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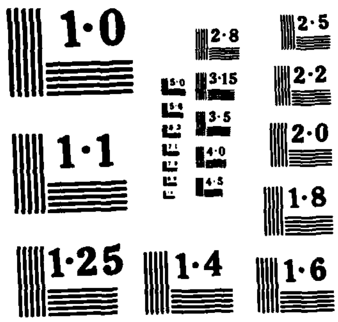

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AD-A162 845

First and Second Quarters 1985
Progress Report

PROBLEM-SOLVING GROUP

Mary S. Riley
Principal Investigator

Structural Understanding in Problem Solving: Specifying and Instructing Cognitive Objectives in Basic Electricity

INSTITUTE FOR COGNITIVE SCIENCE
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August 30, 1985

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Overview

A common instructional objective in domains of math and science is the capability to use formulas and arithmetic procedures to solve problems. Although students are explicitly taught the relevant formulas and principles, are shown worked-out examples, and are given practice, they frequently experience considerable difficulty when asked to solve similar problems. Previous research (Riley, 1984) suggested that difficulties often result from mechanical application of rules and formulas with little understanding of important structural relations between the elements in the problem domain. The objective of our research is to analyze in greater detail what is meant by structural understanding within the domain of basic electricity, the role this understanding plays in performance and learning, and the extent to which important structural relations can be taught more directly. Research has involved (1) empirical studies of the knowledge students acquire (and fail to acquire) both from the Navy's Basic Electricity and Electronics (BE&E) course material and from alternative instructional materials and (2) theoretical analyses in the form of computer simulation models that represent detailed hypotheses about the knowledge underlying students' performance and learning.

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First-Second Quarters 1985
Progress Report

PROBLEM-SOLVING GROUP

Mary S. Riley
Principal Investigator

August 30, 1985

DRAFT

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Group Members

Mary Riley (Principal Investigator), Eric Hestenes (Programmer), Liz Troschinetz and Susan Voss (Research Personnel).

Eva Leeman, Robert Moore, and Lori Prince joined the group for the Spring quarter to work on senior projects concerning issues of learning and performance in basic electricity. (See the section entitled "Unpublished Manuscripts".)

Empirical Studies

We are conducting two main kinds of empirical studies: protocol studies of individual subjects and group studies. The goal of the protocol studies is to provide detailed information about the knowledge underlying problem-solving performance and learning, e.g., information about the sequence and types of solution steps, whether the subject reason using equations or by analogy, whether the subject reason using quantitative or qualitative relations. This information is important in the development of the simulation models and is not directly available from tests administered to large groups.

In the group studies, I am collaborating with Dr. William E. Montague, Naval Personnel Research and Development Center, to obtain performance data from actual BE&E students and graduates solving paper-and-pencil problems like the ones used in the protocol studies. We are using this data, together with information obtained from the theoretical analyses, to develop diagnostic tests for monitoring knowledge and skill acquisition in BE&E. The group data also provides a valuable test of the generality of the findings from the protocol studies.

Protocol Studies

Reasoning about DC Circuits Using Ohm's and Kirchhoff's Laws

During April, May, and June, we obtained verbal protocols from five subjects as they learned about DC circuits from an abbreviated version of the standard BE&E course.[1] To monitor subjects' understanding as they progressed through the course material, a diagnostic set of free-response problems was generated to replace the multiple-choice problems used in the BE&E course materials. In her protocol analysis of multiple choice problems, Riley (1984) found that students did not reason through the answers to determine the correct choice. Rather, they compared patterns of answers eliminating incorrect alternatives. In order to avoid this problem, we developed a diagnostic test that would force students to reason through each problem and to indicate more directly how well a student understood a problem.

1. We had also planned to study the knowledge students acquire about alternating-current (AC) circuits from an abbreviated version of the BE&E course material. Subjects were to have been the same as those who studied the DC circuits, to provide information about how their knowledge of DC circuits influences their ability to learn about AC circuits. However, subjects' time constraints resulting from the quarter class schedule prevented their continuing beyond the instruction on DC circuits.

A major focus of our research concerns the relationship between quantitative and qualitative reasoning about circuit variables. Therefore the diagnostic test included both quantitative and qualitative problems. Quantitative problems give the value(s) of one or more circuit variables (current, voltage, and/or resistance) and ask subjects to solve for the value of another circuit variable. Qualititative problems involve reasoning about increases and decreases in circuit variables without using the actual values of the variables. Qualitative "Effect" problems require the subject to determine the effects of changing the value of one circuit variable on other circuit variables (do they increase, decrease, or remain the same?); Qualitative "Cause" problems require identifying the set of possible events that could have caused specific changes in the value of circuit variables.

Tasks also included pretests to provide specific information about relevant cognitive abilities prior to instruction. In particular we were interested in subjects' understanding of isolated equations involving additive and multiplicative relations. These are the same relations involved in Ohm's and Kirchhoff's laws. If subjects lacked an understanding of these relations in isolated equations, we would expect them to have difficulty applying several equations to reason about simultaneous constraints on circuit variables.

Protocols have been transcribed and coded and initial analyses have been completed. Preliminary results indicate that

- Subjects could solve isolated equations when numbers were provided but had some difficulty reasoning about qualitative relations between variables in these equations.
- Similarly, subjects could reason correctly about circuit problems when numbers were provided but made frequent errors when reasoning about qualitative relations between current, voltage, and resistance.
- Pretest performance appears to be correlated with performance on circuit problems. However, successful performance on the pretest does not guarantee successful performance on circuit problems.
- These data support and extend earlier findings (Riley, 1984).

Learning by Analogy

Our studies indicate that many subjects (and BE&E students) attempt to memorize algorithms for manipulating equations to solve particular problems, without understanding the relationships between the elements in the equations, let alone how these equations relate to the relations between current, voltage, and resistance in electrical circuits. We are exploring teaching subjects important structural relations between circuit variables using a concrete analogy. As a first step, we are analyzing in greater detail protocol tapes from a previous instructional study (Montague, Riley, & Konoske, 1985) that supplemented the standard BE&E course with instructions to think about current, voltage, and resistance in terms of a "Chips" analogy.[2] The analogy was hypothesized to facilitate the acquisition of the structural knowledge by making circuit constraints more salient and by providing subjects with simple procedures for taking those constraints explicitly into account. It was also hypothesized that subjects would be able to map their understanding of circuit constraints from the analogy to their understand the same constraints expressed as equations.

Preliminary results indicate:

- Subjects performed quite well on both quantitative and qualitative problems when they used the analogy.
- Subjects had difficulty envisioning solutions to some problems, forcing them to work out the analogy on paper and pencil.
- Subjects frequently preferred to use equations to solve problems, unless prompted to use the analogy.
- When subjects relied on equations, they frequently made errors of the kind observed in previous studies.

Thus, it seems that the Chips analogy does facilitate performance but mapping knowledge of constraints from the analogy to circuit equations is a subtle and complex issue that requires considerable additional empirical and theoretical work. We plan to conduct additional empirical studies to determine in greater detail the knowledge students acquire from instruction using the Chips analogy, and under what conditions they are able to transfer that knowledge to solve problems using formulas.

Group Data

Dr. Montague administered diagnostic tests to BE/E students who had completed the instruction on DC circuits and passed the standard tests. Some of the students had also successfully completed advanced instruction on AC circuits. The diagnostic tests included questions about qualitative changes similar to those used in the protocol studies. We focussed initially on qualitative problems since these problems are the quite difficult for students. The tests were administered in three separate studies:

- Study 1: Effect problems only, 46 students.
- Study 2: Cause problems only, 77 students.
- Study 3: Effect and Cause problems, 50 students.

2. The analogy involves a stack of chips and one or more slotted boxes connected by wire. The boxes correspond to resistors and the number of slots in a box determines its resistance value. The stack of chips corresponds to the applied voltage and the amount of applied voltage is specified by the number of chips in the stack. For resistors in series, current is determined by simply distributing the chips of total voltage equally among all the resistor slots; the number of chips in any slot corresponds to the current.

We have begun analyzing patterns of correct responses and errors for individual subjects. In all three studies, proportions of errors were quite high, sometimes approaching 1.00. These findings indicate that even when students perform successfully on the standard tests administered in BE&E, they may lack an understanding of important circuit concepts. The types of errors made by subjects in the three groups were similar to those made by subjects in the protocol studies which gives us additional insight into the nature of students' difficulties.

Theoretical Analyses

During the first two quarters, considerable time was spent becoming more familiar with the Dandelion. Initial attempts to implement computer simulation models using LOOPS rules and knowledge structures proved time-consuming and unsatisfactory. Development of the computer simulation models is now progressing smoothly using PRISM which we obtained at the end of July from Pat Langley. We have agreed to serve as a test-site for PRISM and help debug existing problems and implement new features. Eric Hestenes has just completed a menu-interface for PRISM that greatly facilitates the retrieval, display, and modification of production rules and memory.

Following is a discussion of the three main areas of focus in our theoretical analyses.

Levels of Understanding Constraints in Direct-Current Circuits

The current focus of the theoretical analyses is to implement Models 1 and 2 (described in Riley, 1984) in PRISM. The differences in the knowledge included in Models 1 and 2 was hypothesized to represent important differences in understanding circuit relations. In addition, the models will be extended to include the additional knowledge required to solve problems involving power, opens, and shorts. Students have considerable difficulty solving these problems (c.f., Montague, Riley, & Konoske, 1985), yet understanding these relations is important for later performance in BE&E and eventually for maintaining and repairing electronic devices. It is hoped the analyses will help identify the nature of students' difficulties and suggest possible ways to improve instruction.

Once implemented, Model(1) will be extended further to include a mechanism that will enable it to acquire the knowledge in Model(2), the model that represents improved understanding of important circuit relations. A similar mechanism was developed by Greeno (1983) in his analysis of meaningful learning of geometry proof problems. Our analysis will provide a better understanding of the generality of this learning mechanism and show how acquiring new schematizing production plays an important role in bootstrapping conceptual understanding during learning.

Towards a Theory of Errors

Another current focus of our theoretical analyses is the development of a generative theory of errors. In both the protocol studies and group studies, we have accumulated large numbers of error patterns for the Effect and Cause problems. Of course, simply accumulating error patterns is not very interesting, nor very useful. Therefore, we are working to relate those error patterns to a smaller set of specific deficiencies in students' underlying knowledge structures. So far we have developed a set of 30 degraded production rules that is sufficient to generate most of the error patterns on the Effect questions. Our eventual goal is to develop a principled account for how degraded rules are acquired and applied during problem solving. For example, the 30 degraded productions were generated from Model(1)'s correct rules by systematically omitting conditions that specify values of variables that must stay the same for a production to apply. Our hypothesis is that omitting "same" constraints may be a quite general learning mechanism that is appropriate in many contexts but leads to predictable errors in basic electricity.

Learning by Analogy

A model will be developed to simulate solving basic electricity problems using the Chips analogy. Analyses will be conducted to determine how the knowledge included in this model can be applied to the understanding and solution of the same problems using formulas. The analysis will draw on Resnick, Greeno, and Rowland's (1980) formal analysis of how children applied their understanding of the subtraction procedure using Dienes blocks to the standard subtraction procedure using the written number symbols. An important theoretical question in this context is how a learning system identifies the properties that should be incorporated into a new procedure that is formed on the basis of a procedure in another domain.

Publications and Technical Reports

Riley, M. S. (May 1985). *User Understanding*. Technical Report ICS-8504, Institute for Cognitive Science, University of California, San Diego. NR667-538.

Unpublished Manuscripts

Hestenes, E. (July 1985). *The role of previously learned concepts and perceptual processes in learning basic electricity*. Unpublished senior project report. San Diego: University of California, San Diego.

Leeman, E. (June 1985). *Chips analogy*. Unpublished senior project report. San Diego: University of California, San Diego.

Moore, R. (June 1985). *Causal relationships in transitional mental models*. Unpublished senior project report. San Diego: University of California, San Diego.

Prince, L. *Structural understanding: Using a concrete model to understand basic electricity relationships*. Unpublished senior project report. San Diego: University of California, San Diego.

Presentations

Riley, M. S. *Structural understanding in problem solving*. Talk presented at the ONR Contractors' Meeting, University of Washington, 6 - 8 May, 1985.

Riley, M. S. *Analyses of problem solving in basic electricity: Implications for* the design of an intelligent tutor. Talk presented at the workshop on "the Bite-Sized Architecture" sponsored by the Intelligent Tutoring Systems Group, Learning Research and Development Center, University of Pittsburgh, 12 - 13 July, 1985.

Conferences

Mary Riley and Eric Hestenes attended the Cognitive Science Society meeting at the University of Irvine (August 15 - 17).

Eric Hestenes attended the International Joint Conference on Artificial Intelligence at the University of California, Los Angeles (August 18 -23).

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Riley, M. S. (1984). *Structural understanding in performance and learning*. Unpublished doctoral dissertation. Pittsburgh, PA: Learning Research and Development Center, University of Pittsburgh.

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Montague, W. E., Riley, M. S., & Konoske, P. (1985). *Preliminary evaluation of a concrete analogue for teaching basic electronics*. Unpublished manuscript. San Diego: Navy Personnel Research and Development Center.

Resnick, L. B., Greeno, J. G., & Rowland, J. (1980). *MOLLY: A model of learning from mapping instruction*. Unpublished manuscript. Pittsburgh: University of Pittsburgh, Learning Research and Development Center.

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