. Um. I'm just gonna kind of look around, take a look at it for a minute."

The other novices also did not verbalize any of the initial conditions. As shown in the protocols, they attempted to start the unit, discovered it would not start, and then began checking various parts of the generator for problems. This lack of a clear problem representation seemed to prevent the novices from selecting an appropriate plan for troubleshooting.

Problem space representation. Following the acquisition of the initial problem conditions, problem solvers must develop a problem space (Newell & Simon, 1972). In a troubleshooting task, troubleshooters use the problem space to help guide them in the selection of hypotheses that will lead to the identification of the fault in the system. In order to graphically represent the subject's selection of relevant hypotheses, problem space maps were developed. The scatter graph in Figure 2 shows the hypotheses that were generated by both groups on the wire problem. The lightly shaded areas of the map represent the actual problem space for this problem based on the initial symptoms of the generator. It is within this shaded area that the potential faults could occur. Each circle or square represents one hypothesis that was generated and evaluated by a subject and the placement on the problem space map provides a clue as to the nature of the hypothesis. Judging by the appearance of the problem behavior map, all the experts were able to represent the problem space accurately based on the initial problem symptoms. Of all the troubleshooting checks made by the experts, the majority of them were located with the problem space (shaded areas). It can also be seen that the novices generated numerous hypotheses that were outside the true problem space. The lack of an accurate problem space representation forced the novices to use the more random trial and error approach rather than the purposive approach used by the experts.

Problem solution sequence. Clear differences in the subject's sequence through the problem space can also be shown through graphic representations. Figure 3 depicts the sequence of hypothesis selection on the problem behavior map of Expert 1 on the wire problem. After determining the initial symptoms of the problem, Expert 1 used the acquired information to direct him to the sub-system that most likely contained the fault. Expert 1 then proceeded in a logical and efficient sequence which reduced the size of the problem space until the problem was reduced to only one possible fault.

The novices proceeded through the problem space in a completely different manner. As shown in Figure 4, which is the sequence through the problem space by Novice 1 on the wire problem, a seemingly random pattern appears. The

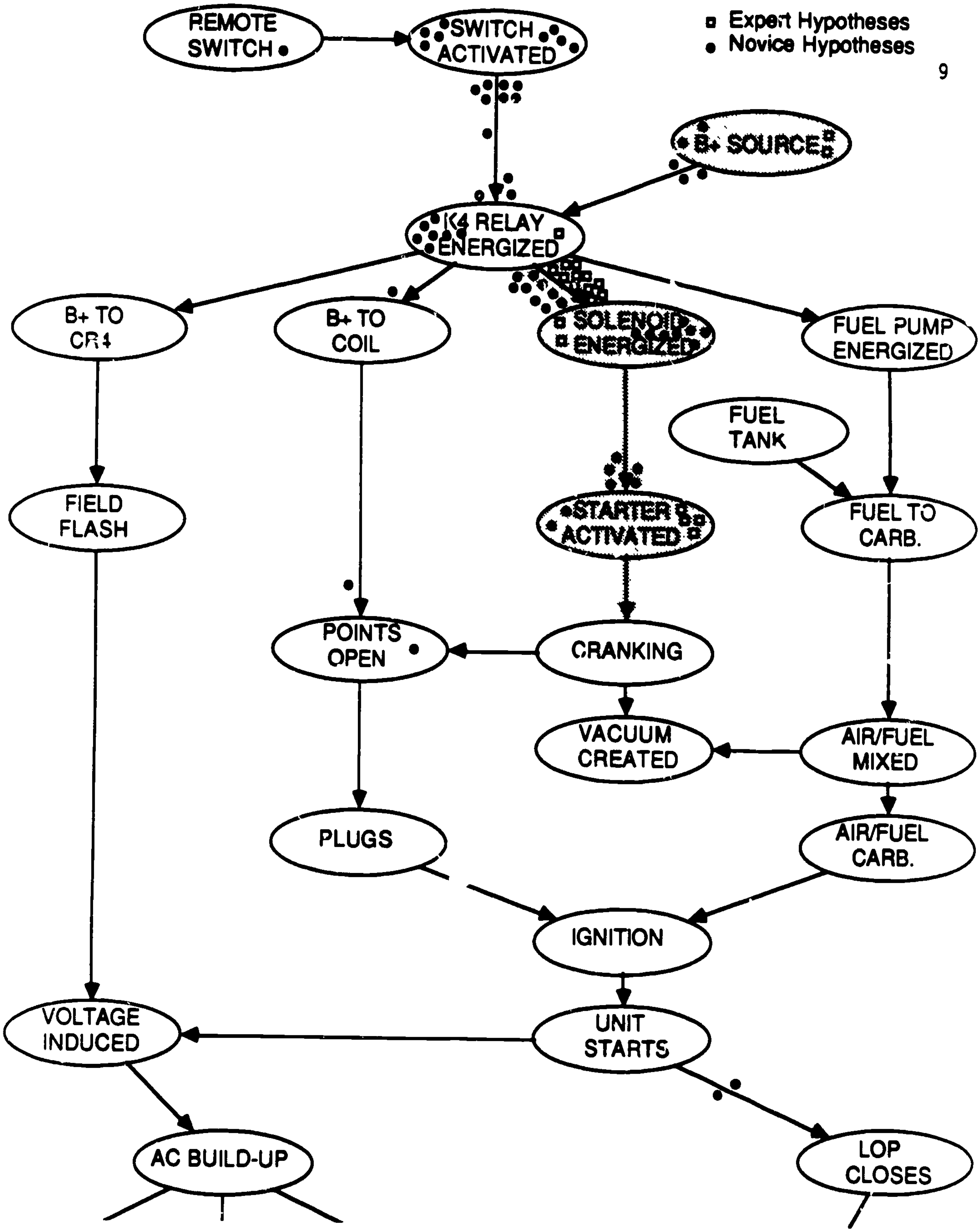

Figure 2. Group problem space map for wire problem.

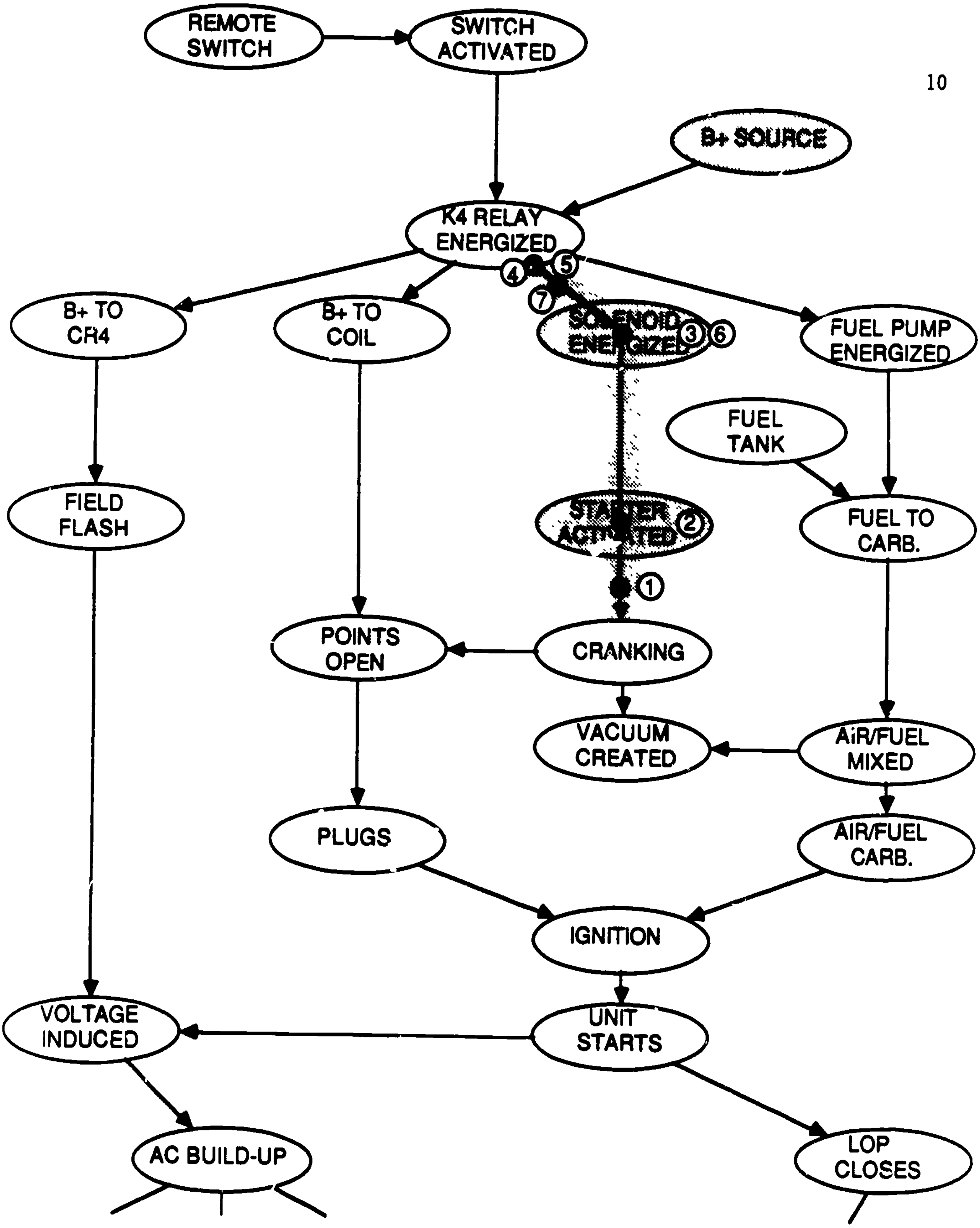

Figure 3. Expert 1 problem behavior map on wire problem.

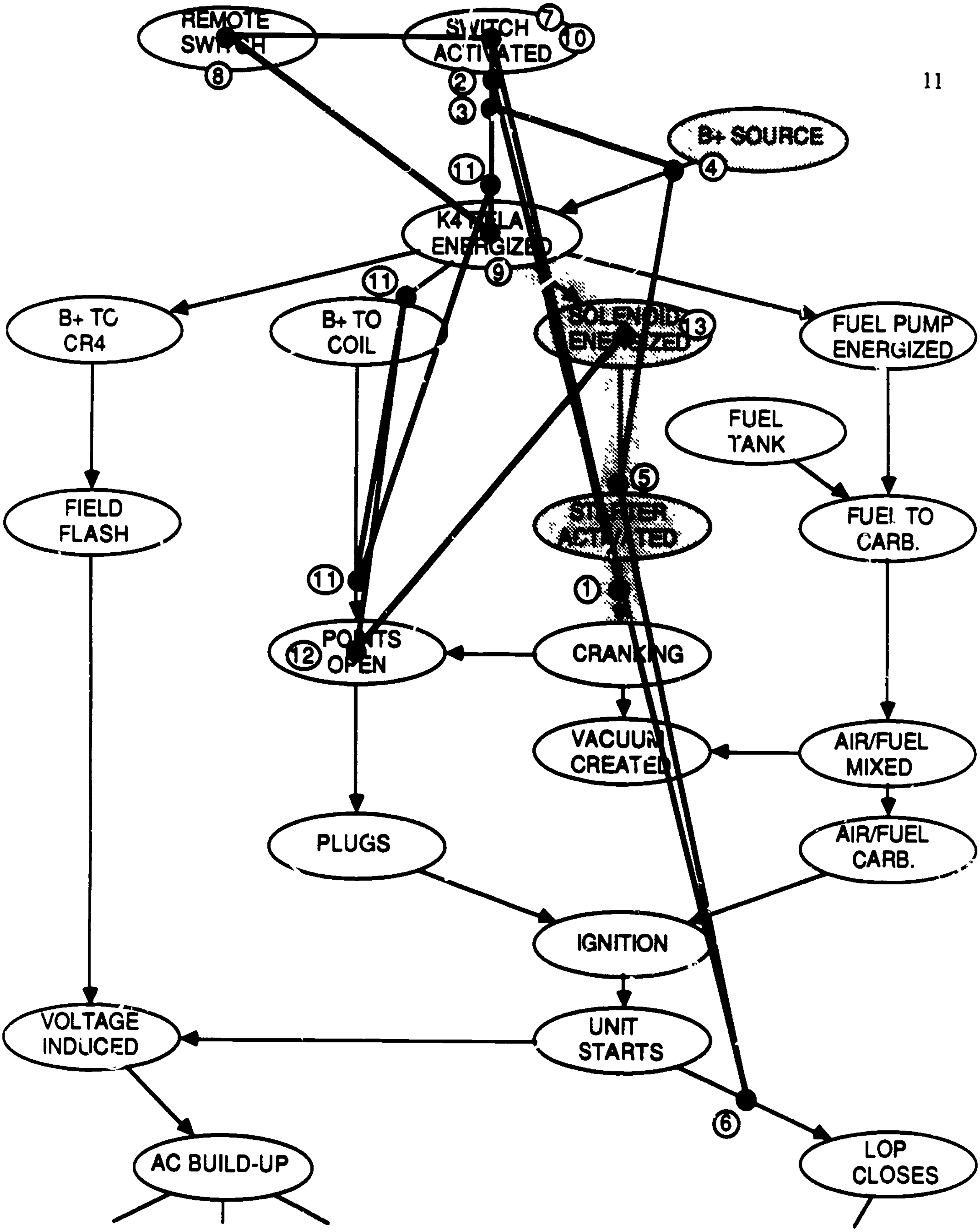

Figure 4. Novice 1 problem behavior map on wire problem.

novice gathered an enormous amount of information which was typically irrelevant to the problem. Because of the irrelevancy of the information that was gathered, the novice was unable to use it to reduce the size of the problem space and therefore could not focus in on the fault. All of the experts exhibited similar efficient and logical behavior while all of the novices appeared to employ the more random approach. For a complete collection of all the subject's sequences through the problem spaces see Johnson (1987).

Summary

The results of this investigation show definite differences between the experts and novices. The primary difference between the troubleshooting performance of experts and novices was that the experts were able to select better information and generate better hypotheses. There appears to be little or no difference in the ability of the troubleshooters to acquire and interpret most types of information, to perform procedural tests, or to generate and evaluate hypotheses. The major difference is in the types of information acquired, the types of procedural tests performed, and the types of hypotheses generated.

While other factors are likely involved, it appears that the two major reasons for the experts' superior skills are because of the amount of knowledge experts have and the organization of that knowledge. Through the organization of their knowledge base, the experts were able to efficiently access their knowledge and match the information cues they observed with those in their knowledge base. This ability to recognize patterns from past experience allowed the experts to quickly make the right decisions regarding the types of information to acquire and the types of hypotheses to generate. The experts were able to acquire and interpret the initial symptoms of the problem. From this initial information, the experts were able to generate an accurate problem space which was used to guide them in the right direction toward the fault. These experts then generated hypotheses that were logical and relevant to the previously obtained information which they tried to verify with powerful technical evaluations. This process continued until the problem fault was determined.

Contrasting this expert behavior with that of the novice it is clear that the novices did not have the amount of knowledge that the experts had. Also, because of their lack of experience, the novices did not have their knowledge efficiently organized. This lack of organized knowledge prevented the novices from having the patterns that the experts seemed to rely so heavily on. The novices began with the same initial symptoms but were often unable to determine what the important symptoms were and when they were determined the novices could not come any closer to the fault. Hypotheses were generated but they were not necessarily based on previous information. Hypothesis selection did not seem to be closely aligned with any logical or efficient strategy and hypothesis verification was attempted with weak, unreliable, sensory dominated tests.

Discussion

A major goal of technical training is to provide trainees with knowledge and skill and to guide them in the development of expertise. Before we can begin to design effective training programs we need to have a deep understanding of the knowledge and skills that are required to troubleshoot technical systems. This study was an attempt to provide that necessary understanding through the investigation of differences between expert and novice service technicians who troubleshoot technical equipment. From the results of this study it is obvious that there are clear differences between expert and novice technical troubleshooters. We now must use the results of this study to design training programs that will reduce those differences.

This study illuminates three areas that must be emphasized to improve technical instruction. First, for technical instruction to be effective, the content domain must be adequately and completely defined. Questions regarding the domain boundaries, the structure of the domain, and the content within the domain must be answered. This study provided one example of a complete analysis of a technical domain. The cognitive task analysis identified the three sub-domains within the larger domain of generators and the important content within each sub-domain. The cognitive task analysis also provided a broad description of the technical system through the development of a system map. This map graphically represented the mental model that the expert troubleshooters used to identify system function and relationships.

Secondly, technical instruction must include content that is specifically related to the technical system being studied. Trainees must be taught the function and operation of the technical system. They must comprehend the relationships between the individual parts and the total system. Instructors must be aware of the need for trainees to develop an accurate mental model of the system and should explicitly teach an idealized mental model. Instruction must also cover the technical evaluation procedures that are likely to be needed. Trainees must know what procedures are available, when they should be used, how they are done, and what the results mean.

The third area of emphasis for technical instruction is to provide trainees with realistic learning experiences. Trainees should be given systems that do not function properly and have them work through the troubleshooting process to identify system faults. This experience should be formalized in a manner that requires the trainees to record initial symptoms, desired information, potential hypotheses, and useful technical evaluations. By recording these important factors in the technical troubleshooting process, instructors will be able to identify mistakes and omissions in the trainees' problem solving processes. These realistic learning experiences provide trainees with the opportunity to develop and strengthen their understanding of the system by integrating the formal knowledge with the practical experience. It is through practice that the organization of knowledge and the development of patterns occurs. Without practice it is doubtful that the transformation from novice to expert could take place.

Implications for Further Research

Following the completion of this research, three areas of need for further research can be identified. First, further research into expertise is definitely needed. This study showed that troubleshooting performance is related to the amount of knowledge and experience of the troubleshooter. It also appears that troubleshooting expertise is not widely transferable. A troubleshooter who performs as an expert on one type of system will likely perform as a novice on another. Because of this lack of consistency across types of technical systems, we need to research the knowledge and skill requirements for each system for which we will be designing training.

Secondly, further investigation into the structure of the knowledge of expert troubleshooters is needed. Through the cognitive task analysis approach, research into the organization of expert knowledge can be completed. The identification of the patterns and mental models that experts have developed through years of experience can provide us with important insignt as we design learning experiences for trainees.

Thirdly, further investigation into the methods of teaching troubleshooting skills is needed. This study has provided an understanding of troubleshooting expertise that can be used to develop better training programs. Formalized research to identify the various instructional techniques and learning experiences that are most effective for developing troubleshooting skills will greatly improve instructional design in training and development.

References

Anderson, R. C., Spiro, R. J., & Anderson, M. C. (1978). Schemata as scaffolding for the representation of information in connected discourse. American Educational Research Journal, 15(3), 433-440.

Bouwman, M. J. (1983). Human diagnostic reasoning by computer: An illustration from financial analysis. Management Science, 29(6), 653-672.

Chi, M. T. H., GLaser, R., & Rees, E. (1982). Expertise in problem solving. In R. Sternberg (Ed.), Advances in the psychology of human intelligence. Hillsdale, New Jersey: Erlbaum.

Egan, D. E., & Schwartz, B. J. (1979). Chunking in recall of symbolic drawings. Memory and Cognition, 7(2), 149-158.

Elstein, A. S., Shulman, L. S., & Sprafka, S. A. (1978). Medical problem solving: An analysis of clinical reasoning. Cambridge, Massachusetts: Harvard University Press.

Ericsson, K. A., & Simon, H. A. (1984). Protocol analysis. Cambridge, Massachusetts: The MIT Press.

Gott, S. P. (1986, April). Utility of cognitive task analysis for examining complex technical skills. Paper presented at the annual meeting of the American Educational Research Association, San Francisco.

Johnson, S. D. (1987). Knowledge and skill differences between expert and novice service technicians on technical troubleshooting tasks (Doctoral dissertation, University of Minnesota, 1987). Dissertation Abstracts International.

Johnson, S. D. (in press). Problem solving behavior research model for industrial education. Journal of Industrial Teacher Education.

Newell, A., & Simon, H. A. (1972). Human problem solving. Englewood Cliffs, New Jersey: Prentice-Hall, Inc..

Sweller, J., & Levine, M. (1982). Effects of goal specificity on means-ends analysis and learning. Journal of Experimental Psychology: Learning, Memory, and Cognition. 8(5), 463-474.

West, L. H. T., Fensham, P. J., & Garrard, J. E. (1985). Describing the cognitive structures of learners following instruction in chemistry (pp. 29-49). Orlando, Florida: Academic Press.