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Quick Development Microcomputer System: Training Automatic Components for Electronic Troubleshooting

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for

Contracting Officer's Representative
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This report investigates how practice aids development of diagnostic troubleshooting skill and how to speed the skill acquisition process using desktop simulation techniques. Experiments show how practice can build up automatic component skills so they can be executed quickly, reliably, with little effort, and be incorporated into more complex skills. The researchers developed objective criteria that can be used in microcomputer software to specify when to promote a student from practicing a component skill to practicing the aggregate skill level.

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QUICK DEVELOPMENT MICROCOMPUTER SYSTEM: TRAINING AUTOMATIC COMPONENTS FOR ELECTRONIC TROUBLESHOOTING
Submitted to: Army Research Institute

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Scientific objective of contract: This program of research investigates how diagnostic troubleshooting skill develops with practice and how to speed the skill acquisition process using desk-top simulation techniques. Experiments map out how practice can build up automatic component skills so they can be executed quickly, reliably, with little effort, and be incorporated into more complex skills. The work develops objective criteria that can be implemented in microcomputer software specifying when to promote a student from practicing a component skill to practicing the aggregate skill level. The work examines questions including: How is controlled cognition utilized during diagnostic reasoning? What role do automatic information processes serve in diagnostic reasoning? How are automatic processes involved in such aspects of diagnostic reasoning as hypothesis generation, control of information search, and evaluation of evidence? How does increasing availability of automatic processes with learning affect the structure of conscious, controlled cognition? How does learning influence reasoning with probabilistic information?

Statement of work fiscal status: The total project involves 96 man-months of work effort. The work expended in this year involves 30 man-months. There are 66 man months remaining. We have used $123,465 of the funds. We have consumed 33% of the time and funds of the project. Expenditures will accelerate in the coming year since we are now fully staffed and most of the equipment has now been received.

Technical Status: Summary. In the first year of the project we have completed five series of experiments, generated three publications and six manuscripts, made four presentations, and developed a set of computerized training procedures to develop combinatoric troubleshooting. We have made major theoretical progress in enhancing the understanding of human working memory capacity, and how practice under high workload enhances skilled performance. We have developed a training system for combinatoric troubleshooting system that has enabled novice, non-technically trained college students to develop substantial troubleshooting skills in 30 hours of training and to enjoy the learning of technical material.

Experiments have been completed in the acquisition of combinatoric troubleshooting using the Quick Development Microcomputer (QDM) software (experiments 1 and 2 of the proposal). College students without any prior technical background trained for thirty hours to acquire combinatoric troubleshooting with circuits containing 30 to 100 components. They were initially trained in the individual gate types (i.e., AND, OR, NAND, NOR, XOR, buffer, and inverter gates) under computerized practice requiring them to predict the output given the input of the gates. The results showed rapid learning of the component tasks and excellent transfer to novel circuits.

Gate knowledge showed a power law learning function with substantial improvements post 500 trials per gate and small improvements post 1200 trials/gate. There was a dramatic improvement in troubleshooting performance after 800 trials of practice per gate (e.g., a 50% reduction in troubleshooting time and number of unnecessary component replacements). Tests of subjects' declarative knowledge indicated that they had perfect knowledge of the verbal rules long before that knowledge was sufficiently automatic (e.g., 20 trials for declarative rule, 800 trials for accurate procedural skill) to adequately support in circuit troubleshooting behavior. Subjects found the task interesting even after performing the task for over 7000 trials.

At the end of training subjects were transferred to novel circuits. The troubleshooting showed perfect transfer (in terms of solution time and efficiency of gate checks). These data suggest that once the procedural skills are well developed, they can be applied in novel combinations in related tasks. This is important because it suggests that extended training of the components can provide a base for many related tasks. General training with the QDM system could develop digital troubleshooting skills that can be applied for any of the digital troubleshooting tasks (e.g., computer troubleshooting, digital communication systems, weapon systems). Note, this training of 7000 trials required only about 20 hours of laboratory time per student.

The QDM training procedures worked well with individuals with apprehension at performing technical tasks. In the last group of 6 subjects, 5 were female, 3 of whom initially claimed they were poor at technical tasks. These 3 students all enjoyed the training (they volunteered to continue without pay) and did very well (one was the best troubleshooter). We feel that providing extensive component training was critical in building the technical skill without the anxiety frequently associated with complex technical problem solving. Before students saw circuits with 100 gates, they had built up confidence and skill over the 7000 trials with simpler circuits. Also, the feedback and rapid learning rate with QDM training allowed students to see their progress.

An unanticipated result was the large difference between massed and distributed performance of the gates. The first block of training involved massed practice of individual gates (144 trials per gate) and the rest of the training involved distributed practice (randomly switching between gates). Subjects required almost 1200 trials of practice until the distributed performance matched the massed performance on trial 5. In addition, switching from massed to distributed performance increased response time by 2.3 times and caused students to extensively use the help facility (40%). These differences were much larger than we expected to see based on past learning theories. The results suggest to us that a major benefit from practice is it allows the student to quickly access information in a random fashion. The declarative knowledge can be fast in massed use but slow and error prone in distributed use. In a task such as troubleshooting, it is critical that the component skills be rapidly accessible in random order. Real circuits involve a variety of gate functions in many combinations. This differential effectiveness when switching from massed to distributed access of knowledge is likely to be important in any problem solving situation. A common remark by instructors of technical topics (e.g., algebra, physics, programming) is that students can perform repeated problems after a technique is presented but then fail to perform the task at the end of the chapter where problems are intermixed. The understanding of the skill transfer from the initial massed training to distributed training will provide data potentially identifying the cause of novices' mistaken confidence about their proficiency early in practice and also establish the marginal utility of practice in massed performance.

The empirical results collected so far suggest a need for substantial revisions in models of skill acquisition. First, extended training is needed beyond that required for declarative knowledge to develop a proficient troubleshooting skill. Theories that provide a strong emphasis on discovery learning alone or learning and debugging only are not supported. Second, we found that gate knowledge does not compose negation gates into simple functions. Anderson (1983) proposed that a major mechanism of learning examines sequential productions and combines them into a single production. This would predict that executing an NAND gate (e.g., perform an AND function and then negate it) should become as fast as the AND gate as it is composed. Our results disconfirm the prediction. After 1200 trials of performing the NAND function subjects required .1 seconds more time than the AND and this difference seemed stable. These data suggest the proposed composition rule either does not exist or is applicable only to very limited conditions. The data are consistent with a view that building automatic components is the principle mechanism of skill acquisition. The automatic components that are created execute the same transformation operations executed by the control processing of the novice. However, with practice these operations become fast (about 100ms) and can be executed with little attention or working memory load. Third, problems in the initial acquisition were NOT because the initial rules are stored in a very limited working memory. We found no interaction between the amount of learning and short-term memory load (in the range of 300 to 1200 trials). This suggests that the benefits in troubleshooting performance post 800 trials is not due to reducing working memory demands. The lack of interaction is counter to the buffer models of short-term memory (e.g., Baddeley 1986, Atkinson & Shiffrin 1968). Fourth, the extreme difficulty our subjects had switching between gates in the distributed performance conditions is incompatible with the short-term memory/long term memory models and supports the need for an intermediate or episodic form of memory. We will be developing a simulation model in the coming year that can account for these phenomena.

We have made major progress in interpreting the use of workload in skill acquisition and high workload performance. Walter Schneider and Mark Detweiler have written "A connectionist/control architecture for working memory" that will appear in the Bower Learning and Motivation Vol 21. This paper provides a new approach to working memory that can account for many of the previously unexplained phenomena of working memory (e.g. robustness of processing, release from proactive interference, acoustic confusions, skilled memory). It provides an interpretation for why massed performance develops so quickly and automatic retrieval develops so slowly. The

Connectionist/Control Architecture (CAP2) is consistent with the known micro, macro, and regional descriptions of cortical information processing. We will be applying this model to fit the acquisition of gate knowledge in the next year.

In order to account for our extended practice results we have produced a new conception of the nature of transfer from low to high workload environments. Understanding these transfer issues is critical for simulator training (e. g., how to maximize transfer of part task training to the final system) and the development of complex skills (e. g., in troubleshooting, how much gate training do you need to reliably use that skill in circuit troubleshooting. The paper "The role of practice in dual-task performance: Toward workload modeling in a connectionist/control architecture" provides a review of the practice literature illustrating the limited transfer from single to dual-task performance. We then provide an interpretation for why transfer may be so limited within the Connectionist/control architecture we are developing to simulate skill acquisition. The model illustrates 7 compensatory activities that occur in high workload situations that do not occur in single task situations. The lack of practice of the compensatory activities provides an interpretation of the limited transfer from single to dual task situations. Of particular importance to the military training community, is that the model suggests how to modify single task training to substantially increase transfer to high workload performance. In brief, using part-task trainers that require time sharing among groups of tasks should develop 6 of the 7 compensatory activities and this training should generalize to any high workload situation. By combining the appropriate parts into part-task training the seventh compensator activity can also be developed in a part-task training. This work may provide guidelines for task analysis, task division for part-task trainer development, and training sequencing to optimize part-task training system design and utilization for skill transfer and maintenance of high performance skills.

The empirical work has shown that the new training techniques can develop substantial troubleshooting skills in 30 hours of training. This skill can be developed in individuals without prior technical or theoretical training. Effective processing seems to occur after several thousand training trials. Although substantial skill can be acquired quickly utilizing the new procedures, it rarely occurs with traditional instructional methods that provide very few trials per component task. The empirical work has mapped out the acquisition of the skill. Theoretically the transition is assumed to occur in five phases spanning about 1000 trials of practice.

The theoretical and technical developments may be applied in an Army context. The theoretical developments provide an interpretation of robust processing under in conditions of high workload and how training may increase the processing speed and reliability. The training programs and software developed in the project can be applied to many troubleshooting courses and have the potential of enhancing performance.

The principal investigator attended the Human Factors Society, Computers in Psychology, and Psychonomics Society, ARI in process review conferences, Air Force workshop on Automaticity and Multiple Resource theory. Research on developing electronic troubleshooting skills, modeling of automatic processing, and the role of practice in reducing resource load was presented during four presentations.

Abstracts of papers and technical reports

Walter Schneider & Mark Detweiler (1986). **Changes in performance in workload with training.** Proceedings of the Human Factor Society. The effects of practice on accuracy, speed, and resource load are briefly discussed. Procedures for measuring resource load and training of high performance skills are illustrated. Analysis of task consistency and procedures for establishing the marginal utility of various training options are described. The alternatives of time-line analysis, subjective measures and multiple resource theory are commented on.

Walter Schneider (1987). **Connectionism: Is it a paradigm shift for psychology?** (Presidential Address, Psychonomic Society Meeting, 1986). Behavior Research Methods, Instruments, & Computers, 19, 73-83. Connectionism is a method of modeling cognition as the interaction of neuron-like units. Connectionism has received a great deal of interest and may represent a paradigm shift for psychology. The nature of a paradigm shift (Kuhn, 1970) is reviewed with respect to connectionism. The reader is provided an overview on connectionism including: an introduction to connectionist modeling, new issues it emphasizes, a brief history, its developing sociopolitical impact, theoretical impact, and empirical impact. Cautions, concerns, and enthusiasm for connectionism are expressed.

Walter Schneider & Mark Detweiler (1987a). **A connectionist/control architecture for working memory.** In G. H. Bower (Ed.) The psychology of learning and motivation, Vol 21. New York: Academic Press. A connectionist/control architecture and simulation are described. The model is detailed at three levels of scale. The system-scale includes regions that specialize in different classes of processing. The activity of the regions is coordinated by a central control structure that routes control signals among regions and sequences transmissions among regions to limit message interference. One region serves as a context storage mechanism that can reactivate messages contained on an innerloop of processing. At the macro scale, each region is divided into a number of levels that sequentially or spatially input or output the patterns to other levels. Each level has a control structure that monitors the activity of all the modules in its level and controls the signals to coordinate the sequential storage and processing of information. At the micro scale, each level includes multiple modules. Each of these modules involves a connectionist network that processes vectors of information. A module can store, categorize, maintain, and prioritize a received vector. This architecture provides an interpretation of working memory phenomena including the magic number 3 or 4, acoustic confusions, sequential processing, problems with digit cancelling, difficulty maintaining order information, elaborative versus maintenance rehearsal, episodic versus semantic memory, release from proactive interference, long-term memory recency effects, robust processing during short-term memory overload, and proactive and retroactive interference effects.

Walter Schneider & Mark Detweiler (1987b). **The role of practice in dual-task performance: Toward workload modeling in a connectionist/control architecture.** Submitted to Human Factors. The literature on practice effects and transfer from single- to dual-task performance and part-whole task learning are briefly reviewed. The results suggest that single-task training produces limited transfer to dual-task performance. Past theoretical frameworks for multi-task performance are reviewed. A connectionist/control architecture for skill acquisition is presented. The architecture involves neural-like units at the microlevel, with information transmitted on vectors between modules at the macrolevel. The simulation of the model exhibits five phases of skill acquisition. Dual-task interference and performance are predicted as a function of the phase of practice the skill has reached. Seven compensatory activities occur in the model during dual-task training that do not appear in single-task training: 1) task shedding, delay and buffer preloading; 2) letting go of high-workload strategies; 3) utilizing noncompeting resources; 4) time multiplexing; 5) shortening transmissions; 6) converting interference from concurrent transmissions; and 7) chunking transmissions. Future research issues suggested by the architecture include: Mapping out the marginal utility of single- to multi-task transfer; investigating the classification of multi-task compensatory activities; evaluating the role of part-task trainers for multi-task skills; and developing and testing quantitative models of skill acquisition.

Richard A. Carlson & Walter Schneider (1987). **Learning and using causal rules.** Submitted to Memory and Cognition. It has been suggested that a general causal schema constrains procedures for reasoning with causal knowledge. The present study investigates the possibility that procedures for using causal rules depends on representations used for instruction and task demands in initial practice. College-student subjects learned to use causal rules describing digital logic gates (e.g., for a NAND gate if all inputs are 1, the output is 0) to make either prediction or diagnosis judgments. Initial rule instructions used either verbal rule or truth table representations. Judgment latency was the primary dependent variable as subjects practiced for about 200 trials per rule. The results support the conclusion that acquisition context affects the procedures developed for using causal rules, casting doubt on the hypothesis that a general causal schema strongly constrains reasoning. Truth table representations resulted in superior performance, especially for diagnostic judgments. Transfer between judgment types was asymmetric, with greater difficulty in transfer from prediction to diagnosis judgment. Several unexpected results have important theoretical implications: Initial massed practice with each rule was quite easy, but mixing the rules substantially increased judgment difficulty. Diagnosis judgments required more time, as did judgments about negated rules. It appears that learning simple cognitive skills severely taxes working memory. Alternative process accounts of the structure of causal judgment are considered.

Richard A. Carlson, Marc A. Sullivan, & Walter Schneider (1987). **Practice and working memory effects in building procedural skill for causal judgments.** Submitted to Journal of Experimental Psychology: Learning, Memory and Cognition. Several current theories of skill acquisition share the assumption that increases in fluency (a) result primarily from reorganization or *restructuring* of component processes, and (b) reduce the working memory capacity needed to carry out procedures. Subjects in the present study learned to predict and verify output states of simple rule-governed devices, digital logic gates. In Experiment 1, subjects practiced these judgments for about 20 hours (over 8000 trials). Initial massed practice with single rules resulted in very fast, accurate responses. There was a large decrement in performance, however, when rules were randomized within blocks. This result is interpreted as reflecting the role of loading judgment components into working memory. Rule type, negation, and judgment type had strong interactive effects that declined but did not disappear with practice. This result appears to disconfirm the assumption that practice results in the restructuring of component processes. Experiment 2 tested subjects' ability at two levels of practice to make these judgments in the retention interval of a working memory load that was either relevant or irrelevant to the judgment. Task-relevant information not actually used to make judgments did not interfere with the judgment process, suggesting a goal-related encapsulation limiting access between separate information structures in working memory. This interpretation is supported by a cost for accessing information in working memory in order to make judgments. This cost does not decline substantially with practice, suggesting that the use of working memory to carry out cognitive procedures does not change with practice. A descriptive model that assumes a cascaded inference process with changes only in the reliability of component processes captures the major effects of rule type, negation, judgment type, and learning. Implications of the results for single-workspace models of working memory are also discussed.

Richard A. Carlson, Marc A. Sullivan, & Walter Schneider. **Use of causal functions in network problems**. Problems in many domains can be represented as networks of causal relations, and fluency in reasoning about single causal relations is plausibly a substantial component of expertise in these domains. Eight undergraduate subjects solved a variety of network problems in the domain of digital electronics, as their skill at reasoning about single causal relations in that domain increased. They practiced making judgments about single digital logic gates for 1360 trials. Learning data for these causal functions are examined in detail in another paper (Carlson, Sullivan, & Schneider, 1987). Here, five experiments involving network problems are reported. At several levels of practice, subjects solved network problems that required forward or backward reasoning, and did or did not involve reasoning about logic gates. At the end of the project, transfer to untrained networks was tested. The results demonstrate that fluency in reasoning about causal functions is important in a problem-solving context, but may not be adequately predicted by judgments about those causal relations made outside a problem-solving context. The present findings suggest that learning to integrate components of complex problem-solving tasks in working memory is an important part of skill acquisition. Implications for theories of problem solving and skill acquisition are discussed.

Richard A. Carlson **Processing nonlinguistic negation**. Psycholinguistic research suggests that negation serves both logical and other linguistic functions in natural language. To isolate the processing of negation as a logical function, the present study examines how individuals process negation in a nonlinguistic context, making judgments about digital electronic components known as logic gates. Standard symbols and terminology for these components (a) use natural language terms for logical functions (e.g., "and," "not") and (b) represent negation explicitly. One group of subjects (*logic gate*) was instructed with these standard symbols and terms. A second group (*arbitrary/explicit*) saw arbitrary symbols that explicitly represented negation, but received instructions that avoided the use of natural language terms for logical functions. A third group *(arbitrary/implicit)* saw arbitrary symbols that represented negation only implicitly. Negated functions resulted in longer latencies in the logic gate condition. Subjects in the arbitrary/ explicit group also showed a strong effect of negation, but subjects differed in terms of which function (e.g., AND or Not AND) was taken as the affirmative reference. A similar but much smaller effect of negation was apparent in the arbitrary/implicit condition. The results indicate that the effect of negation on judgment latency does not depend entirely on linguistic factors. The pattern of results is consistent with a serial stage model of processing logical negation.

Richard A. Carlson & Walter Schneider. **ET II: Overview of a longitudinal study of skill acquisition.** This report provides an overview of a longitudinal study of the development of a complex cognitive skill -- troubleshooting simulated digital electronic circuits. Six undergraduate subjects spend about 56 hours practicing this skill and participating in tests of component skills.

List of publications and manuscripts for submission

Schneider, W., & Detweiler, M. (1986). Changes in performance in workload with training. Proceedings of the Human Factors Society, 2, 1128-1132.

Schneider W. (1987). Connectionism: Is it a paradigm shift for psychology? Behavioral Research Methods, Instruments and Computers, 19, 73-83.

Schneider, W., & Detweiler, M. (1987). A connectionist/control architecture for working memory. In G. H. Bower (Ed.), The psychology of learning and motivation, Volume 21. New York: Academic Press. (in press)

Schneider, W., & Detweiler, M. (1987). The role of practice in dual-task performance: Toward workload modelling in connectionist/control architecture. Human Factors (submitted for publication).

Carlson, R. A., & Schneider, W. (1987). Learning and using causal rules. Submitted to Memory and Cognition.

Carlson, R. A., Sullivan, M. A., & Schneider, W. (1987). Practice and working memory effects in building procedural skill for causal judgments. Submitted to Journal of Experimental Psychology: Learning, Memory and Cognition.

Carlson, R. A., Sullivan, M. A., & Schneider, W. Use of causal functions in network problems. (In preparation).

Carlson, R. A. Processing nonlinguistic negation. (In preparation).

Carlson, R. A., & Schneider, W. ET II: Overview of a longitudinal study of skill acquisition. (In preparation).

Plans for coming year

The work in the past year has mapped out the changes in performance as students acquire combinatoric troubleshooting skill. We will be continuing our planned studies with some modifications in procedures based on the results of the first year.

Concurrent controlled processing during troubleshooting

In the first year we found substantial improvements in performance as students practiced in excess of 800 trials per gate. However we saw no interaction of processing with short-term memory load after the first 300 trials per gate. The lack of interaction with working memory disconfirms the predictions of single process working memory accounts (e. g., ACT*, SOAR). The lack of interaction is consistent with the proposed Connectionist/Controlled architecture (CAP2). CAP2 proposes that after about 200 trial per component rule the skill in the controlled assist phase requires no working memory and only small amounts of controlled processing (e. g., attending to the transformation rules). This suggests that concurrent process tasks will interact with practice levels in the post 200 trial training range whereas short-term memory tasks do not. This experiment extends the research described in experiment 2 of the proposal.

This experiment will examine whether troubleshooting under high workload will interact with the degree of practice. Students will perform the troubleshooting task while concurrently listening to a series of tones at a rate of several per second. The tone task will be a varied mapping task (see Schneider & Shiffrin 1977) in which subjects search for a new tone on every trial. When the tone occur they are to press a response key. They also concurrently perform the gate judgment and troubleshooting tasks. Subjects will be trained for about 20 hours to determine whether the secondary task workload effect reduces with training. We will use access and expect conditions as in the working memory task we used last year. The tone probe will indicate to the subjects that they are to update their memory of a test point that may subsequently be used in the troubleshooting task. For example, there might be 3 tones 200, 800, 3200 hertz. On a given trial a subject listens for one of the tones (e. g., 3200 hertz). The tones occur at a 3 per second rate and one probe occurs at random in each sequence of 10 tones. Test point A is assumed to be a 1 at the beginning of the trial. Whenever the subject hears the high tone he/she presses the new state of test-point A (e. g., press the 1 key of high tones, 1,3,5... and the 0 key on 2,4,6,...). On some tests the A signal is used, on most it is not. The analysis will examine the single and dual task performance as a function of practice.

The resulting data will facilitate theoretical and applied training issues. Theoretically it is important to determine functionally what is changing during extended training. These results may provide the applied training community with techniques to access how much training is needed before the component skill should be considered sufficiently automatic to be reliable in higher level skills.

Guided learning in an electronic troubleshooting context

With each training study performed in this project our training procedures have become more directly guided. We will examine various procedures of guiding the learner in combinatoric troubleshooting (experiment 5 original proposal). We have observed our subjects troubleshoot several hundred problems in the past year. Some subjects developed strategies that facilitated acquisition. We believe that a computer controlled guided training procedure can be implemented that will substantially speed acquisition of troubleshooting skills. There will be 3 groups in this study with four levels of guided training. One group will do discovery based exploration as our previous groups. A second group will receive move by move guidance in which they are told the reason and the correct response whenever they make an incorrect response. The third group will be trained to identify the consistent fault set (i. e. the set of components in which a fault would be consistent with the information gathered so far). This last strategy seems to be the one that our best subjects use. At various points the student will be expected to use a mouse to label components that could be at fault. This allows assessment of the working memory load of the hypothesis set they are considering and the accuracy of the interpretation of previous tests.

The data will allow evaluation of these three training methods to acquire combinatoric troubleshooting skills. The experiments will also develop techniques for quickly developing these three tutorial methods in acquiring troubleshooting. Finally, the data will provide information on how differential learning strategies transfer to circuit troubleshooting.

Studies of Expert Electronic troubleshooting

Expert electronic technicians will be tested to compare novice and expert technicians to identify the strategies used by experts when troubleshooting with our training systems. Technicians will be asked to trouble shoot simple combinatoric circuits and computer boards (serial I/O cards on IBM PCs) to identify faulty systems (see experiments 8-10 of the original proposal). Subjects will be technicians at the University of Pittsburgh. Sessions will be videotaped and the computer will maintain detailed records of what troubleshooting behaviors are executed. In addition to troubleshooting systems, technicians will be asked to verbalize their strategies, perform gate prediction tests, and indicate the consistent fault set of potentially bad components while troubleshooting. We expect experts to have good gate knowledge and be skilled at maintaining information in working memory while making predictions. The expert data will provide user evaluation of our simulation environment and frequency of occurrence of various strategies in troubleshooting tasks.

Skill maintenance 6 months later

A critical issue in military training environments is developing skills that can be maintained over periods when they are not in use. A new technician may go several months between the time a topic was covered in the initial troubleshooting course and the time when that knowledge is applied in the field. Skill maintenance is important theoretically since some procedural skills seem to be maintained over extended periods of time. For example, Alice Healy in another ARI supported project has found that automatic perceptual skills had perfect retention after 6 months (i. e. performance on the first session was as good as on the last session 6 months earlier). If extended component training of the diagnostic skills shows similar retention, this would provide strong support for orienting skill training to build up component skills. In this study we will take five of the six students trained six months earlier and assess their current knowledge. They will be tested for their declarative knowledge on the gate types, troubleshooting behavior, ability to make logic input output predictions, and effects of working memory. We will also train a set of subjects without extended component training (i. e. give them declarative knowledge and about 50 trials per gate (about what they would get in a typical technician school) and assess the skill decay after six months (this assessment will be completed in the third year of the project).

Understanding the nature of skill maintenance will enhance the modeling of skilled performance and provide another measure of training efficiency. Current modeling of fast and slow learning (see Schneider & Detweiler 1987a) suggests that declarative knowledge can be very fast (e. g. thirty seconds per component), but may only be useful for a short period of time (e. g., at the multiple choice test at the end of the lesson covering that topic). Building procedural skills is slow (e.g., requiring hundreds of trials and half an hour per component), but may be available to a technician for hundreds of hours thereafter. Data illustrating this tradeoff may help lesson designers determine the relative merits of adding more declarative knowledge at the expense of not automating the critical component knowledge.

Initial massed acquisition

One of the unexpected results in the first year was the extreme difficulty subjects had moving from massed training of one gate type to distributed training. A new experiment will examine initial acquisition in massed and distributed conditions. This will involve a relatively short duration experiment to provide data on the relative learning rates in the two conditions. A large number of subjects (20 per group) will be trained on alternative arrangements of massed training (24 trails per gate) and then transferred to distributed training and retested on mass training. Subject expectations on the difficulty of performing distributed trials and declarative knowledge will be assessed after the initial massed blocks. Performance in the distributed conditions will be examined to see if runs of the same gate show the equivalent learning curves as the massed gates. One group of subjects will be run with just distributed training to assess the benefit of the massed training to develop the declarative knowledge.

These data are needed to estimate parameters for the fast learning rates in the model for context learning (see Schneider & Detweiler, 1987a). They will also provide data on whether learners develop a false sense of mastery during these early massed training trials.

Part-task to Dual task transfer

Theoretical analysis of single to dual task transfer within the connectionist/control architecture suggests guidelines for optimizing part-task to dual task transfer. The model predicts that training in high workload situations after the skill reaches the controlled assist phase (see Schneider & Detweiler 1987b) should lead to good transfer to many high workload situations. This is a fundamental prediction and important for modeling skill acquisition. The prediction is that to train tasks A, B, and C to perform well together, you should train A, B, C, AB, and BC and then show good transfer to AC and ABC. In contrast, training on A, B, and C should show significantly less transfer to AC and ABC. This is due to compensatory activities developing during the dual task training. In electronic troubleshooting the learner must learn to perform multiple tasks concurrently (e. g., perform gate prediction, memory updating, goal tree selection, and operating test equipment). If part task training (e. g., on the gate prediction task) does not develop compensatory activities (e. g., short duration automatic transmissions), transfer to the aggregate task will be limited.

We will first carry out a single to dual task training study to test the transfer predictions of the model. We will return to traditional dual task procedures to assess this transfer and to use calibrated loading tasks. There will be four tasks: a category search, a digit search, a shape search (respond to a diagonal of blocks) and a tone detection task. All tasks will be consistently mapped. They will be trained individually and in combination. One group will be trained in the single tasks and transferred to the total task. Other groups will be trained in paired combinations and transferred to the total task (see above). A final group will just perform the total task. The total training time for all groups will be compared.

Assuming the traditional dual task experiment is successful, an analogous experiment will be carried out within the electronic troubleshooting context. Subjects will be trained to perform gate predictions either in individual gate tasks or embedded in the higher level skill. Similarly the tasks associated with: memory updating, goal tree selection, and test equipment operations will be combined. Transfer from combinations of single and multiple task to the full task will be compared.

Data on the part-task full-task training will enhance the understanding of the skill acquisition process, provide data for testing models, and provide guidelines for increasing the efficiency of training. To illustrate the benefit of efficiency, consider training gate prediction and backplane pin counting (i. e. counting the pins of a chip in the process of trying to locate a specified signal). In a single task to learn the individual gates, the student can execute about 500 trials/hour. In training on finding chips and pin counting, a student can perform about 50 trials per hour. If the subjects need to perform both tasks, they would probably average only 30 trials per hour. Note if 800 trials per gate are needed to get the dual gate knowledge automatic, practice in the total task would be inefficient. However, if training in the single task does not transfer to the dual task, training in the single task would also be inefficient. On the basis of the model (Schneider & Detweiler, 1987b), the best training would entail training groups of part tasks in which the speed is not seriously compromised (e. g., gate prediction in schematic diagram troubleshooting, and pin counting in following a decision tree). This experiment will begin to map out the relative benefits of these training regimes.

Simulation modeling of combinatoric logic acquisition

A new simulation environment CAP2 (Controlled Automatic Processing Model 2) will be developed for modeling the acquisition of troubleshooting behavior. The model will be the next generation of the CAP1 used to simulate human skill acquisition behavior (see Schneider and Mumme 1987). The model is a hybrid incorporating techniques from connectionist modeling (e. g., delta and back propagation learning rules) while being able to perform instructed learning (e. g., as in production system models like SOAR or ACT*). This model is capable of simulating performance through the various phases of skill acquisition. The system will be written in the C programming language and will run on large scale IBM PCs (286 or 386 machines with several megabytes of memory).

The code will be highly modular and well documented to enable other researchers to operate with this architecture. The system will include an experiment runner module to facilitate executing experiments in a manor analogous to what subjects experience. CAP2 will include a variety of learning rules (e. g., delta, back propagation) to improve learning rate and skill transfer. It will also include module based code compression techniques (e. g., Ballard 1987) to improve performance for learning large scale problems and transfer.

The acquisition of gate knowledge will be modeled within CAP2. The phenomena to be modeled include: 1) practice effects in acquiring gate knowledge; 2) initial benefit of massed practice and limited transfer to distributed practice; 3) sequential attentional processing of components of the schematic diagram; 4) interactions of practice and working memory and secondary task loading; 5) increase in processing time for negated gates; and 6) sequential time course of processing through schematic diagrams. The simulation results will be compared with human performance results. The simulation will be run through various training regimes to identify optimal training procedures. The modeling will also be applied to learning in multi-task paradigms to detail the phases of practice in making a component automatic. In the third year we will model the troubleshooting behavior involved in solving combinatoric circuits.

This modeling will provide a new architecture for skill acquisition, provide theoretical evaluation of training procedures, and facilitate communicating the role of practice in building high performance skills. Currently, modeling in cognitive psychology is split between the connectionist and production system camps (see Schneider 1987). CAP1 is the first model to deal directly with the phenomena that are central to each of these groups (e. g. one trial learning is easily modeled in production system models whereas non-brittle mutual constraint satisfaction is easily modeled by connectionist models). The hybrid model has the ability to predict the full skill acquisition function in a manor that is physiologically feasible. The model's predictions will suggest training guidelines that can be evaluated empirically.

An important benefit of the model is that it can be shown to instructors to help them appreciate the role of practice in developing high performance skills (see Schneider 1985). The output of the model can be run in an animation to be shown to instructors. In a five minute demonstration, instructors can be challenged to perform simple dual-tasks. The difficulty they experience increases their appreciation of the importance of practice in making a component automatic. In about ten minutes instructors can see an animation illustrating the changes in performance as a function of practice. This helps them to visualize what is happening during the hundreds of trials of practice typically required to develop an automatic process. In general, most instruction is targeted at declarative knowledge. There is a heavy bias toward presenting a large amount of material briefly rather than making critical components automatic. Having instructors visualize the benefits of making component skills automatic can encourage them to develop automatic skills. The animations run on Zenith IBM PCs and hence can be easily shown many groups.

Technical achievements

In the process of implementing this research we have developed a variety of software tutorial systems to train troubleshooting behavior. The major programs include: LET - logic element trainer to teach basic gate types; SST - system state trainer for combinatoric troubleshooting problems; and LAT - Logic Analyzer Trainer to train micro processor troubleshooting using a logic analyzer interface. We have had 1500 subject hours experience with these programs and have found they work well as training systems with little instructor input. In the coming year we will be modifying the programs to speed lesson development for the instructor.

Mouse pointing within troubleshooting programs. We will be adding mouse based pointing within the SST program to allow the student to directly move to the gate of interest. In the current program the student uses cursor commands which can somewhat slow down the tracing functions. This will also allow us to more accurately record movement times between gates. In addition we will implement a virtual window system so portions of the display can be made visible to track where the student "looks" (i. e., uses the cursor to expose information). We will attempt to reprogram the graphics interface so it can operate on color displays on EGA display devices. This will allow use of color as a cue and enable using the programs on Zenith PC computers that support EGA graphics. Such compatibility would facilitate using these programs in military training classes since the Zenith PC is becoming the standard instructional machine.

Direct data acquisition of digital signals. The major time required to set up lessons in the LAT program involves specifying the waveforms for the systems being debugged. To automate this process, data acquisition software is being developed that allows recording of data directly from the target system and storing signals in a format for use in the LAT program. With this program, a technician can code an existing hardware system at the rate of one to two test points per minute. This is much faster than coding the actual data.

Waveform editing on signals. Faulty systems can be coded either by recording from faulty hardware or by editing the signals from the good system. A waveform editing program will allow graphical editing of the waveforms. This will enable the instructor to rapidly modify the signals that would be produced by various fault conditions.

Forms based generation of lesson segments. In several of our development projects we have found that a forms based user interface makes it much easier to specify experiments than either a command language or menu based interface. The lesson development programs now use a command language format. We will develop form-based interfacing tools. In the form system the instructor fills in forms specifying options in a language familiar to the instructor rather than by computer code commands. The system also provides help for each field. The form system greatly simplifies the task facing subject matter experts when performing debugging tasks. This system can also guide the novice through troubleshooting tasks.