## Title
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# The Effect of Experience on Across-Domain Transfer of Diagnostic Skill

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## Abstract

Transfer across domains has been generally difficult to find. Recent studies have indicated that abstract skills may transfer if adequate task analyses are used to define the target skill and people receive the proper training in attaining the skill. This study examined transfer of diagnostic skill across domains for experienced subjects (extensive programming experience but no electronics) and inexperienced subjects (no programming or electronics experience) when domain-specific information was provided. Four levels of diagnostic skill were identified. Inexperienced subjects could solve problems but did not display an advanced level of diagnostic skill in either domain. However, all experienced subjects displayed high levels of skill on most problems, both in the domain of expertise and in the domain in which they were inexperienced. Results suggest that a general diagnostic skill can transfer spontaneously across domains with extensive practice in one domain and is not acquired to an advanced level without training.

## Introduction

Transfer occurs when knowledge learned in one situation is used in learning and performing in a second situation. In the study of transfer, many researchers have made a distinction between across-domain transfer and within-domain transfer. For this experiment, a domain was considered an area of study such as medicine, physics, or economics. Tasks were considered to be actions that people could perform such as interpretation, design, or prediction. So, within-domain transfer was defined as performing the same or different tasks in the same domain; whereas, across-domain transfer was defined as performing the same tasks in different domains.

Evidence has accumulated showing that under many conditions, knowledge is specific to the situations in which it is learned (Carraher, Carraher, & Schliemann, 1985; Nesher, 1989; Singley & Anderson, 1989). Indeed, it has been a fundamental assertion about the nature of expert skill that it is domain specific, that is, confined to the domain in which the skill is initially acquired (Chi, Glaser, & Farr, 1988). Moreover, subjects have been found to have difficulty with across-domain transfer, even when only surface features of problems are changed (Chipman, Segal, & Glaser, 1985; Gick & Holyoak, 1980, 1983; Kotovsky, Hayes, & Simon, 1985; Larkin, 1989; Resnick, 1987).

Recent research, however, has been finding ways to elicit transfer across domains. First, finding the particular components of skill that might transfer across domains has been facilitated by applying task analyses to focus on the components of skill before trying to measure their transfer (Singley & Anderson, 1989), and by separating out those components that might be domain specific from those that might potentially be domain general (Larkin & Reif, 1978; Voss, Green, Post, & Penner, 1983). Second, across-domain transfer has been found when extensive and varied training was provided in the target skill. For example, skills such as diagnosis and the application of algebra transferred across domains when subjects were explicitly trained in the skill and trained in a content independent manner (Bassok & Holyoak, 1989; Klahr & Carver, 1988), although these studies have been criticized because the initial training problems and target transfer problems shared the same surface features (Singley & Anderson, 1989). Finally, transfer across domains may be found if we target an abstract or higher order skill. For example, Perfetti has argued that reading should be studied as a skill which can transfer across domains (Perfetti, 1989). Weak methods, skills which can be learned without formal training and are generally applicable to a wide range of problems, have also been shown to transfer across domains (e.g., means-ends analysis, Newell & Simon, 1972). Transfer has also been demonstrated for general skills such as a scientific method (Nisbett, Krantz, Jepson, & Kunda, 1983; Larkin & Reif, 1978; Tweney, 1981).

The goal of this research was to investigate the extent to which some components of a sophisticated diagnostic skill developed in one domain (e.g., program debugging) would transfer and be accessible while learning diagnosis in another domain (e.g., electronic troubleshooting). Clearly, for each domain, there is domain-specific information that would not be expected to transfer. But, will the diagnostic strategy component transfer if the domain specific information is supplied? The idea is that diagnostic skill will transfer across domains either because a person is already an expert in the first domain or because a person has learned the skill in the first domain in a way that liberates the strategy from its content. The experiment reported here tests whether expertise in diagnosis transfers.

## Overview of Experiment

In order to investigate the nature of diagnostic reasoning as a component of expert programming skill, and to investigate its transfer, it was first necessary to identify those aspects of diagnostic reasoning in our two domains that could be considered domain specific and those that could be potentially domain general. The domain-specific knowledge consisted of facts, tests, and causal relationships between processes and outcomes. The domain-general component was the basic diagnostic strategy that was evident from the literatures of medical diagnosis, mechanical device diagnosis, program debugging, and circuit troubleshooting (Clancey, 1983, 1988). From these literatures, we developed descriptions of four "levels" of diagnostic strategy ranging from random testing of components to what we identified as the "expert" diagnostic strategy. This expert diagnostic strategy was expected to transfer across domains, if the domain specific components were provided. Evidence for the power of such an analysis can be found in the work of Voss (Voss, Green, Post, & Penner, 1983) in the use of a general social science method which needs specific information about the country to which it will be applied. Thus, one would expect transfer of the general, abstract skill across domains when specific information about the target transfer domain is provided.

This experiment tested three hypotheses. First, we hypothesized that when a person develops expertise in a domain involving diagnosis as a component, that they would then possess advanced levels of the diagnostic skill, which could be used to solve problems in that domain. Under this hypothesis, experienced computer programmers would be expected to learn diagnostic strategies in their domain of expertise through training and exposure to debugging programs. To test this idea, experienced programmers were asked to solve program debugging problems and we measured their diagnostic skill levels.

Second, we hypothesized that the diagnostic skill that we would measure would *not* be a weak reasoning method that is regularly acquired without training. In this case, subjects who had no experience with a skill domain in which diagnosis was a central component would not demonstrate advanced levels of diagnostic skill even when domain-specific information is provided. To test this idea, subjects, with no experience in program debugging or electronic troubleshooting, were asked to solve debugging and troubleshooting problems. Since the inexperienced subjects were not expected to know either programming or electronics, subjects were provided with information about each domain before and during problem solving and they were allowed to ask questions to obtain any other information they thought they needed.

Third, we hypothesized that an experienced person might be able to transfer the domain-general component of advanced diagnostic skill when provided with the domain-specific components of the new target domain. To test this idea, experienced programmers were asked to solve problems in electronic troubleshooting. Since experienced programmers would not necessarily be expected to know the domain specific facts of electronic troubleshooting, subjects were provided with the essential information (correct functioning of circuit elements) and allowed to ask questions to obtain any other information they thought they needed. Thus, experienced subjects would have experience in the first domain, programming, but not in the second domain, electronics.

## Method

Subjects. The *experienced* subjects were 8 graduate students currently enrolled at the University of Colorado from the Departments of Computer Science and Management Information Sciences. They had an average of 9.9 years of programming experience. They had not taken a course in either logic circuits or electrical circuits, and they scored at a zero level of knowledge on the electronics questions of a knowledge assessment questionnaire. Experienced subjects' average GRE scores were 655 verbal, 701 quantitative, and 667 analytic. The *inexperienced* subjects were 8 graduate students from the Department of English Literature. They had no experience in *either* program debugging or electronic troubleshooting and scored at a zero level of knowledge on both programming and electronics questions on a knowledge assessment questionnaire. Inexperienced subjects' average GRE scores were 711 verbal, 686 quantitative, and 655 analytic. The two populations were chosen because, at a department level, the two populations had equivalent GRE verbal and math scores. Our two samples from these populations did not differ reliably on their GRE scores. All subjects were paid volunteers.

Design. Within experienced and inexperienced subjects, four of each were assigned to one of two groups. Group 1 solved program debugging problems first and electronic troubleshooting problems second; group 2 solved electronic troubleshooting problems first and program debugging problems second. The programming-first group allowed a pure measure of experienced subjects' diagnostic skill levels. The electronics-first group allowed a pure measure of spontaneous transfer of diagnostic skill. No order effects were found however, so all analyses are reported without consideration of this design variable.

Materials. Subjects were asked to solve two different types of problems: program debugging problems and circuit troubleshooting problems. For programs (see Figure 1), subjects were given a program and told that there was one buggy line. The goal was to find the buggy line. Subjects could run a program by selecting a button ("Place object" in Figure 1). Running the program by selecting the program button resulted in both the expected output, what one would "expect" to see if the program were running correctly, and the actual output, what one actually saw after running the program with the bug in it. Program lines were only partially displayed. Subjects could see the full line of the program by selecting "Show program line" and then typing in a number (e.g., in Figure 1, line 7 is incomplete and subjects could request to see the whole line). In addition, subjects could place a print statement to examine variable values after a certain program line had executed.

For circuit problems (see Figure 2), subjects were given a circuit and told that one element was faulty. Subjects could test the whole circuit with "Test Circuit". This action would show the expected results (if the circuit were working properly) and the actual results (results with the faulty circuit element). In order to find the faulty element, subjects could test individual elements by clicking on the element. The result up to that point would be shown to the right of the element. Subjects also could change the input to circuit elements.

Procedure. Subjects were first told the nature of the experiment and then provided with information sheets listing domain-specific information. This included information on the correct functioning of program statements and circuit elements. This information, as well as information on how to use the computer, was provided on the computer before problem solving. Subjects were also told that they could ask questions for additional information.

Problems were presented on a Macintosh computer using HyperCard. Subjects solved five problems in the first domain followed by a break. Then, they solved five problems in the second domain. Subjects were videotaped as they solved problems and were asked to talk aloud as they worked. After problem solving, subjects were asked to complete a general questionnaire on their background and were given a knowledge assessment questionnaire on programs and circuits. The session took approximately 1 - 1.5 hours for experienced subjects and 2.5 - 3 hours for inexperienced subjects. All subjects were requested to solve all problems.

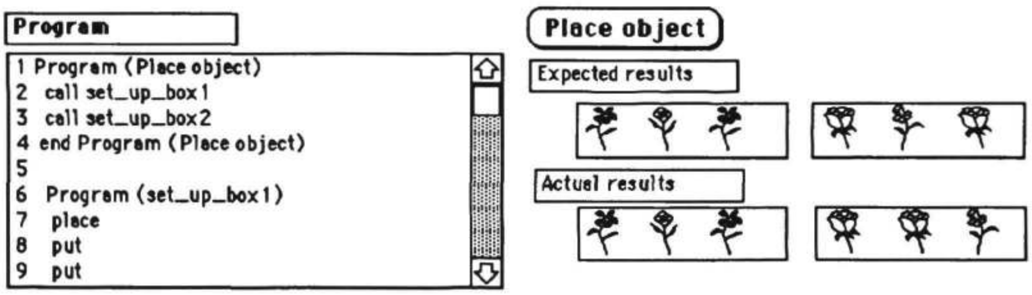


Figure 1. Example of program debugging problem.

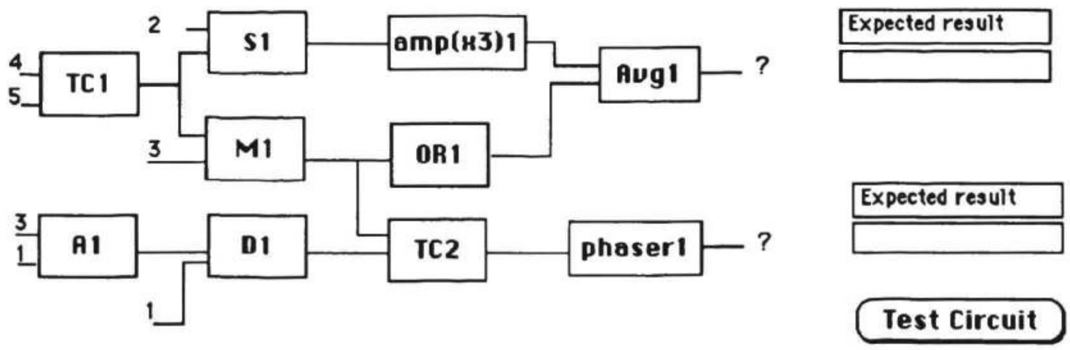


Figure 2. Example of circuit troubleshooting problem

## Results

Knowledge Assessment & GRE. Experienced subjects had a mean score of 11.5 out of 12 on the program assessment but a 0.3 on the circuit assessment. Inexperienced subjects had a mean score of 0 on the program assessment and a 0.3 on the circuit assessment. There was no significant difference between groups for scores on all parts of the GRE exam. Thus, for the purposes of this experiment, the two populations were of equivalent "intelligence," but not of equivalent initial domain knowledge.

Scoring of Diagnostic Skill Level. Four levels (level 0 to level 3) of diagnostic skill were used. At the lowest level (level 0), subjects randomly chose circuit elements or program lines to test. At the next level (level 1), subjects used a systematic forward or backward pattern. For example, a subject using a systematic forward movement might start in the upper left hand corner of the circuit and test elements to the right. A systematic backward movement would start at one of the elements connected to a place where the expected and actual outputs did not match. Then the subject would test each element backward until no error in output was found. At level 2, subjects targeted certain areas of the circuit or program to test first. For example, if a subject noticed that the expected and actual outputs did not match for the top circuit element but they did match for the bottom circuit element, then a subject using a targeting strategy would test each element connected only to the top circuit element and not to the bottom one. Finally, the highest level strategy (level 3), reasoning from output characteristics, not only targeted a certain area but also used process-outcome pairings. By process-outcome pairing, we mean that a subject would examine the expected and actual output and notice the difference between those outputs. Then, the subject would identify those circuit elements or program statements that could cause that difference. Thus, level 3 is a combination between both targeting a certain area just based on a difference *and* targeting certain specific elements or program lines within that area to test.

For scoring these levels, subjects' action sequences and transcribed verbal protocol data, along with a listing of the levels of diagnostic skill, were provided to two independent coders. An action sequence may look like: Test circuit, Test unit M1, State fault M1. A strategy could be inferred from the action sequences. The protocols were used as converging evidence. For example, subjects sometimes indicated directly in their verbalizations what strategies they were using ("I'm just going to guess this one"). For each problem solution, a number was assigned describing the strategy level for that problem. If subjects changed strategies in the middle of solving the problem, both strategies were recorded and the higher level was used for analyses; switching occurred most frequently for inexperienced subjects.

Scoring of the problems was blind to condition. Percent agreement was 85%. In the case of a disagreement, the lower of the two level scores was kept for the experienced programmers and the higher level number was used for the inexperienced subjects.

Diagnostic Level. Experienced subjects showed higher levels of diagnostic skill overall (mean = 2.8) than inexperienced subjects (mean = 1.5), $F(1,12)=138.32$, $p<.01$) (see Figure 3). As stated previously, there were no effects of the domain order in which subjects solved problems and no interactions with order. This result implies that experienced subjects possess advanced levels of diagnostic skill in their area of expertise, programming. In contrast, inexperienced subjects who had no experience in programming demonstrated that they did not possess advanced levels of the diagnostic skill, even when provided with the required domain specific programming knowledge. Although it might seem unreasonable to expect that inexperienced subjects would display advanced diagnostic strategies in a programming domain in which they had no experience, even if they had them, we argue that if this were a weak reasoning method analogous to means-ends strategies, then this is exactly what we would see. However, the possibility remains that the inexperienced subjects possess advanced diagnostic strategies but fail to display them in the programming domain because such strategies are specific to the domain in which they are learned or practiced.

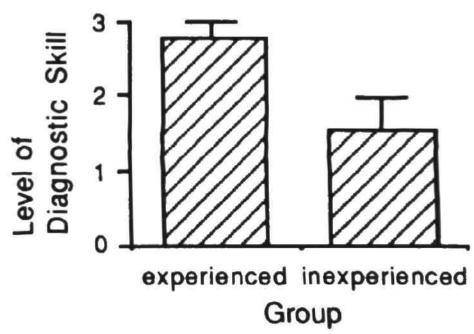


Figure 3. Level of diagnostic skill for program debugging for experienced programmers and inexperienced subjects.

If advanced levels of diagnostic strategies are specific to the domain in which they are learned, then we would expect to see experienced and inexperienced subjects performing at the same level in electronic troubleshoot. However, as shown in Figure 4, subjects experienced in programming (but no experience in electronic troubleshooting) were able to solve the circuit troubleshooting problems using advanced levels of diagnostic skill (mean = 2.8) when they were provided with the domain-specific circuits information. That is, their diagnostic reasoning strategies showed spontaneous transfer from programming to circuits. However, the inexperienced (in programming) subjects were again unable to display advanced levels of diagnostic strategies (mean = 1.5). Both groups of subjects were presented with the same domain-specific information and also showed equivalent levels on our measures of verbal, quantitative, and analytic intelligence. Thus, these results show that the diagnostic skill is not a weak method that everyone has without training because inexperienced subjects did not possess the skill. In addition, since programmers with no circuit training were able to perform at a high level on circuit troubleshooting, spontaneous transfer of diagnostic skill can occur when domain specific information is provided and a person has extensive experience with that skill in another domain.

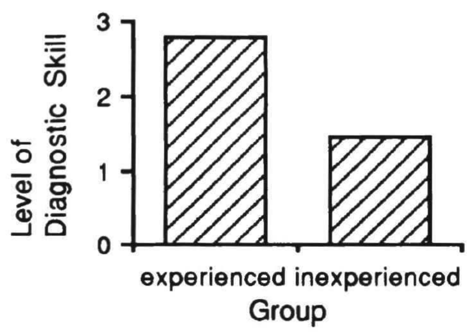


Figure 4. Level of diagnostic skill on circuit problems for experienced programmers and inexperienced subjects.

Number of items chosen. Number of items chosen indicates how selective subjects were in their testing. Fewer items chosen was an indication of a higher diagnostic skill level. Thus, the number of program lines shown or the number of individual circuit elements was counted. Experienced subjects tested fewer items overall for both programming and circuit problems than did inexperienced subjects, $F(1,12)=51.23$, $p<.01$. This effect did not interact with the type of problem (circuits, programs), again supporting our claim of spontaneous transfer for the experienced subjects. These results indicate that experienced subjects were able to narrow their testing to confined areas therefore exhibiting a higher level of skill.

Time to complete problems. The time to complete each problem set was recorded and compared. Experienced subjects spent less time on the problems overall than inexperienced subjects, $F(1,12)=11.45$, $p<.01$. Consistent with the levels and items chosen data, these results indicate that experienced subjects were using more advanced levels of skill because they were taking less time to make their selections. Again, this result was constant across the type of problems, showing spontaneous transfer.

## Discussion

Previous experiments on across-domain transfer have produced mixed results. Recent work by Bassok and Holyoak (1989) and by Klahr and Carver (1988), has demonstrated some transfer of abstract skills across domains. This experiment was designed to test the idea that transfer across domains can occur when subjects are experienced in a skill and they are provided with the domain-specific knowledge of the target transfer domain.

The results indicate that experienced programmers possessed advanced levels of diagnostic skill because they were able to use that skill in solving program debugging problems. English literature graduate students were able to solve problems in both domains but did not demonstrate the advanced levels of diagnostic skill in either domain. Therefore, this advanced diagnostic skill is not a weak reasoning method that can be regularly acquired without training. Experienced programmers also displayed advanced diagnostic strategies when solving circuit troubleshooting problems. Thus, a general diagnostic skill can spontaneously transfer across domains with extensive practice to the level of expertise in one domain.

In studies comparing experts and novices, there is always the problem of comparability of populations. In this research, we matched experienced and inexperienced subjects on GRE scores, held to be moderately predictive of programming ability. Thus, we argue that our two groups were close in terms of "ability," and in terms of the kinds of quantitative and analytic knowledge measured by the GRE exams. However, other kinds of motivational and self-selection differences cannot be completely ruled out. Our informal observations during the talk-aloud sessions revealed that both groups were engaged and persistent in problem solving and did not appear to be discouraged or express thoughts that they weren't able to tackle this "kind" of problem. One solution to this problem is to conduct training studies in which these potential subject differences are controlled (see Lee, 1993).

For this study, two domains were chosen in which transfer would be likely but not automatic. Our long-term goal is to understand how general the diagnostic strategy is and how close two domains have to be to allow application of the strategy once it is liberated from its content. Therefore, one extension of this research will be to examine a new domain that is more distant from programming, such as medical diagnosis or diagnosis of a complex mechanical system.

An additional direction for our research is to investigate the types of training that could liberate a diagnostic strategy from its content. Asking subjects to reflect on the skill that they are learning can produce transfer of that skill to another domain (Brown & Campione, 1981; Hiebert & Lefevre, 1986; Larkin & Reif, 1976; Schoenfeld, 1985). Thus, additional studies using inexperienced subjects are currently examining the effects of extensive training and reflection on the acquisition and transfer of diagnostic skills (Lee, 1993).


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### References


Bassok, M., & Holyoak, K.J. 1989. Interdomain transfer between isomorphic topics in algebra and physics. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15*, 153-166.

Brown, A.L., & Campione, J.C. 1981. Effects of system display format on performance in a problem solving: Suggestions from research. *American Psychologist, 41*, 1078-1089.

Carraher, T. N., Carraher, D. W., & Schliemann, A. D. 1985. Mathematics in the streets and in the schools. *British Journal of Developmental Psychology, 3*, 21-29.

Chi, M. T. H., Glaser, R., & Farr, M. (Eds.) 1988. *The nature of expertise.* Hillsdale, NJ: LEA.

Chipman, S., Segal, J., & Glaser, R. (Eds.), 1985. *Thinking and learning skills* (Vol. 2). Hillsdale, NJ: Erlbaum.

Clancey, W.J. 1983. Heuristic classification. *Artificial Intelligence, 27*, 289-350.

Clancey, W. J. 1988. Acquiring, representing, and evaluating a competence model of diagnostic strategy. In M. T. H. Chi, R. Glaser, and M. J. Farr (Eds.), *The nature of expertise* (pp. 343-418). Hillsdale, NJ: LEA.

Gick, M.L. & Holyoak, K.J. 1980. Analogical problem solving. *Cognitive Psychology, 12*, 306-355.

Gick, M.L., & Holyoak, K.J. 1983. Schema induction and analogical transfer. *Cognitive Psychology, 15*, 1-38.

Hiebert, J., & Lefevre, S. 1986. Conceptual and procedural knowledge in mathematics: An introductory analysis. In J. Hiebert (Ed.), *Conceptual and procedural knowledge: The case of mathematics.* Hillsdale, NJ: Erlbaum.

Klahr, D., & Carver, S.M. 1988. Cognitive objectives in a LOGO debugging curriculum: Instruction, learning and transfer. *Cognitive Psychology, 20*, 362-404.

Kotovsky, K., Hayes, J.R., & Simon, H.A. 1985. Why are some problems hard? Evidence from Tower of Hanoi. *Cognitive Psychology, 17*, 248-294.

Larkin, J.H. 1989. What kind of knowledge transfers? In L.B. Resnick (Ed.), *Knowing, learning and instruction.* Hillsdale, NJ: LEA.

Larkin, J.H., & Reif, F. 1978. Analysis and teaching of a general skill for studying scientific text. *Journal of Educational Psychology, 68*(4), 431-440.

Lee, A. Y. 1993. *Across-Domain Transfer of Diagnostic Skill.* Unpublished doctoral dissertation, University of Colorado, Boulder, CO.

Nesher, P. 1989. Microworlds in mathematical education: A pedagogical realism. In L.B. Resnick (Ed.), *Knowing, learning, and instruction.* Hillsdale, NJ: LEA.

Newell, A., & Simon, H.A. 1972. *Human problem solving.* Englewood Cliffs, NJ: Prentice-Hall.

Nisbett, R.E., Krantz, D.H., Jepson, C., & Kunda, Z. 1983. The use of statistical heuristics in everyday inductive reasoning. *Psychological Review, 90*(4), 339-363.

Perfetti, C.A. 1989. There are generalized abilities and one of them is reading. In L.B. Resnick (Ed.), *Knowing, learning, and instruction.* Hillsdale, NJ: LEA.

Resnick, L.B. 1987. Learning in school and out. *Educational Researcher, 16*(9), 13-20.

Schoenfeld, A.H. 1985. *Mathematical problem solving.* New York: Academic Press.

Singley, M.K. & Anderson, J.R. 1989. *The transfer of cognitive skill.* Cambridge, MA: Harvard University Press.

Tweney, R.D. 1981 (Nov). *Confirmatory and disconfirmatory heuristics in Michael Faraday's scientific research.* Paper presented at Meeting of the Psychonomic Society, Philadelphia.

Voss, J.F., Green, T.R., Post, T.A., & Penner, B.C. 1983. Problem solving skills in the social sciences. In G. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol 17). New York: Academic.