DOCUMENT RESUME

ED 354 339 CE 063 048

AUTHOR	Satchwell, Richard E.; Johnson, Scott D.
TITLE	The Effect of Conceptual Diagrams on Aviation Mechanics' Technical Systems Understanding.
SPONS AGENCY	National Center for Research in Vocational Education, Berkeley, CA.; Office of Vocational and Adult Education (ED), Washington, DC.
PUB DATE	4 Dec 92
NOTE	25p.; Paper presented at the Annual Meeting of the American Vocational Association (St. Louis, MO, December 4, 1992).
PUB TYPE	Speeches/Conference Papers (150) -- Reports - Research/Technical (143)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	Aviation Education; *Aviation Mechanics; *Cognitive Development; *Cognitive Structures; Curriculum Development; *Diagrams; Educational Research; Higher Education; Instructional Effectiveness; *Instructional Materials; *Material Development; Teaching Methods; Thinking Skills

ABSTRACT

A quasi-experimental study explored the effect of functional flow diagrams on technical system understanding. An individualized field training package which contained schematic diagrams that illustrated an aircraft's electrical system was complimented with functional flow diagrams. In a 4-week treatment, a control group of 10 students enrolled in Aircraft Systems II in the Institute of Aviation (University of Illinois at Urbana-Champaign) received the instructional package that contained only schematic diagrams. The treatment group of eight students enrolled in the same course received an instructional package that contained the schematic diagrams and additional conceptual diagrams of the systems. Following each of the four units of instruction, subjects were given unit tests designed around the structure, function, and behavior of the system. T-tests were used to compare test scores. Four subjects from each group were also randomly selected to perform card sorting tasks at the end of each unit. Results showed that use of functional flow diagrams improved overall system understanding related to the electrical systems and improved significantly subjects' ability to reconstruct conceptual models similar to those of an expert. The functional flow diagrams were an effective instructional medium for enhancing students' conceptual understanding of the causal behavior of the system. (Appendixes include 4 tables, and 4 figures.) Contains 38 references. (YLB)

The Effect of Conceptual Diagrams on Aviation Mechanics' Technical Systems Understanding

Richard E. Satchwell and Scott D. Johnson

University of Illinois at Urbana-Champaign

Department of Vocational and Technical Education

Paper presented at the annual meeting of the American Vocational Association,

December 4, 1992

St. Louis, Missouri

Running head: CONCEPTUAL DIAGRAMS

Author Notes

The research reported in this paper has been supported by the National Center for Research in Vocational Education, under a grant from the Office of Vocational and Adult Education, U. S. Department of Education. This paper has not been reviewed by the National Center and is not an official Publication of the Center. Please direct all correspondence to Scott D. Johnson, University of Illinois, 1310 South Sixth Street, Champaign, IL, 61820.

The Effect of Conceptual Diagrams on Aviation Mechanics' Technical Systems Understanding

Abstract

This quasi-experimental study explored the effect of functional flow diagrams on technical system understanding. An individualized field training package which contained schematic diagrams that illustrated an aircraft's electrical system was complimented with functional flow diagrams. A four week treatment was administered with a control group receiving the instructional package which contained only schematic diagrams. The treatment group received an instructional package that contained the schematic diagrams and additional conceptual diagrams of the systems. The following research questions were addressed:

1. Do functional flow diagrams increase student's understanding of the structural, functional, and behavioral aspects of technical systems?

2. Do functional flow diagrams enhance student's knowledge structures of technical systems?

Results of this study show that the use of functional flow diagrams was effective for improving overall system understanding related to the electrical systems. The functional flow diagrams were also found to be an effective instructional media for enhancing students' conceptual understanding of the causal behavior of the system. In addition, the use of the functional flow diagram was found to significantly improve the subjects' ability to re-construct conceptual models that were similar to those of an expert.

The Effect of Conceptual Diagrams on Aviation Mechanics' Technical Systems Understanding

Research directed at expert and novice differences in domains such as financial reasoning (Bouwman, 1983), physics and mechanics (Chi, Feltovich, & Glaser, 1982; Larkin, McDermott, Simon, & Simon, 1980), medical diagnosis (Elstein, Shulman, & Sprafka, 1978), and electronic troubleshooting (Johnson, 1987) has attempted to identify those characteristics that are associated with expertise. As a result of this research, it appears that experts have large detailed knowledge structures related to how systems operate that partially stems from experiential knowledge of the system (Chi, Glaser, & Farr, 1988). One goal of technical training and vocational education is to bring the novice closer to the expert's level of understanding. The use of an expert's causal mental model of how a system works may prove beneficial when training novices. The expert's model may resolve the ambiguities of the system and provide more robust component models of the device. "From the learner's perspective, the simply constructed, but correct causal model can serve as a cognitive framework for organizing forthcoming refinements derived from models with fewer implicit assumptions" (de Kleer & Brown, 1983, p.184). In line with this reasoning, Brown and Burton (1987) advocate teaching technicians (a) conceptual knowledge, based on qualitative, causal models of how systems function; (b) how to develop causal mental models from the structure of the device; and (c) how to use the developed model to understand the rationale behind various troubleshooting procedures.

A major goal for vocational and technical training is to develop reasoning skills that will enhance a person's problem solving capabilities, as well as facilitate learning at a conceptual level. However, current instructional materials developed for technical instruction do not appear to be effective in helping students develop this level of understanding (Johnson, Foster, & Satchwell, 1989; Mayer & Gallini, 1990; National Alliance of Business, 1988). For example, a typical approach to fluid power systems instruction is to use schematic diagrams to describe the function and operation of that system and its component parts. When students do not have a sufficient background in hydraulics to fully comprehend the complex, abstract nature of the schematic diagram they are unable to develop the conceptual understanding of the system. Other types of graphic representations may prove beneficial to technical systems instruction.

The major focus of this inquiry was to examine the effectiveness of two types of network diagrams for improving college level aviation mechanics students' understanding of technical systems. Specifically, the effectiveness of complimenting the schematic network diagram with the functional flow diagram was explored.

Mental Models

Recent cognitive science research has studied how people mentally represent complex phenomena. Resultant theories suggest that when people interact with their environment, with other people, or with technological devices, they form internal mental models of themselves and the things with which they are interacting. These models help to predict or explain our interactions with our environment, other people, and with technical apparatus (Norman, 1983). Novices often lack a mental model or begin with a general model of the system which becomes more detailed as they gain experience. For example, some people can imagine how a cassette tape recorder works to record a favorite song. They can mentally visualize how devices like these might work, compiling a "picture" in their mind of the components within the system (e.g., recording head, microphone, magnetic tape, etc.). Whether accurate or not, they can construct explanations of how the recording device works based on their prior knowledge of the component parts within that system. In order to develop a deeper level of understanding with respect to the cassette tape recorder and its specific components, people need a basic understanding of the system's physical structure, knowledge of the function of it's component parts, and an understanding of how these components interact with each other. While our understanding of these underlining principles and concepts may not be complete or even accurate, we must possess some knowledge of these concepts if we are to develop an understanding of technical systems.

The recording device example identifies a type of mental model (i.e., causal mental model) that is thought to be critical for complete understanding of technical systems. This notion was initially introduced by de Kleer and Brown (1981, 1983) during their investigations on how people acquire an understanding of technological devices. A causal mental model is an internalized representation of the relationships within a given system. A person can mentally "run" the model, producing a mental simulation that predicts the system's actions. For example, an expert troubleshooter can mentally insert various faults into their causal mental model of a technical system and analyze the results.

Causal mental models influence not only how a problem is represented but also which stimuli are encoded and how these stimuli are encoded. In this way, causal mental models serve as mnemonic devices that facilitate remembering in the same manner as schemata (Borgman, 1982; Gott, Bennett, & Gillet, 1986; Johnson, 1987, 1988; Norman, 1983).

Research suggests that experts rely on these causal mental models to understand technical devices. Kieras and Bovair (1984) have investigated the role of a mental model in learning how to operate an unfamiliar piece of equipment. The results of their study suggests that a device model is not needed for procedures that are easy and familiar, although for more difficult unfamiliar procedures, the device model does improve performance on learning and retaining the operating procedures of a device.

People may also develop several other types of mental models when reasoning about an electrical system. Simple, qualitative physical models may be developed to explain an electrical circuit at a micro level, for example a structural model might convey how electrical charges are redistributed through a resistor when the current across the resistor changes. Another model may be developed to convey the high-level functionality of the circuit, for example a functional model might represent the system's purpose and how the subsystems within the circuit interact to achieve the system's purpose. The third model is known as the behavioral model. This type of model is developed to explain the behavior of the system at the component level, for example, how changes in the state of one component can cause changes in the states of other components (White and Frederiksen, 1987).

Network Diagrams for Instruction

The use of graphic materials to compliment regular classroom instruction has become a common instructional technique at all levels of education. After reviewing over 650 articles related to the use of visualized instruction, Dwyer concludes that "present methods of selecting and using visual materials for instructional purposes are grossly ineffective and wasteful and that, in many cases, for specific educational objectives visualization of content material is no more effective than the same instruction without visualization"(1978, p. xiii). Literature related to visual materials and pedagogical approaches echo the concerns expressed by Dwyer. "One of the major questions of future research dealing with training techniques should be how the internal model can be developed efficiently and correctly" (Braune & Trollip, 1982, p. 997).

Dwyer's conclusions and more recent concerns expressed in the technical training literature, have guided this research to investigate the use of two different types of network diagrams (i.e., functional flow diagrams and schematic diagrams) for improving student understanding of technical systems. According to Waller (1981), a network diagram is a graphic representation of a system, a process, an organization, or a mechanism. This type of diagram is often used in technical instruction to illustrate a company structure, an industrial process, or technical system.

Functional flow diagrams. Studies have suggested that different features of diagrams might convey different types of information. For this investigation, the functional flow diagram is used to represent the fundamental concepts or essential component parts of a system and to organize meaningful relationships between these concepts and component parts. Current literature has stressed the importance of meaningful learning of concepts and principles in school learning (Ausubel, Novak, & Hanesian, 1978; DeKlerk, 1987; Novak & Gowin, 1984; Stice, & Alvarez, 1986). Several investigations have attempted to "map" the concepts held by students (Novak, Gowin, & Johansen, 1983; Pankratius, & Keith, 1987; Stice, & Alvarez, 1986). According to Ausubel's learning theory, concepts play an important role in the acquisition and use of knowledge. In order to learn meaningfully, students must relate ideas to one another and to their existing conceptual schema.

Schematic diagrams. In this study, a schematic network diagram is one that uses abstract symbols to represent the component parts of a technical system and connects these abstract symbols with lines to indicate their relationship. Schematic diagrams are used extensively to illustrate electronic circuits, to diagram system components in troubleshooting manuals, and to provide visual clarity during technician instruction. Use of the schematic diagram for developing technical system understanding is advocated by the United States Navy in a electricity and electronics training series produced by the Naval Education and Training Program Development Center (1985). This publication entitled; Introduction to Electrical Conductors, Wiring Techniques, and Schematic Reading states that, "the schematic diagram is the most useful of all the diagrams in learning overall system operation" (p. 39). Even though the schematic diagram is used widely as a visual aid for instruction, and highly advocated by the United States Navy as the most useful type of diagram when learning the operation of a system, no research has been identified that has investigated it's instructional effectiveness.

Functional flow diagrams vs. schematic diagrams. The following differences between these two types of network diagrams have been identified for this study.

1. The functional flow diagram has the ability to convey a conceptual level of understanding about the system, displaying the conceptual function of only the system's essential component parts, whereas, the schematic diagram conveys a component level of understanding about the system, displaying the relationship of all component parts of the system.

2. The functional flow diagram conveys the causal relationships between the system's essential component parts (e.g., activating component A causes component B to activate), whereas, the schematic diagram does not explicitly convey any causal relationships among the component parts of a system.

3. The functional flow diagram has the ability to impart a time sequence on the system (i.e., component A must change before component B changes), whereas, the schematic diagram represents the system at only one moment in time.

4. The functional flow diagram has the ability to disclose a sense of motion to the current flowing through the system (i.e., one can easily follow the current flow through the system as it is indicated on the functional flow diagram by the use of arrows and action oriented

words such as; activated, energized, etc.), whereas, the schematic diagram conveys the current in a stationary or static state.

In summary, the cognitive research suggests that in order for the progression from novice to expert to take place, novices must develop accurate causal mental models of the technical systems with which they interact. The United States Navy, in a electricity and electronics training series has made the claim that the schematic diagram is the most useful type of network diagram for learning how technical systems operate. After extensive searching, no reported research could be found to back the Navy's claim about the effectiveness of using schematic diagrams for developing technical system understanding; therefore, the question still remains as to what pedagogical approaches are most appropriate for developing the novice's causal mental model.

The purpose of this experiment was to explore the effect of functional flow diagrams on technical system understanding. The following research questions were addressed: (1) Do functional flow diagrams increase students' understanding of the structural, functional, and behavioral aspects of technical systems, and (2) Do functional flow diagrams enhance students' knowledge structures of technical systems?

Method

Subjects

During the Fall semester of 1991 eighteen male students were enrolled in AVI 170, Aircraft Systems II in the Institute of Aviation of the University of Illinois at Urbana-Champaign. Students enrolled in this course were divided by the Institute of Aviation into two laboratory sections. Section A met every Monday and Wednesday from 8:00 a.m. - 11:00 a.m. and section B met every Monday and Wednesday from 1:00 p.m. - 4:00 p.m. Students from both sections attended a lecture and discussion class every Thursday from 1:00 p.m. - 3:00 p.m. This study used a quasi-experimental design. Laboratory section B had eight students and was randomly selected as an intact treatment group for this study. Section A had ten students and became an intact control group for this study.

Research suggests that prior experience (Chi, Glaser, & Farr, 1988), as well as skill level (Gitomer, 1988) may influence a person's knowledge structure. Therefore, it was important to establish that the two groups were equal in that regard. Aptitude indicators for both groups were obtained from the archival records of the Institute of Aviation. These included the American College Testing Program (ACT) examination scores, Survey of Mechanical Insight scores, and University of Illinois grade point averages. Domain specific indices included grades earned in the prerequisite basic electronics course AVI 145, and the AVI 170 final examination scores. The AVI final examination was an instructor prepared comprehensive examination comprised of 75 multiple choice and 15 short answer items. This examination covered topics including instrumentation, navigational communications, and general electrical systems.

Two standardized examinations were used as aptitude measures. The ACT and The Survey of Mechanical Insight (SMI) examinations are general measures of academic and mechanical aptitude and are used for entrance screening by the university and the Institute of Aviation. The Survey of Mechanical Insight was developed by Daniel R. Miller (CBT/McGraw Hill, 1955). Reliability of the SMI as determined by KR-20 was .87 in trials with 277 oil company applicants. Split half reliability corrected by the Spearman Brown formula was .88 with 250 industrial personnel.

The aptitude and domain specific knowledge characteristics of the two groups were compared to ensure that the group differences would not affect the outcome of the study. Data were analyzed using the SAS System statistical program (release 5.18, 1986) on the main-frame computer at the University of Illinois Computing Services. There were no significant differences between the two groups in this study. Table 1 presents the results associated with t-test differences between the two groups.

Insert Table 1 about here

Instructional Materials

The field training package entitled Introduction to King Air Electrical Systems, published by the Beech Aircraft Corporation (1986), currently being used for instruction in the AVI 170 course was utilized for this study. This individualized instructional package teaches about the electrical systems and subsystems of the King Air 90, 200, and 300 series aircraft. This package introduces the major electrical concepts of DC generation, dual-bus DC distribution, multiple-bus DC distribution, and AC generation/distribution. This training package makes regular use of the schematic diagram to illustrate the systems and subsystems of the King Aircraft. The first electrical system introduced in the training package was voltage regulation. Figure 1 illustrates the schematic diagram used to depict the voltage regulation system. This diagram is typical of those used throughout this package to illustrate the systems under study.

Insert Figure 1 about here

Experimental materials. The treatment for this investigation consisted of preceding each schematic diagram used in the current training package with a functional flow diagram showing the system at a conceptual level, indicating the causal nature of the system. A subject matter expert from Flight Safety International and one from Lucas Aerospace were consulted in the initial phase of this study to assist in the conceptualization and verification of the functional flow diagrams. As the diagrams were completed and verified, they were included in the training package designed for the treatment group. In addition, the existing text within units 3, 4, 5, and 6 was supplemented for the treatment group with a brief explanation of the functional flow diagram. Figure 2 illustrates the functional flow diagram used to depict a voltage regulation system. This diagram is typical of those used throughout the treatment of this study.

Insert Figure 2 about here

Units 1 and 2 of this training package cover the use of the training manual, service manual and nomenclature. These units do not include schematic diagrams or instruction concerning electrical systems, therefore were of little concern to this investigation. In total, 39 schematic diagrams appear in the original training package and were complemented with 25 researcher developed functional flow diagrams.

The number of functional flow diagrams differ from that of the schematic diagrams because during treatment development, it was determined that 7 schematic diagrams in the unit covering DC generation and the generator starting sequence could be preceded by only 1 functional flow diagram that illustrated the information about the system from the generator start to the generator on sequence. This functional flow diagram allows the student to see the causal nature of the entire generator starting sequence across two side-by-side pages of the training package. In addition, 6 schematic diagrams appearing in the control material were part of an application exercise where students were asked to identify the location of specific parts on a schematic diagram. It was not appropriate to include a functional flow diagram for these schematic exercises. The last discrepancy occurs because one functional flow diagram preceded two schematic diagrams illustrating the aircraft's reverse current protection system on both the multiple-bus and the dual-bus system. It was determined that the two systems function identically at the conceptual level, therefore, only one functional flow diagram was needed to represent both systems.

Each functional flow diagram was verified for it's content validity by technical experts at the Institute of Aviation and a technical expert at Flight Safety International located in Wichita, Kansas. Caution was taken by the researchers when modifying the existing training package to duplicate the existing page layout, font style, font sizes, and paper weight to eliminate possible treatment effects. Additional precautions were taken to reduce treatment effects, this training package was administered in the same manner that it had historically been administered with one exception. Historically, students were given approximately eight weeks to complete two of these training packages. This treatment took place over a four week period.

Test Development.

Royer (1986), indicated that if a person has developed understanding from instruction, they should be able to demonstrate their acquired knowledge by using this knowledge in a meaningful way. While discussing the theory of qualitative reasoning, de Kleer (1985), indicated that in order for a person to develop a causal mental model of a physical system, one would have to reason qualitatively about the system's structure, function, and behavior.

Combining Royer's notion of understanding with de Kleer's theory of qualitative reasoning results in the following working definition of technical system understanding. For the purpose of this inquiry, technical system understanding was defined as one's ability to use the knowledge about a technical system acquired during instruction in a meaningful way, to qualitatively reason about three aspects of the technical system studied: (a) the structure of the system, (b) the function of the components within the system, and (c) the behavior of those components.

The structure of a system is thought of as it's schematic. This is considered a static concept, in that it does not change over time. A system's structure is always the same.

The function of the system is also considered to be static. The system's function is thought of as the operational characteristics of individual circuit components. The function of a component equates to the purpose of the component (i.e., the purpose or function of a diode is to control current flow, regardless of what system or circuit it is placed in).

The behavior of a system is interpreted as what the system does. The behavior of a system is considered a dynamic concept that is time dependent. One must consider at what point in time is the system being considered.

The three aspects of system understanding are considered to have an hierarchical relationship, in that the structure of a system is thought to be the lowest level of understanding. One does not have to reason about the function or behavior of a system to understand it's schematic. This information can be derived by observing the schematic diagram of the system. The function of the system is considered the next level of understanding. One must know how the parts are connected (i.e., system structure) and understand the operational characteristics of individual components within the system to possess system understanding at this level. The highest level of system understanding is considered to be at the behavioral level. At this level of understanding it is assumed that, one not only knows how the parts are connected and has an understanding of how individual components operate, but they can also reason about how the entire system will behave at different points in time.

Keeping the three aspects of the system understanding in mind, four tests were designed to assess subject knowledge of the structure, function, and behavioral aspects of the King Aircraft's electrical systems introduced in the training manual. Table 2 reflects several sample questions directed at each of the three levels of system understanding.

Insert Table 2 about here

Three domain experts were provided a copy of the definitions and sample questions related to system structure, function, and behavior and asked to label each test question according to what type of understanding covered by the question. An interrater agreement measure was determined to be .91. These tests were administered during laboratory sessions following completion of each of the four units of interest.

Procedure

The treatment took place over a four week period. Each week students were assigned on unit of instruction to be completed outside of class. Subjects were asked to complete each unit of instruction using the following procedures: (a) view a video tape that accompanied the package (b) read each unit of instruction, and (c) answer related questions at the end of each unit. Following each unit of instruction, the subjects were given unit tests which were designed around the structure, function, and behavior of the system. The unit tests were analyzed using appropriate t-test which compared the scores obtained from the two groups.

To provide additional depth of analysis, four subjects from each group were randomly selected to perform several card sorting tasks at the end of each unit of instruction. During each card sorting session, up to 4 individual knowledge structures were collected from each subject of the sub-group. The card sorting tasks consisted of one of two types. The first type was a modified version of the fill-in-the-structure technique as outlined by Naveh-Benjamine and Lin, (1991). This procedure had the subjects arrange cards labeled with the concepts according to their knowledge structure of the system. During this task, subjects were given a sheet of paper to arrange their cards on that contained the expert's structure of the system without the labels. The complexity of this task varied from 5 to 15 different concepts to be placed by each subject. At the end of a five minute period, subjects were asked to glue their cards onto the paper. Each card sorting session began with this type of task because it is considered the easiest of the two.

The second type of card sorting task is considered to be more difficult to perform. During this task each subject was provided a blank sheet of paper and between 5 and 15 cards to sort. Subjects were asked to arrange the cards to represent the functional flow diagram of the selected concepts. At the end of five minutes the subjects were asked to glue their cards in place and then draw lines to establish the relationship between concepts and place arrowheads at the ends of each line to indicate the direction of current flow.

In total, 11 knowledge structures were collected for 6 of the eight subjects in this sub-group. One subject from the treatment group missed the card sorting session for unit 5, resulting in a total of 8 knowledge structures being collected for him and another subject belonging to the control group missed the card sorting task for unit 6, resulting in a total of 10 knowledge structures being collected for that subject.

Results

Test Analysis

Raw scores for the four unit tests, as well as the classification scheme (i.e., structure, function, behavior) were entered into the SAS System. Central tendencies of the two groups were then computed and t-tests were run to determine if there were any differences between the groups' general level of system understanding (see Table 3). A significant difference was obtained based on the total test scores of each group; $t(16) = 3.21$, $p < .01$. This finding shows that the students who used the instructional package which contained conceptual diagrams achieved significantly higher scores on the unit tests.

Follow-up analysis was then conducted to determine if there were treatment effects based on the classification scheme. Test scores were segmented into the classifications of structure, function, and behavior, and then t-tests were calculated to determine if there were any differences between the groups for level of system understanding. The results, as shown in Table 3, suggest that the use of the concept maps had little effect of subjects' understanding of the structure and function of the technical systems while a significant difference was found in behavioral understanding, $t(16) = 3.65, p < .01$.

Insert Table 3 about here

Knowledge structure analysis. The data resulting from the card sorting tasks performed by the selected sub-group during interviews were analyzed in a number of ways. A total of 84 concept maps were collected from this sub-group. First, the maps were analyzed to determine their measure of spatial association. The question being asked at this point was, how closely do the knowledge structures of the subjects resemble those of the expert like mental model? To answer this question and provide data for further analysis, data matrices were constructed for each concept map. The generalized measures of association between data matrices were then determined using MicroQAP, a microcomputer implementation of generalized measures of spatial association (Anselin, 1986). Correlation coefficients comparing subject structures to expert-like structures were calculated and averaged across all card sorting tasks. Results of t-test calculations identified significant differences between the accuracy of the control and treatment groups. $t(82) = -4.705$, $p < .001$. This finding suggests that the use of concept maps lead to the creation of more expert-like mental models of technical systems than was possible through schematic-oriented instruction.

To provide another index of similarity and further illustrate any differences between the control and treatment groups' ability to create an expert-like mental model, the total number of correct responses were tabulated for each subject's knowledge structure related to the selected concepts being assessed. This measure provides an overall similarity index of the subjects' cognitive structures to that of the expert's (Naveh-Benjamine, & Lin, 1991). Table 4 indicates the number of correct responses by knowledge structure for each group. This finding suggests that the use of concept maps during instruction increases the accuracy of students' knowledge structures related to the selected concepts assessed through the card sorting task.

Insert Table 4 about here

Each of the remaining six knowledge structures of the second type of card sorting task were assessed to determine how they vary from the ideal organization. Group knowledge structures were generated for each of these remaining concepts for both experimental groups to determine if any misconceptions were held by the group.

Figure 3 represents the group knowledge structure generated for the control group, during the fourth unit of instruction covering the dual-bus DC distribution system. The particular concept that the students were asked to diagram was a generator assisted start with the right engine running. This group knowledge structure represents the conceptual structure held by at least two of the four control subjects. A comparison between the control group's representation and the expert-like structure shows that there are several inconsistencies. The control group erroneously connect the right starter/generator to the right generator bus and the line contactor to the left starter/generator. This error indicates a misconception about the line contactor, a component which must close before power from the right generator can pass through the system. In addition, only one subject from the control group represented the correct connection between the left starter relay and the left starter. One subject represented this connection in reverse, indicating that the majority of subjects from the control group lack an appropriate understanding about the left starter relay. The starter relay must close before power can reach the left starter to assist with the start of the left generator. When examining erroneous connections related to relays on the remaining knowledge structures generated for both experimental groups, it was revealed that the control group made more errors than the treatment group. This suggests that the use of conceptual diagrams during technical system instruction may assist the student in developing a more conceptual understanding related to the function of system components.

Insert Figure 3 about here

The group knowledge structure generated for the treatment group, shown in Figure 4, was generated in the same fashion as the control group's structure. A comparison between the treatment group's representation and the ideal representation shows that there are few inconsistencies. Of the eight expected connections (including left starter/generator to nothing), only two connections were not completed by all four subjects from the treatment group. This suggests fewer misconceptions in the relationships between components for those students receiving instruction using functional flow diagrams than was possible through schematic-oriented instruction.

Insert Figure 4 about here

Discussion

After reviewing the results of this study it appears that complimenting schematic diagrams with functional flow diagrams, which illustrate the causal nature of the system, may have a positive effect on a learner's overall understanding of the system. In addition, concept maps appear to support the development of behavioral understanding which is critical for complete understanding. This pedagogical approach appears to be an effective way to assist the students' developing knowledge structure when reasoning about the behavior of electrical systems.

Why were the functional flow diagrams effective at increasing the higher levels of system understanding? While other factors may have been involved, it appears that three major characteristics of the functional flow diagram may account for this effect. One obvious characteristic of the functional flow diagram is it's simplicity. The functional flow diagrams developed for this study show only the <u>essential</u> components, in contrast to the schematic diagrams used in the control package that show <u>non-essential</u> parts of the system. The functional flow diagram may resolve the ambiguities of the system. The second characteristic that may account for this effect is the functional flow diagram's ability to organize meaningful relationships between the concepts and component parts of a given system in contract to the abstract symbols used in the schematic diagram. This may provide the student to with a better conceptual understanding of the system. The third characteristic unique to the functional flow diagram is it's ability to illustrate the causal nature of the system to the learner, bringing the learner closer to the expert's causal mental model.

The card sorting task, although not the focus of this study, proved to be an effective way to very quickly assess student understanding. Students appeared to enjoy this task, seeing it as a challenge rather than another test. This technique lends itself to a variety of applications where a person's knowledge structure is to be assessed. Further refinements in this technique are encouraged as it may prove to be a viable means to assess student understanding in other endeavors of inquiry.

<u>Limitations</u>

Care must be taken when interpreting the findings of this study. First, it is important to realize that this study was designed and conducted for the purpose of contrasting the schematic diagram used in isolation with the schematic diagram complimented by a functional flow diagram. This excludes several different types of pictorial illustrations found in the literature (e.g., black and white photographs, color photographs, analogous pictures, etc.). Second, because of the small sample size, the results of this study cannot be generalized to a population other than the limited population of college level aviation mechanics from which the subjects were selected. The results can, however, be used as indicators for future investigations of pedagogical approaches in other technical systems.

Implications for Instructional Media

This study was conducted with support from the National Center for Research in Vocational Education. This organization has vested interests in the improvement of materials used for technical training and instruction. The implications of this research should, therefore, focus on the improvement of instructional media used during technical instruction

A major goal for vocational and technical training is to develop reasoning skills that will enhance a person's understanding of technical systems, as well as facilitate learning at a conceptual level. Investigating pedagogical approaches to find appropriate methods for developing the novice's causal mental model will benefit technical training and vocational education in several ways. One gain to be realized is the reduction in training time. The current training time to transform a person from the novice level to an expert level is enormous (Glaser & Chi, 1988, Posner, 1988). Through investigations of this type we will find the optimum pedagogical methods to acquire expertise. In addition, a potential cost reduction of training may be realized. If we can find methods to advance the novice more efficiently we will reduce the cost of training. Besides the reduction in time and training cost, vocational and technical education will realize a better product. The technician who is able to develop a causal model of the system with which they are interacting will be better able to understand the structural, functional, and behavioral aspects of the system. The technician able to reason about the system in this way may become a more efficient troubleshooter, resulting in a reduction of the high cost of maintenance.

With the constant sophistication of technical systems, the information we must teach continues to change. These changes require teachers to constantly review, revise, enhance and develop new instructional materials. From the results of this study it is clear that instructional materials used for technical systems instruction can be enhanced to develop a higher, conceptual level of system understanding. Additional research must be conducted to verify the use of the functional flow diagram across other systems, as well as other types of instructional media.

References

Anselin, L. (1986). MicroQAP, a microcomputer implementation of generalized measures of spatial association [Computer program]. Santa Barbara, CA: Department of Geography, University of California. (National Science Foundation Grant No. SES-8600465)

Ausubel, D. P., Novak, J. D., & Hanesean, H. (1978). Educational psychology: A cognitive view (2nd Ed.). New York: Holt, Rinehart and Winston.

Beech Aircraft Corporation. (1986). Introduction to King Air electrical systems, Field training package. Wichita, KS: Author.

Borgman, C. L. (1982). Mental models: Ways of looking at a system. Bulletin Of The American Society For Information Science, 9, 38-39.

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

Braune, R. J., & Trollip, S. R. (1982, October). Towards an internal model in pilot training. Aviation Space, and Environmental Medicine. 996-999.

Brown, J. S., & Burton, R. R. (1987). Reactive learning environments for teaching electronic troubleshooting. In W. B. Rouse (Ed.), Advances in man-machine systems research. (pp. 65-98). Greenwich, CN: JAI Press Inc.

Chi, M. T. H., Feltovich, P. J., & Glaser, R. (1982). Categorization and representation of physics problems by experts and novices. Cognitive Science, 5, 121-152.

Chi, M. T. H., Glaser, R., & Farr, M. J. (Eds.) (1988). The nature of expertise. Hillsdale, NJ: Lawrence Erlbaum Associates.

de Kleer, J. (1985). How circuits work. In Bobrow, D. G. (Ed), Qualitative reasoning about physical systems. (pp. 205-280). Cambridge, Massachusetts: The MIT Press.

de Kleer, J., & Brown, J. S. (1981). Mental models of physical mechanisms and their acquisition. In J. R. Anderson (Ed.), Cognitive skills and their acquisition. (pp. 285-309). Hillsdale, NJ: Erlbaum.

de Kleer, J., & Brown, J. S. (1983). Assumptions and ambiguities in mechanistic mental models. In D. Gentner & A. L. Stevens (Eds.), Mental models (pp. 155-190). Hillsdale, NJ: Erlbaum.

DeKlerk, L. F. W. (1987, April). The role of prior experience in learning from instruction. Paper presented at the annual meeting of the American Educational Research Association, Washington, DC. (ERIC Document Reproduction Service No. ED 286 931).

Dwyer, F. M. (1978). Strategies for improving visual learning. State College, PA: Learning Services.

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

Gitomer, D. H. (1988). Individual differences in technical troubleshooting. Human performance, 1(2), 111-131.

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

Gott, S. P., Bennett, W., & Gillet, W. (1986). Models of technical competence for intelligent tutoring systems. Journal of Computer-Based Instruction, 13(2), 43-46.

Johnson, S. D. (1987). Knowledge and skill differences between expert and novice service technicians on technical troubleshooting tasks (Tech. Report No. 20). St. Paul: University of Minnesota, Training and Development Research Center. (ERIC Document Reproduction Service No ED 284 054).

Johnson, S. D. (1988). Cognitive analysis of expert and novice troubleshooting performance. Performance Improvement Quarterly, 1(3), 38-54.

Johnson, S. D., Foster, W. T., & Satchwell, R. (1989). Sophisticated technology, the workforce, and vocational education. Springfield, IL: Department of Adult, Vocational and Technical Education, Illinois State Board of Education.

Kieras, D. E., & Bovair, S. (1984). The role of a mental model in learning to operate a device. Cognitive Science, 8, 255-273.

Larkin, J., McDermott, J., Simon, D. P., & Simon, H. A. (1980). Expert and novice performance in solving physics problems, Science, 208, 1335-1342.

Mayer, R. E., & Gallini, J. K. (1990). When is an illustration worth ten thousand words? Journal of Educational Psychology, 82(4), 715-726.

Miller, D. R. (1955). The survey of mechanical insight. CBT/McGraw Hill.

National Alliance of Business. (1988). Shaping tomorrow's workforce. Washington, DC: Author.

Naval Education and Training Program Development Center. (1985). Module 4-Introduction to Electrical Conductors, Wiring Techniques, and Schematic Reading (Navel Education and Training Command Publication No. 0507-LP-172-0405). Washington, DC: U. S. Government Printing Office.

Naveh-Benjamin, M., & Lin, Y. (1991). Assessing students' organization of concepts: A manual for measuring course-specific knowledge structures. Ann Arbor, MI: The University of Michigan, National Center for Research to Improve Post Secondary Teaching and Learning. (ERIC Document Reproduction Service No. ED 338 124).

Norman, D. A. (1983). Some observations on mental models. In D. Gentner & A. L. Stevens (Eds.), Mental models (pp. 7-14). Hillsdale, NJ: Erlbaum.

Novak, J. D., Gowin, D. B., & Johansen, G. T. (1983). The use of concept mapping and knowledge vee mapping with junior high school science students. Science Education, 67(5), 625-645.

Novak, J., & Gowin, D. B. (1984). Learning how to learn. Cambridge: Cambridge University Press.

Pankratius, W. J., & Keith, T. M. (1987, March). Building an organized knowledge base: Concept mapping in secondary school science. Paper presented at the annual meeting of the National Science Teachers Association, Washington, DC. (ERIC Document Reproduction Service No. ED 280 720).

Posner, M. I. (1988). Introduction: What is it to be an expert? In M. T. H. Chi, R. Claser, & M. J. Farr (Eds.), The nature of expertise (pp. xxix-xxxvi). Hilldale, NJ: Lawrence Erlbaum Associates.

Royer, J. M. (1986). Designing instruction to produce understanding: An Approach based on cognitive theory. In Phye, G. D., & Andre, T. (Eds), Cognitive classroom learning: Understanding, thinking and problem solving. (pp 83-117). New York: Academic Press.

SAS (1986). The SAS system release 5.18 [Computer program]. Cary, NC: SAS Institute Inc.

Stice, C. F., & Alvarez, M. C. (1986). Hierarchical concept mapping: Young children learning how to learn (A viable heuristic for the primary grades). (Report No. 5). Nashville, TN: Tennessee State University, Center of Excellence, Basic Skills for the Disadvantaged, Reading/Writing Component. (ERIC Document Reproduction Service No. ED 274 946).

Waller, R. (1981, April). Understanding network diagrams. Paper presented at the annual meeting of the American Educational Research Association. Los Angeles, CA. (ERIC Document Reproduction Service No. ED 226 695).

White, B. Y. & Frederiksen, J. R. (1987). Causal model progressions as a foundation for intelligent learning environments (Report No. 6686). Boston: BBN Laboratories.

Table 1.

Means, Standard Deviations and t-tests for Demographic Data

	Treatment			Control				
Demographics	n^a	Mean	SD	n^b	Mean	SD	t value	p
Mechanical Insight	4	.72	.15	8	.50	.29	-1.4168	.19
ACT	7	22.14	4.91	10	24.70	3.30	1.2893	.21
AVI 145[c]	8	3.50	1.07	10	3.60	0.97	0.2082	.84
GPA[d]	8	3.79	.51	8	3.91	.23	0.6633	.52
AVI 170[e]	8	84.37	5.50	10	87.40	5.87	1.1162	.28

[a] Numbers of subjects out of 8 who's data was available. [b] Numbers of subjects out of 10 who's data was available. [c] Maximum score = 5.0. [d] University Of Illinois Grade Point Average. [e] Maximum Score = 100.

Table 2.

Sample Test Questions Directed at Three Levels of System Understanding

Levels of System Understanding	Sample Test Questions
•Structure	- The regulator output to the generator field is from GCU pin ____. - Generator output voltage from terminal "B" is sensed at pin ___ of the generator control panel. - List the component(s) that current from the battery must travel through before reaching the battery switch. - Which bus does the battery feed directly into? - The external power unit supplies power to which bus(es)?
•Function	- When both gererators are on-line and producing power, which generator feeds current to the number 2 Dual-fed bus? - Explain the function of a bus. - What compoinent must close before the current from an operating generator can reach it's respective generator bus? - What is the function of a diode? - Explain what happens within the generator control unit (GCU) during reverse current protection.
•Behavior	- Explain why reverse current protection is provided on an aircraft's electrical system. - Explain the purpose of the voltage regulation system. - If the starter switch is activated with a generator on-line, the generator will ________. - Dose current have to flow through the center bus to reach the right generator bus tie? - If the battery relay closes, can the triple-fed bus receive power from the battery?

Table 3.

Means, Standard Deviations and t-Tests for Combined Unit Tests Scores

	Structure		Function		Behavior		Total	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Control (n=10)	11.20	2.44	8.10	1.52	23.40	3.80	42.7	5.68
Treatment (n=8)	11.75	1.03	9.12	0.83	28.5	1.07	49.37	1.60
t value	-0.59		-1.70		-3.65		-3.21	
p value	.56		.10		.00*		.00*	

*$p < .001$

Table 4.

Percentage of Correct Responses by Concept

Concept	Percentage of Correct Responses	
	Treatment	Control
Voltage Regulation	48 of 48 = 100%	27 of 48 = 56.25%
Reverse Current Protection	35 of 40 = 87.50%	24 of 40 = 60.00%
Generator Reset-Generator on	37 of 56 = 66.07%	16 of 56 = 28.57%
Starter Removes Generator From Service	27 of 40 = 67.50%	11 of 40 = 27.5%
DC Bus Distribution	6 of 6 = 100%	6 of 6 = 100%
Electrical Load Distribution	71 of 76 = 93.42%	65 of 76 = 85.52%
Generator Assisted Start Right Engine Running	29 of 32 = 90.62%	15 of 32 = 46.87%
Right Engine Start	12 of 18 = 66.67%	9 of 24 = 37.50%
Left Engine Start	22 of 27 = 81.48%	17 of 36 = 47.22%
Both Generators On-Line	41 of 60 = 68.33%	50 of 80 = 62.5%
Power Select Relay	25 of 32 = 78.12%	12 of 24 = 50.00%

Figure 1. An example of the type of schematic diagram used for the control group. From Introduction to King Air electrical systems, Field training package (p.3-4) by Beech Aircraft Corporation, 1986, Wichita, KS: Author. Copyright 1986 by the Beech Aircraft Corporation. Reprinted by permission.

VOLTAGE REGULATION

The generator output voltage is sensed at the generator side of the line contactor. The control panel supplies the generator field excitation current required to supply the electrical load and maintain a bus voltage of 28.25 VDC.

The generator voltage sense input to the generator control panel is at pin "B", voltage regulator power input is at pin "J" and the regulator output to the generator field is from pin "M" of the control panel connector.

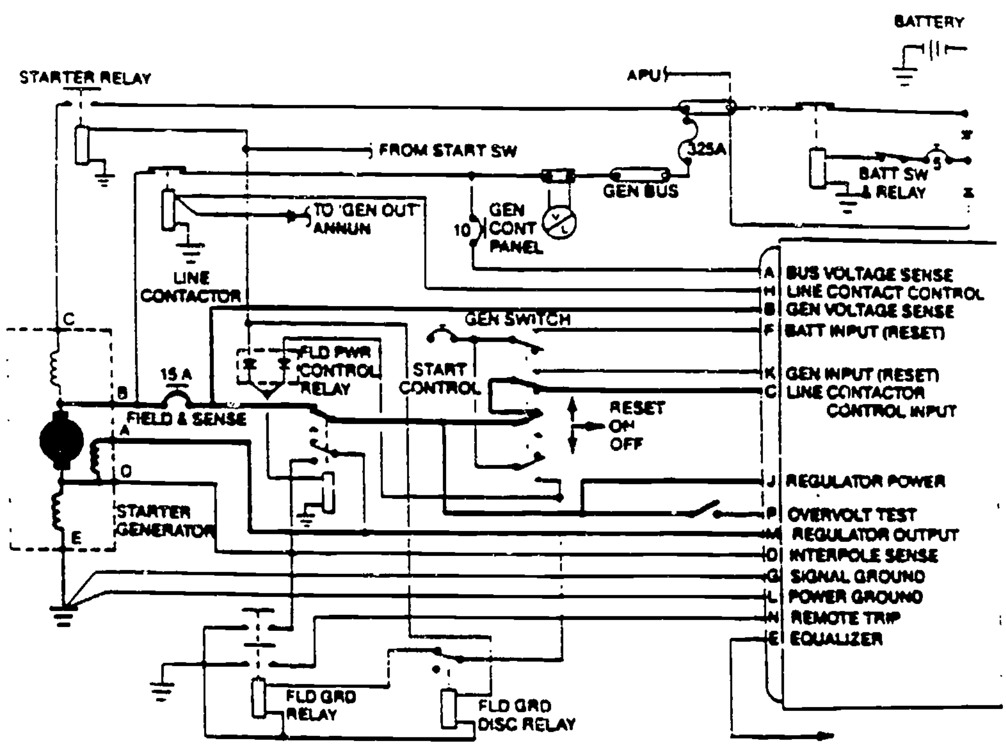


Figure 3-2 Voltage Regulation

Figure 2. An example of the type of functional flow diagram used for the treatment group.

VOLTAGE REGULATION

The generator output voltage is sensed at the generator side of the line contactor. The control panel supplies the generator field excitation current required to supply the electrical load and maintain a bus voltage of 28.25 VDC.

The generator voltage sense input to the generator control panel is at pin "B", voltage regulator power input is at pin "J" and the regulator output to the generator field is from pin "M" of the control panel connector.

Figure 3-2-1 provides a conceptual model of the voltage regulation system. The generator output voltage from terminal "B" enters the generator control unit at pin "J" where it is compared to the reference voltage from a sync oscillator. If the generator control panel detects too little voltage is being produced by the generator it increases the generator excitation and the shunt field strength increases. On the other hand, if the generator is producing too much voltage, the generator control panel decreases generator excitation and the shunt field strength is decreased. The regulated voltage exits the generator control panel at pin "M" and travels to terminal "A" of the generator where it passes through the generator armature and back to the generator output at terminal "B". This cycle continues as long as the generator is operating.

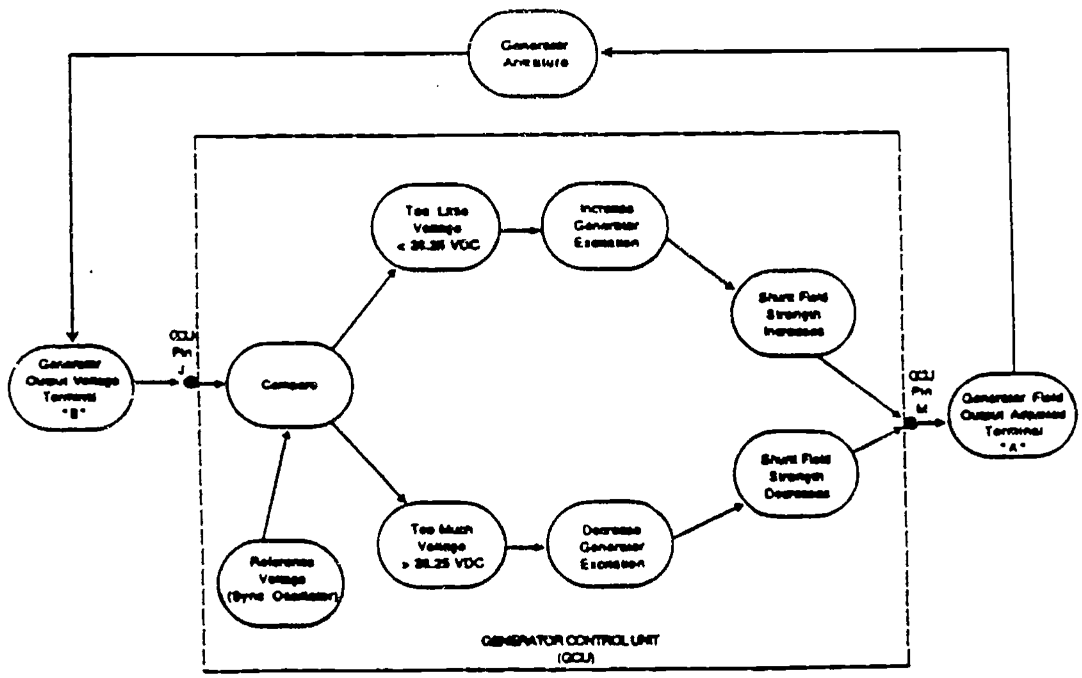
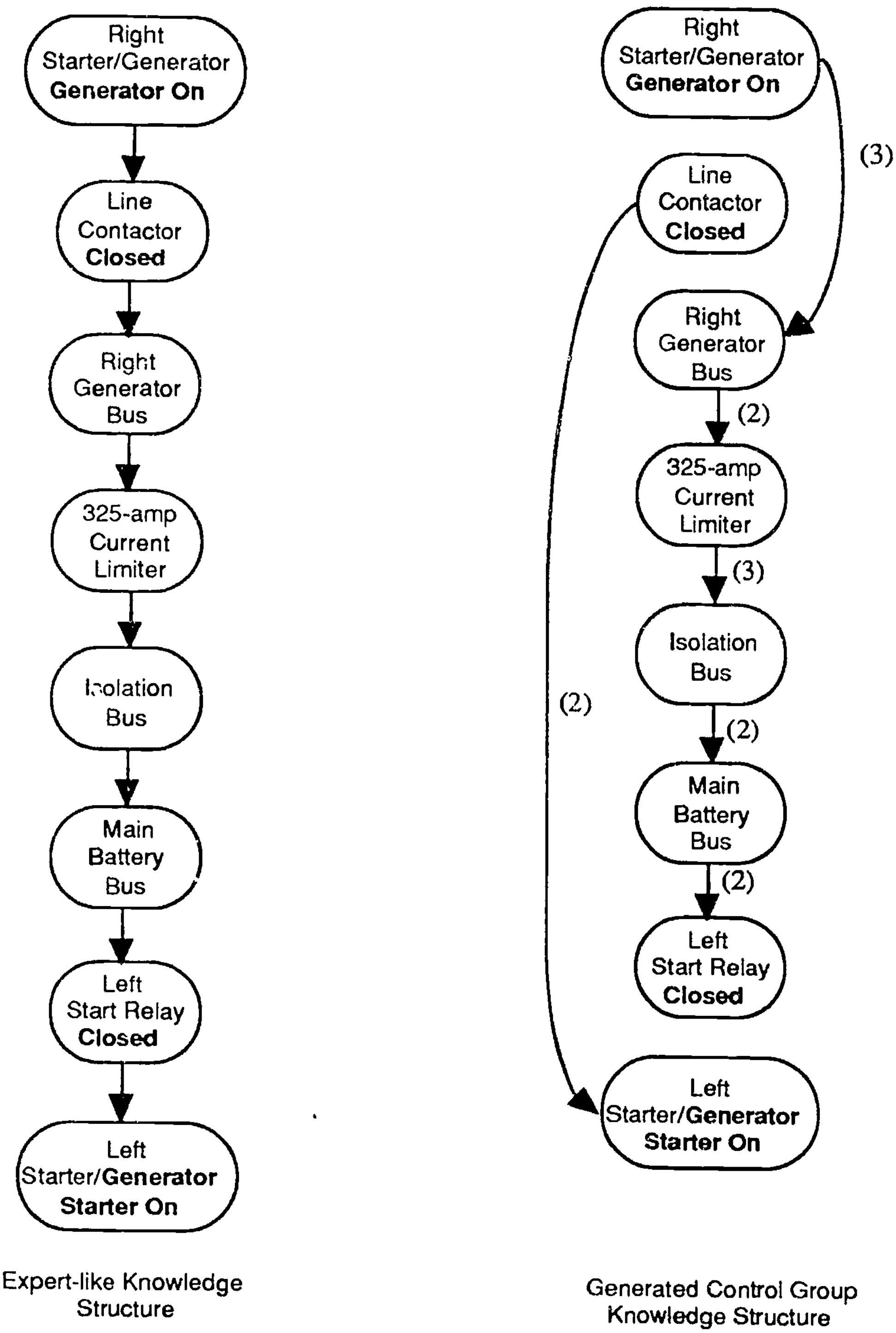


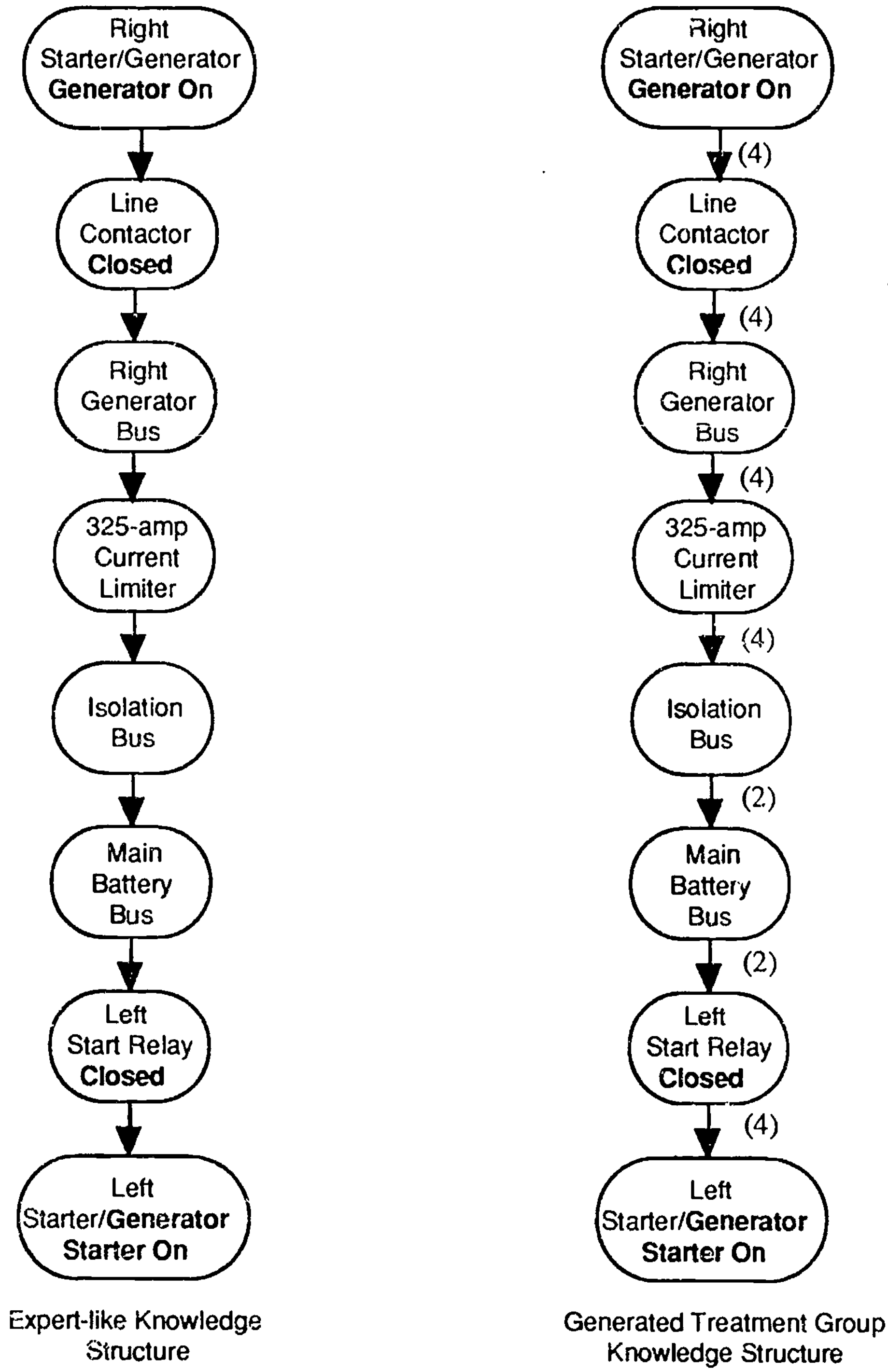
Figure 3-2-1 Voltage Regulation

Figure 3. An example of a Generated Group Knowledge Structure for the control group. The concept being represented is - Generator Assisted Start With the Right Engine Running.



Note: The numbers in parentheses indicate the number of subjects out of four, representing this connection in their individual knowledge structures.

Figure 4. An example of a Generated Group Knowledge Structure for the treatment group. The concept being represented is - Generator Assisted Start With the Right Engine Running.



Note: The numbers in parentheses indicate the number of subjects out of four, representing this connection in their individual knowledge structures.