Graduate Theses and Dissertations

Graduate College

2009

Effects of metacognitive instructional strategies in secondary career and technical education courses

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Effects of metacognitive instructional strategies in secondary-level career and technical education courses

by

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A dissertation submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Major: Agricultural Education

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Iowa State University

Ames, Iowa

2009

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ACKNOWLEDGMENTS

First, I thank God for my salvation and the guidance He has provided in my life. Several special people also deserve recognition for the support and guidance they have given me throughout my studies.

Acknowledgment is in order for my wife, friends, and family for all of their support and endurance while I pursued my dreams. Thank you, Miranda, for your encouraging words. You have fought the good fight and kept faith in me. Madilynn, thank you for keeping me grounded. Your spirit has kept me going.

I thank Dr. Greg Miller for finding potential in me. Without you, this would not have been possible. Your guidance through my program leaves me with a feeling of preparedness for the future. Thank you for enduring my self-doubt and placing me on the right track.

To my committee members, Drs. Wade Miller, Tom Polito, Michael Retallick, and Gary Phye, I thank each of you for your suggestions, advice, and insights. I truly appreciate the support you have provided.

To Dr. Robert Martin, thank you for providing the funding for my research program and the opportunities to serve the department. The experiences have strengthened my professional development.

I extend my sincere gratitude to the cooperating teachers that have made this research possible. Your dedication to improving student learning is inspiring.

To anyone I may have forgotten, please accept my sincere apologies and gratitude. As I conclude, I hope to repay each debt owed. I sincerely thank you all.

CHAPTER I. GENERAL INTRODUCTION

In this chapter, the background and setting for this study are established in this chapter. A statement of the problem is provided, followed by the objectives of the study. Organization of this dissertation is described, and assumptions and limitations are provided. Finally, key terms used in the study are defined.

Background and Setting

Technology is being used more than ever in agriculture, from automated production lines in the food processing industry to tractors equipped with automated guidance systems. The intricacies of this technology have increased the difficulties that technicians might face when attempting to repair equipment problems. Maclean and Ordonez stated, "…what we are witnessing today is not just a series of technological breakthroughs or fine tuning of lifestyles and existing systems, but the dawn of an entirely new way of living and working never experienced before" (p. 124). This enhances the need for educators to equip students with skills to solve problems associated with this new technology. Employers will want employees who can identify problems and find solutions to those problems (Johnson, 1991).

Statement of the Problem

Because performing repetitive technical skills is no longer a primary job requirement for Agriculture industry employees, there is an argument that hands-on activities are no longer sufficient for career and technical education (Johnson, 1991). Emphasis is now being placed on skills such as critical thinking, problem solving and decision making (Johnson, 1991; Maclean & Ordonez, 2007). "Agriculture and science should be the vehicle to learn not only content, but also thinking" (Ulmer & Torres, 2007, p. 114). Current research in agricultural education (Parr, Edwards, & Leising, 2006; Ulmer & Torres) implies that

agricultural educators should put considerable effort into developing and implementing instructional methods that show promise in developing students' higher order thinking. Research has shown that certain metacognitive instructional strategies can significantly improve students' problem-solving success (Dunlosky & Metcalfe, 2009; Pasher et al., 2007). However, little research has been done to empirically test the effectiveness of these instructional strategies with secondary-level career and technical education students.

Purpose and Objectives

The purpose of this study was to analyze the effectiveness of metacognitive instructional strategies with a specific focus on secondary-level career and technical education students' problem solving. Specific objectives were:

1. Determine if the use of thinking-aloud pair problem solving (TAPPS) improves success rate and time to completion of secondary-level students troubleshooting small engine faults in career and technical education courses.

2. Describe secondary-level career and technical education students' cognitive processes while troubleshooting.

3. Determine if the use of regulatory checklists improves success rates of secondary-level students solving simple circuit problems using algebraic manipulation of Ohm's law in career and technical education courses.

Dissertation Organization

This dissertation is divided into six chapters. Chapter one is a general introduction. Chapter two establishes a theoretical framework for metacognitive learning strategies based on cognitive learning theory, problem solving, and the role of metacognition. Chapter three is a research article that reports the results of applying a metacognitive learning strategy called

TAPPS to troubleshooting instruction. Chapter four is a research article that provides a

descriptive interpretive analysis of students' oral verbalization during the use of TAPPS

while troubleshooting. The fifth chapter is a research article that reports the results of

applying metacognitive self-questioning to Ohm's law instruction. Chapter six presents

general conclusions.

Assumptions

Several assumptions were made during this study.

- It was assumed that random assignment to treatment groups would control for

  extraneous such as some students may have initially had a greater technical

  knowledge of engine theory; others may have special skills in working with others or

  asking questions.

- It was assumed that students' maturity level would not influence their use of the

  TAPPS strategy, and that students had received the prerequisite instruction needed to

  develop the domain-specific knowledge necessary for problem solving in the content

  areas in this study, and that students had previous experience working with small

  engines.

Limitations

Several limitations of this study were noted.

- This study took place during secondary school hours and class periods, which limited

  the time available for data collection.

- Travel distance also limited the number of data collection sites available to include in

  the study.

- Curriculum and instruction regarding engine theory and operating principles may have varied between data collection sites.

- The number of subjects available to participate in the study was limited by student attendance and laboratory space and equipment.

- The troubleshooting protocol had to be modified because of malfunctions with ignition and compression testing equipment.

Definitions of Terms

Key terms used in the study are listed below with their contextual definitions.

1. **Cognition**: a term that refers to the thinking processes of an individual. These processes include attention, perception, memory, knowledge representation, language, problem solving, reasoning, and decision making (Kellogg, 2007; Marzano & Kendall, 2007).

2. **Metacognition**: a term defined by researchers as the process of controlling one's own thinking. The person takes an active role in processing their thoughts in order to stay on task (Novak, 1990).

3. **Troubleshooting**: a type of problem solving used to find and repair faults with technology. The process includes evaluation of the problem, generation of hypotheses, testing of the hypotheses, and hypothesis evaluation (Johnson, 1989).

4. **Think-aloud pair problem solving (TAPPS)**: a teaching technique used to force students to verbalize their thoughts in order to gain more control over their thoughts (Lochhead, 2000). Students work in pairs; one is a problem solver who verbalizes their thought process, and the other is a listener who

probes the problem solver with questions to get them to clarify their thinking. The listener does not help the problem solver; they only ask questions about the problem solver's methods.

5. **Small engine**: a type of internal combustion engine producing less than 25 horsepower. Small engines usually have a single cylinder but may have more than one cylinder. In a small engine, a stroke of the piston occurs every half revolution of the crankshaft (Webster, 2001). A cycle consists of four strokes. Each stroke is identified by the function it performs: intake, compression, power, and exhaust (Roth, 2000). Small engines consist of several critical components that enable proper functioning. These include a carburetor, electrical system, exhaust system, governing system, piston, piston rod, piston rings, numerous gaskets, and a lubricating system. Small engines are designed to transfer potential energy by combusting a flammable fuel during the power stroke. When the fuel is ignited, energy stored in the fuel forces the piston down in the cylinder, rotating the crankshaft. The mechanical energy is measured in the form of horsepower (Webster).

6. **Engine compression system**: the system that maintains cylinder pressure in order for combustion to take place. The engine compression system compresses the air/fuel mixture toward the spark plug for ignition. Without cylinder pressure, the air/fuel mixture is not volatile enough to generate the force to turn the crankshaft. The compression system also contains the force when the air/fuel mixture is ignited and directs the energy generated to turn

the crankshaft (Roth, 2000). The cylinder block must be sealed so there is enough pressure for combustion to be generated and maintained.

7. **Ohm's law**: Georg Simon Ohm defined the relationships between current, voltage, and resistance in a circuit. The relationships are expressed in a mathematical formula. Current in a circuit is directly proportional to the voltage applied to the circuit and inversely proportional to the resistance of the circuit (Holzman, 2002).

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CHAPTER II. THEORETICAL FRAMEWORK

This chapter establishes a theoretical framework for metacognitive learning strategies based on cognitive information processing learning theory, development of problem-solving skills, metacognition, and the role of instructional strategies.

Cognitive Information Processing Learning Theory (CIPLT)

CIPLT views learning as a series of mental processing activities through which information is sorted, retrieved, and transformed into knowledge (Andre & Phye, 1986). The theory uses the analogy that the mind functions similar to a computer program (Kellogg, 2007). Proponents of this theory propose that as information flows through the mind, it is encoded through input buffers or sensory registers and processed into short-term memory, where it is acted on (Andre & Phye). Short-term memory, however, is limited in capacity and duration (Chi, 1976). If information is to be retained and retrieved for use over an extended amount of time, it must be stored in long-term memory as schemata (Andre & Phye). This is done through various levels of processing and elaborative rehearsal techniques (Kellogg).

A crucial element of CIPLT is the cognitive process of executive control, which has been viewed as the most important element for problem solving (Borkowski, Chan, & Muthukrishna, 2000). The executive control functions similarly to a computer's operating system by monitoring what information is being used, controlling the flow of information in memory, and identifying tasks to receive mental resources (Andre & Phye, 1986).

CIPLT suggests that a sequence of mental processes that transpire between stimuli and responses stimulates knowledge development (Schunk, 2008). This is consistent with the information acquisition process, which is essential for expert-like troubleshooting (Gitomer, 1988; Johnson, 1989; Johnson, Flesher, & Chung, 1995; Jonassen, 2003; MacPherson, 1998).

Knowledge construction occurs through attended sensory reception of information that is then encoded as new knowledge or related to existing knowledge in memory (Shuell, 1986). However, this knowledge has no practical use until action is taken through application (Phye, 2005). Application of knowledge requires realization of the need to retrieve existing knowledge from long-term storage and proper execution of that knowledge for the given situation (Andre & Phye, 1986).

Learning and behavior develop through a person's interaction with the environment, previous experiences, and current knowledge (Andre & Phye, 1986). People possess the unique ability to cognitively construct and apply knowledge to best adapt to a current situation (Phye, 2005), and learners actively search for and develop knowledge via information processing. In the classroom environment, students are engaged in information processing through classroom assignments that require problem solving (Phye, 2001).

Development of Problem-Solving Skills

The typical problem structure includes a set of givens, a goal, and obstacles (Anderson, 1990). Givens are the known and unknown details and their relationships that define the problem's initial state. The goal is the desired situational outcome. Obstacles are characteristics of the situation and problem solver that make reaching the desired situational outcome difficult.

Problem solving often is viewed as the execution of either mental or behavioral activities to transform the initial state of the problem to yield the desired results (Anderson, 1990). CIPLT holds that learning to problem solve requires attainment, retention, and application of a combination of declarative, procedural, and strategic knowledge in the form of schemas called production systems (Andre, 1986). A mental representation of the initial

state of the problem must be formed in short-term memory to activate these production systems in long-term memory, (Schunk, 2008).

The collective mental efforts required to achieve the desired goal have been called the search process (Andre, 1986). Searching the problem space could involve the use of heuristics, algorithms or creative thinking (Kellogg, 2007). Some search strategies work well in a variety of situations, whereas others often are useful in specific domains (Andre). Correct mental representation of the problem is crucial for correctly identifying a correct solution path (Chi & Glaser, 1985).

Schunk (2008) suggests that problem solving promotes learning only when it involves challenges and unapparent solutions with the execution of self-regulation by the learner. Problem solving requires the ability to monitor the productivity of the search and determine if the solution generated meets the desired goal. Planning and monitoring are essential to this process and help an individual identify possible solutions as well as monitor their cognitive processes and states of knowledge (Kellogg, 2007). "Possessing the requisite of declarative and procedural knowledge to perform a task does not guarantee students will perform it well" (Schunk, p. 185). Borkowski et al. (2000) emphasize that executive control is essential to task analysis, planning, monitoring, and evaluation of strategies while problem solving.

Metacognition and the Role of Instructional Strategies

Metacognition is the deliberate, attentive, goal-directed management of thinking (Hacker, 1998). It includes awareness of one's knowledge and regulation of cognitive activities (Schraw & Dennison, 1994). Novak (1990) defined metacognitive learning as a person's acquisition of some general strategy that facilitates learning or understanding of knowledge. It seems metacognition is requisite for successful problem solving.

Metacognitive thought functions within the CIPLT paradigm as the executive control over the flow of knowledge in and out of a system of mental structures (Hacker). Flavell (1979) stated that metacognitive knowledge "can lead you to select evaluate, revise, and abandon cognitive tasks, goals, and strategies in light of their relationships with one another and with your own abilities and interests with respect to that enterprise" (p. 908). Metacognition also seems essential for generating effective mental representations and guiding processing for effective problem solving (Resnick, 1985). During problem solving, it is important for students to know what knowledge to apply along with when and why to use it (Schunk, 2008).

Metacognition often exists as an internal conversation (National Research Council, 2000). Yet it is assumed that individuals may not develop this internal dialogue on their own (Bloom & Broder, 1950; Greenfield, 1987; Griffiths, 1976). However, research has shown that metacognition is not dependent on intellect or academic achievement (Pressley & Ghatala, 1990; Swanson, 1990). Because metacognition does take the form of an internal dialogue, many students may be unaware of its importance unless it is overtly taught (National Research Council). Thus, students' metacognition may develop with instruction, modeling, practice, and reinforcement. Research has demonstrated that use of metacognitive instructional strategies can increase students' achievement (Pasher et al., 2007).

Conclusion

Career and technical education researchers currently are calling for improvement of students' thinking skills (Johnson, 1991; Maclean & Ordonez, 2007; Parr, Edwards, & Leising, 2006; Ulmer & Torres, 2007). Metacognitive instructional strategies should enable students to perform better and learn more in the classroom (Pintrich, 2002), and this explicit

instruction should help students connect the strategies to other knowledge they may already have to improve problem solving. The effect of metacognitive instructional strategies needs to be examined empirically within content-driven lessons in secondary-level career and technical education courses.

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CHAPTER III. EFFECTS OF THINK-ALOUD PAIR PROBLEM SOLVING ON SECONDARY-LEVEL STUDENTS' PERFORMANCE IN CAREER AND TECHNICAL EDUCATION COURSES

A paper prepared for submission to the Journal of Agricultural Education

Michael L. Pate and Greg Miller

Abstract

A randomized, posttest-only control group experimental design was used to determine the effects of think-aloud pair problem solving (TAPPS) on the troubleshooting performance of secondary-level career and technical education students. Students who participated in the TAPPS group were randomly assigned a listening partner and orally verbalized their thought process while troubleshooting a small gas engine. Results were not statistically different between the experimental and control groups (p = .39). Thirty-eight percent of students in the control group were successful at identifying the engine fault and the correct engine system affected and correctly described how to repair it in order for the engine to operate. Twenty-five percent of students in the TAPPS group were successful at the same tasks. Among students who were successful, there were no significant differences in completion time between treatment groups. Further research should be conducted to identify and describe key differences in oral verbalization between troubleshooters who are successful and those who are not.

Introduction/Theoretical Framework

Solely hands-on career and technical education (CTE) is no longer sufficient because performing repetitive technical skills is not an option for employees (Johnson, 1991). Emphasis is now being placed on skills such as creative thinking, problem solving, and decision making (Maclean & Ordonez, 2007). "Agriculture and science should be the vehicle

to learn not only content, but also thinking" (Ulmer & Torres, 2007, p. 114). Current research in agricultural education implies that agricultural educators should put considerable effort into developing and implementing instructional methods that show promise in developing students' higher order thinking (Parr, Edwards, & Leising, 2006). Edwards (2004) reviewed cognitive learning research and concluded that "cognitive learning, including student behaviors involving critical thinking, higher-order thinking skills, and problem-solving, ought to be occurring in secondary agricultural education" (p. 234). This raises a question: How effective are cognitive learning strategies at improving students' technical problem solving?

The theoretical framework for this study is built on troubleshooting as a complex problem-solving activity, metacognition, and think-aloud pair problem solving (TAPPS) as a strategy to invoke self-regulation during problem solving.

Troubleshooting

Holyoak (1995) defined a problem as a situational goal that an individual desires to achieve for which the solution path is not immediately known. All problems consist of three elements: givens, obstacles, and a goal state (Anderson, 1990). Givens are the limitations and characteristics that define the initial state of the problem. Obstacles are known or unknown givens that make it difficult to reach the desired solution. The goal state is simply the desired outcome or solution. An individual encounters a problem when an obstacle interferes with achieving a situational goal (Marzano & Kendall, 2007).

Problem solving has been defined as "thinking in relation to some task whose solution is not immediately obvious to the task performer" (Soden, 1994, p. 15). Rubinstein and Firstenberg (1987) stated, "Problem solving requires an integrated use of thinking skills

and an appropriate knowledge or data base" (p. 23). Their review of the literature suggests that problem solving requires higher-level knowledge and thinking skills. Davidson, Deuser, and Sternberg (1994) describe problem solving as "the active process of trying to transform the initial state of a problem into the desired one" (p. 207-208). Solving problems requires individuals to direct their behavior toward identifying, evaluating, and using possible options that will accomplish the desired situational goal.

Troubleshooting is a unique problem-solving approach for ill-defined problems (MacPherson, 1998). Solutions to these types of problems do not appear rapidly after the problem solver has analyzed the givens and obstacles of the situation (Davidson et al., 1994). Ill-defined problems contain numerous undefined givens and obstacles (Jonassen, 2000) and also may require testing a variety of possible solutions. During troubleshooting, the solution to the problem is not apparent or specific; rather, it is a systematic elimination of possible solutions until the correct solution is attained (Johnson, 1989).

Effective troubleshooting, as described by Johnson (1989), involves a cyclic pattern of hypothesis generation and testing to generate a solution. The problem solver may have only a general awareness that a problem exists (e.g., recognizing that a piece of equipment will not function properly). The problem solver must then define the goal for the situation (e.g., establishing a standard for the equipment to function correctly). The problem solver would then inspect various components of the equipment to identify the obstacle causing the malfunction.

Multiple obstacles could arise during troubleshooting depending on the complexity of the problem. Once obstacles are identified, possible solutions can be identified and evaluated to reach the established standard. Davidson et al. (1994) noted that obstacles could be

characteristics of the problem solver. Gitomer (1988) stated that novices lack practice at organizing new information, the ability to sift through strategies to use, and the ability to access knowledge out of context. Poor troubleshooters engage in random repairs without first defining the problem space and determining paths to a solution (Morris & Rouse, 1985). Identification and implementation of an effective strategy is the most difficult skill set for troubleshooters to develop (Johnson 1989).

Individuals often infuse systematic errors into procedures when solving problems (Brown and Burton, 1978). These errors, called "bugs," are a result of faithfully following self-constructed rules from stepwise instruction of procedural knowledge (Marzano & Kendall, 2007). The ability to analyze errors of mental procedures involves actively monitoring and controlling one's thinking. This suggests that awareness of mental procedures would improve troubleshooting success.

Metacognition

Metacognition is the awareness to monitor and control one's thinking. Flavell (1979) stated that metacognitive knowledge "can lead you to select, evaluate, revise, and abandon cognitive tasks, goals, and strategies in light of their relationships with one another and with your own abilities and interests with respect to that enterprise" (p. 908).

According to Davidson et al. (1994), the metacognitive processes that contribute to problem solving involve identifying the problem, defining the problem space, mentally representing the problem, planning how to proceed, and evaluating what is known about the individual's own performance. "Metacognition guides the problem-solving process and improves the efficiency of this goal-oriented behavior" (Davidson et al., p. 207).

Marzano and Kendall (2007) argued that metacognition allows individuals to establish goals in relation to the acquisition of new information. This helps the individual plan procedures to meet established goals and monitor and control their thinking. Metacognition allows a student to recognize that a problem exists, define what is known about the problem, determine the desired outcome of the problem, develop a plan to reach the solution, and determine if the solution works (Davidson et al., 1994).

These mental procedures seem obvious. Yet individuals are often unaware of their own thought processes (Bloom and Broder, 1950). Lochhead (1981) stated that it is a difficult task for an individual to become aware of even fragments of their thinking. Greenfield (1987) found that poor problem solvers tend to lose focus on their solution plan without being aware they had become lost. A lack of attention to reasoning and monitoring tends to lead students to spontaneous and unsound attempts at a solution (Gourgey, 1998). "Good control does not require that one always make the right decisions, but does require that one be able to recover from a false start, to realize that a strategy is not working, and to consider alternatives" (Gourgey, p. 87-88).

Researchers have suggested that curriculum content should be strongly linked with instruction in metacognitive training techniques to improve students' problem solving abilities (National Research Council, 2000; Pintrich, 2002; Schraw, 1998). TAPPS is an instructional technique offered by Whimbey and Lochhead (1986) to improving students' self-regulation during problem solving.

Think-aloud Pair Problem Solving

The TAPPS strategy involves one student solving a problem while a listener asks questions to prompt the student to verbalize their thoughts and clarify their thinking

(Lochhead, 2001). The focus is on having students express their thoughts aloud while engaging in problem-solving activities to externalize the thinking process. While solving a problem, the student verbalizes each action or thought that they engage in to the listener. The listener prompts the problem solver to explain what actions or thoughts are taking place and why. The listener's role is to ensure the solver explains his or her reasoning (Gourgey, 1998) and continues talking by challenging even the shortest silence with statements such as, "Tell me what you are thinking now." The listener also queries the problem solver at any time the problem solver's thinking is unclear to the listener by using statements such as, "Tell me why you did that." Listeners are not allowed to solve the problem or ask questions or make statements that guide the problem solver toward a solution (Lochhead & Whimbey, 1987). The goal of TAPPS is to develop the problem solver's ability to monitor their cognitive and metacognitive progress (Gourgey). The TAPPS strategy may allow students to control or filter possible solutions to the problem during troubleshooting. Heiman and Slomianko (1987) indicated the think-aloud process helps the problem solver avoid skipping steps in reasoning, skipping over important information, or being unaware of getting consumed with a component of the problem. The successfulness of TAPPS may result from problem solvers engaging in self-monitoring, clarifying their thinking, and considering useful solution strategies in order to reach their goals (Bransford, Sherwood, Vye, & Rieser, 1986; Silver, 1987).

Research in CTE has shown that TAPPS significantly improves postsecondary students' problem-solving success (Johnson, & Chung, 1999; Pate, Wardlow, & Johnson, 2004). However, the TAPPS method has not been tested at the secondary level in CTE

courses. Will secondary-level students who use TAPPS as a self-regulation strategy improve their troubleshooting performance?

Purpose

The purpose of this study was to determine if the use of TAPPS improves secondary-level students' success rate and time to completion when troubleshooting small engine faults in CTE courses.

Hypotheses

1. There will be no significant differences in success rate for troubleshooting a small engine compression system fault between students who use TAPPS and students who do not use TAPPS.

2. There will be no significant differences in completion time for troubleshooting a small engine compression system fault between students who use TAPPS and students who do not use TAPPS.

Methodology

Participants

This study involved five secondary schools in Iowa. Students enrolled in selected CTE courses dealing with small engine technology were purposely selected to be participants in this study. The study population consisted of 34 students enrolled in the selected courses during the fall semester of 2008 and spring semester of 2009. Students' ages ranged from 14 to 17 years.

Research Design

This study used a randomized, posttest-only control group experimental design (Campbell & Stanley, 1968; Figure 1). Students were assigned randomly to two groups. The

control group did not think aloud while troubleshooting. The control group was not audio recorded. The researcher observed the control group to ensure students followed protocol. Observations indicated that students did not break protocol. The experimental group used the TAPPS technique while troubleshooting. Audio recordings were used to ensure the fidelity of the experimental treatment.

Students completed the troubleshooting exercise only once and served as subjects in either the control group or the experimental group. The order in which the groups completed the troubleshooting exercise was assigned randomly at the first school site. The completion order was then alternated at each remaining school. To control for the possible threat of diffusion between treatment groups, data from the group that completed the troubleshooting exercise first at each school was used, and data from the second group at each school was removed from the data set. This resulted in four sets of data for the TAPPS group and three sets of data for the control group.

If the control group was selected to go first, the treatment group participated in an unrelated, off-site activity with their classroom teacher. If the treatment group was selected to go first, the control group served as their listening partners. Listening partners were assigned randomly to students in the TAPPS group. Students serving as listening partners were given oral instructions on how to be a listening partner. Students in the control group were told not to help, lead, or assist in solving the problem. Each student serving as a listening partner was given a list of questions to use when probing the troubleshooter. These questions were developed to ensure the listener asked the TAPPS student to vocalize all major steps they took to solve the problem.

		Compression Fault		Compression Fault
R	C	Os, Ot		
R			TA	Os, Ot

Figure 1. Illustration of randomized, posttest-only experimental design. R = random assignment; Os = observation of successfulness; Ot = observation of time to solve the problem; TA = TAPPS group; C = control group.

Procedure

Prior to the experiment, the researcher provided each student with identical instruction regarding domain-specific knowledge on troubleshooting small gas engines via a protocol adapted from Webster (2001). Students received information on the three major systems required for an engine to operate: compression, ignition, and air/fuel intake. Students were instructed to systematically check each system to determine if it was functioning correctly. Examples of possible faults were given for various system malfunction scenarios and the troubleshooting protocol was modified because of malfunctioning ignition testers and a lack of compression gauges. For checking spark in the ignition system, students were instructed to remove the spark plug from the cylinder head while attached to a high tension lead, ground the spark plug threads to the engine block, and crank the engine over using the rewind starter. The researcher explained that if the students observed a blue spark jumping between the electrode gap, the engine's ignition system was functioning properly. To check compression, students were instructed to remove the spark plug from the cylinder head and then pull the rewind starter with their finger over the spark plug hole in the cylinder head. The researcher explained that if the engine had adequate compression, the cylinder pressure would force their finger off the spark plug hole. Students were also told to notice the amount of resistance they experienced when pulling the starter rope because a lack of resistance indicates a lack of compression.

Treatments

Students were assigned randomly to the experimental or control group. The only difference between groups was the use of TAPPS. Identical small gasoline engines were prepared with an identical fault in their compression system: a missing valve spring retainer. Each troubleshooter was provided a complete set of basic engine repair tools and a 45-minute period in which to identify the correct fault, identify the correct engine system affected, and correctly describe how to repair the fault. No clues were given about the problem, but students were told the problem did not require them to remove the cylinder head or the crankcase cover. Workstations were separated by distance so students could not observer each other's progress. To discourage students from observing each other's progress and discussing the activity between classes, students were told that each engine had a different problem and that each round of troubleshooting had a different problem. The researcher was present during the troubleshooting process to ensure students followed instructions. For safety purposes, students were asked not to repair the fault and run the engine. A task outcome (successful or unsuccessful) was recorded for students on the basis of whether they were able to identify the correct fault, identify the correct engine system affected, and correctly describe how to repair it in order for the engine to operate.

Students in the control group worked alone to troubleshoot their small engine. They received no oral or written instructions regarding TAPPS. Troubleshooting solution(s) were checked to determine successfulness. The researcher recorded successfulness and time to completion for each student.

Students in the experimental group used TAPPS while troubleshooting. They received oral and written instructions on how to think aloud. Each TAPPS student was

randomly assigned a listening partner. Listening partners asked questions to prompt the

TAPPS students to verbalize their thoughts and clarify their thinking. The TAPPS students

were required to orally verbalize their thoughts throughout the troubleshooting exercise. Each

TAPPS student was equipped with a digital voice recorder and an attached lapel microphone.

During the TAPPS exercise, students' oral verbalizations were recorded with the digital

audio recorders to verify that they followed experimental protocol. Following Ericsson and

Simon's (1993) protocol for collecting verbal data, the TAPPS students received two practice

word problems to allow them to become familiar with the TAPPS procedure. These problems

were adapted from Lochhead (2001). The practice task was sufficiently dissimilar so as not

to introduce bias into students' reports during the troubleshooting task. Troubleshooting

solution(s) were checked to determine successfulness. The researcher recorded

successfulness and time to completion for each student.

Analysis

The Chi-square test of association was used to test for differences between the two

groups in the nominal dependent variable, task completion for each problem (successful or

unsuccessful). An independent t-test was used to determine if there were significant

differences in completion times between successful students in the experimental and control

groups.

Results

Because students were assigned randomly to groups, it was assumed that any

preexisting group differences would fall within the range of expected statistical variation and

would not confound the results. Table 1 presents descriptive statistics for student

performance on the troubleshooting task by group.

Table 1

Student Performance on the Compression Troubleshooting Task by Group

	Task outcome[a]				Minutes to completion[b]	
	Successful		Unsuccessful			
Group	*n*	*%*	*n*	*%*	*M*	*SD*
Control (*n* = 18)	7	38.9	11	61.1	12.7	8.4
TAPPS (*n* = 16)	4	25.0	12	75.0	16.5	7.8

[a] $\chi^2 (1) = .747$, $p = .39$

[b] Based on only students with a successful task outcome; $t (9) = -.74$, $p = .48$.

Hypothesis 1: There will be no significant difference in success rate for troubleshooting a small engine compression system fault between students who use TAPPS and students who do not use TAPPS.

Seven out of 18 students who worked silently were able to identify the correct fault, identify the correct engine system affected, and correctly describe how to repair it in order for the engine to operate. Four out of 16 students who used TAPPS were able to successfully complete the same tasks. There was no significant difference in success rate between TAPPS students and students in the control group ($\chi^2 (1) = .747$, $p = .39$). Therefore, hypothesis 1 was retained.

Hypothesis 2: There will be no significant difference in completion time for troubleshooting a small engine compression system fault between students who use TAPPS and students who do not use TAPPS.

Successful students who worked silently had an average completion time of 12.7 minutes. Successful students who used TAPPS had an average completion time of 16.5 minutes. Among students who successfully completed the troubleshooting task, there was no significant difference in mean time to completion between groups ($t (9) = -.74$, $p = .48$). Levene's test for equality of variances revealed that the assumption of equal variances was met ($F (6, 3) = .05$; $p = .82$). Therefore, hypothesis 2 also was retained.

Conclusions/Recommendations/Implications

Even though results from this exploratory study indicate that success rates were not statistically different between the experimental and control group, the secondary-level CTE students who orally verbalized their thoughts while troubleshooting a small gas engines had a lower success rate than students who worked silently. This is in contrast to Pate et al.'s (2004) conclusions that thinking aloud yields higher troubleshooting success rates for postsecondary students. Interestingly, the proportion of successful secondary-level students that worked silently in this study (38.9%) was similar to the proportion of successful postsecondary students who worked silently in Pate et al.'s study (41% and 44%). However, the proportion of successful secondary-level TAPPS students (25%) differs drastically from the proportion of successful postsecondary TAPPS students in Pate et al.'s study (89.9% and 83.3%). Veenman, Van Hout-Wolters, and Afflerbach (2006) argue that elementary levels of metacognitive thought develop during early childhood but become more sophisticated and academically oriented through instructional interventions requiring the explicit utilization of metacogntion. This may mean the impact of TAPPS depends on student maturity and experience. Future research should examine variables that moderate the effect of TAPPS.

There was also a difference in the level of instruction provided to secondary-level students in the present study and postsecondary students in Pate et al.'s (2004) study. All secondary-level students received one class period of troubleshooting instruction. Students were given notes and a demonstration on how to troubleshoot the air/fuel delivery, ignition, and compression systems. Students were told the engine needed all three systems to function correctly, and possible faults for each system were described to the students. Postsecondary students in Pate et al.'s study were enrolled in a junior-level college course that required a

prerequisite agricultural technology course in which basic engine principles were taught. Davidson et al. (1994) observed that amount of and quality of a problem solver's domain-specific knowledge can be a limiting factor in their ability to reach a solution. However, secondary-level students' knowledge of basic engine principles and operating theory was not formally assessed prior to this study. Future research should investigate the relationship between secondary-level CTE students' knowledge of basic engine principles and their ability to use TAPPS successfully.

Time to completion was not significantly different for successful secondary-level CTE students who participated in the TAPPS group compared with successful students who worked silently. Even so, average time to completion for the TAPPS students was 4 minutes longer than for students in the control group. The time required for secondary-level students to overtly verbalize thoughts orally may impede troubleshooting progress, and from an industry perspective, time spent on repairs is an important factor. Considering this potential economic implication together with the lower troubleshooting success rate, we do not recommend widespread use of TAPPS at the secondary level. Although this exploratory study offers no support for using TAPPS at the secondary level, the reader is cautioned against making generalizations from this relatively small sample of 34 students. This study does not rule out the possibility that TAPPS could be useful with other secondary-level students, and we strongly recommended that future research incorporate a larger sample size.

The experimental design allowed the use of only one group from each school. As a result, there was a loss of subjects. A recommendation for further research involving secondary-level students is the use of a clinical approach, such as establishment of a laboratory setting that allows one-on-one interaction between the researcher and student. This

procedural change would further increase control over diffusion of information between students and minimize interferences generated by other students. To further limit diffusion between students outside of the experiment, several engine faults could be assigned randomly to students and analyzed as an additional factor.

It is unclear if students who used TAPPS engaged in oral verbalizations that were conducive to successful problem solving. Further research should be conducted to analyze the audio recordings of students' verbalizations to identify and describe key differences between secondary-level CTE students who were and were not successful at the troubleshooting task. Future research could lead to modifications of the TAPPS strategy that may allow secondary-level students to control or filter possible solutions to the problem during troubleshooting. By identifying appropriate metacognitive behavior during problem solving, this research could inform educational practices to assist student development toward expert-like problem solving.

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CHAPTER IV. A DESCRIPTIVE INTERPRETIVE ANALYSIS OF STUDENTS' ORAL VERBALIZATION DURING THE USE OF THINK-ALOUD PAIR PROBLEM SOLVING WHILE TROUBLESHOOTING

A paper prepared for submission to the Journal of Agricultural Education

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Abstract

Researchers assert that the metacognitive nature of think-aloud pair problem solving (TAPPS) improves students' problem solving by focusing their attention on their own thinking. The purpose of this study was to identify and describe oral verbalizations indicating cognitive processes of secondary-level career and technical education students who used TAPPS while troubleshooting. The study design incorporated a mixed-methods approach. A qualitative interpretive approach was used to describe and interpret students' thoughts while they were engaged in TAPPS. A quantitative analysis was used to compare levels of oral verbalization between successful and unsuccessful TAPPS students. Analysis of the qualitative data revealed that students' domain-specific knowledge was not strong enough to support troubleshooting. Secondary-level career and technical education teachers should ensure their students possess the prerequisite knowledge before asking them to performing troubleshooting tasks.

Introduction/Theoretical Framework

Students encounter problems throughout their lives, and problem solving is a fundamental and significant component of career and technical education. Instructional efforts have focused on developing students' abilities to solve real-world problems (Technology for All Americans Project, 1996). Hill (1997) stated, "It is imperative that professionals in the field incorporate problem solving concepts and strategies as a significant

element in curriculum design and implementation" (p. 32). Research has led to the

development of several techniques that have shown promise for improving student problem

solving (Dunlosky & Metcalfe, 2009).

One technique of interest is the use of questioning to invoke self-explanations (Pasher

et al., 2007). Pasher et al. recommended that teachers find opportunities to have students ask

and answer questions to promote explanations that are metacognitive in nature. The National

Research Council recommended that metacognition should be integrated into the curriculum

across several subject matter areas. Because metacognition often occurs as an internal

dialogue, many students may be unaware of its importance unless it is overtly taught

(National Research Council). It is reasonable to assume that individuals could develop this

internal dialogue through training and instruction (Borkowski, Chan, & Muthukrishna, 2000;

Cardelle-Elawar, 1995; Pintrich, 2002; Schraw, 1998).

Pasher et al.'s (2007) meta-analysis revealed strong evidence that self-questioning

improves students' comprehension and learning. A variation of the method called think-aloud

pair problem solving (TAPPS) significantly improved postsecondary career and technical

education students' problem-solving success (Pate, Wardlow, & Johnson, 2004; Johnson &

Chung, 1999).

The theoretical framework for this study revolves around problem solving, the role of

metacognition, the impact of verbalization on thinking, and TAPPS.

Problem Solving

An individual encounters a problem when an obstacle interferes with achieving a

situational goal (Marzano & Kendall, 2007). The individual desires to achieve the goal but

does not immediately know the solution path (Holyoak, 1995). Problems generally consist of

three components: givens, obstacles, and a goal state (Anderson 1985). Givens are limitations

and characteristics that define the initial state of the problem. Obstacles are known or

unknown givens that make it difficult to reach the desired solution. The goal state is simply

the desired outcome or solution.

Solving problems involves thinking processes directed at reaching a solution

(Davidson and Sternberg, 1998; Soden, 1994). Davidson, Deuser, and Sternberg (1994)

described problem solving as "the active process of trying to transform the initial state of a

problem into the desired one" (p. 207-208). Students engage in problem solving when their

thinking is directed toward reaching a solution. This behavior is characterized by

identification, evaluation, and utilization of potential solution paths that would accomplish

the desired end result. In relation to problem solving, metacognition aids an individual in

recognizing there is a problem, defining the context of the problem, and understanding how

to reach a solution.

Metacognition

The ability to monitor and control one's thinking to accomplish a desired goal is

central to metacognition (Dunlosky & Metcalfe, 2009). Schraw and Dennison (1994) referred

to metacognition as "the ability to reflect upon, understand, and control one's learning" (p.

460). Presumably, metacognition is essential to the idea of directed thinking during problem

solving, which is goal oriented and rational (Gilhooly, 1982). Typical directed thinking

involves isolating a solution path to achieve a clear goal (Kellogg, 2007). "Metacognition

guides the problem-solving process and improves the efficiency of this goal-oriented

behavior" (Davidson et al., 1994, p. 207). According to Davidson et al., metacognition aids

problem solving by helping an individual focus on identifying the problem, defining the

problem space, generating a mental representation of the problem, planning how to proceed, and evaluating what is known about their own performance.

Another important part of metacognition is self-assessment of one's own thinking (Kluwe, 1982). A problem solver's assumptions regarding their inabilities to solve a problem may serve as a barrier to success. Pressure to perform well before peers may make it difficult for students to monitor and regulate their performance. If students believe they are awful problem solvers, they may make fewer attempts to monitor and regulate their thinking, which in turn, may lower the number of solutions examined (Hacker, 1998).

Oral Verbalization

Because thinking and learning happen internally, it is difficult to depict and assess what processes are happening during problem-solving tasks (Hill, 1997). One type of research that has shown promise for describing cognitive processes is the analysis of verbal reports (Chi, 1997; Ericsson & Simon, 1980, 1993; Pressley & Afflerbach, 1995). Verbatim transcripts of recorded oral interactions preserve raw data in a solid form (Ericsson & Simon, 1993), and the information processing model of cognitive processes allows researchers to examine think-aloud verbalizations by supporting an encoding process that is explicit and objective, so that hypotheses entering into the think-aloud process can be examined objectively (Ericsson & Simon, 1993).

Hacker and Dunlosky (2003) suggested that having students explain their thoughts during problem solving through oral verbal reports helps invoke metacognitive thinking. Verbal reports are the product that results when a student is asked to orally describe his or her thoughts (Ericsson & Simon, 1993). These reports can be retrospective or concurrent. Retrospective reports are designed to describe a subject's thinking that occurred during a task

after the task has been completed. Retrospective reports are not designed to change thinking as it occurs but may change a subject's future thinking (Dominowski, 1998). Concurrent reports are generated when students are asked to say out loud what they are thinking during a task.

Verbalization can occur on three levels (Ericsson & Simon, 1993). Level one is the verbalization of working memory content. Level two is verbalization of nonverbal information that must be converted to an oral response, such as describing a sensation (Dominowski, 1998). Verbalization levels one and two are not likely to change students' thought process, which neither helps nor hinders problem solving (Ericsson & Simon, 1993). Level-three verbalizations involve explanation or reasons for thoughts that are active in working memory (Dominowski).

Hacker and Dunlosky (2003) suggested that concurrent reports of level-three verbalizations benefit students during problem-solving activities. This type of oral verbalization requires students to explain their ongoing problem solving, give justification, and rationalize their thinking as they are actively engaged in the problem (Dominowski, 1998). Research supports the use of level-three concurrent verbalizations as a strategy for improving student problem-solving performance (Ahlum-Heath & Di Vesta, 1986; Berry, 1983, Stanley, Mathews, Buss, & Kotler-Cope, 1989; Stinessen, 1985). Hacker and Dunlosky stated, "Students must deliberately change the course and structure of their thoughts as they verbalize responses to the instructions. Moreover, because such instructions can be conversational, students must think more to create a coherent response for listeners" (p. 76).

Berardi-Coletta, Buyer, Dominowski, and Rellinger (1995) investigated the effects of having students provide reasons for the solution path they took during problem solving. They

suggest that metacognitive processes are invoked when students respond to the required explanation demands. Subjects who gave reasons for their actions performed superior to subjects who were silent, asked to talk aloud, or asked problem-focused questions. Berardi-Coletta et al. stated that the improved performance was due to a shift in students' focus from problem-oriented to process-oriented thinking. In other words, the additional thinking needed to give justification for their problem-solving activities may be responsible for students' problem-solving success (Dominowski, 1998).

<p style="text-align:center">*Think-aloud Pair Problem Solving*</p>

TAPPS is a method for invoking verbalization during problem solving with the goal of developing the problem solver's ability to monitor their thoughts (Gourgey, 1998). The TAPPS procedure involves a student solving a problem while a listener asks questions to prompt the student to verbalize their thoughts and clarify their thinking (Lochhead, 2000). This method teaches students how to think outwardly through oral verbalization of their thoughts. This type of reflective thinking is an essential component of metacognition. Researchers assert that the metacognitive nature of the TAPPS method improves students' problem solving by focusing their attention on their own thinking (Berardi-Coletta et al., 1995; Heiman & Slominako, 1987; Pate et al., 2004; Whimbey & Lochhead, 1984). The TAPPS method also may allow students to control or filter possible solutions.

Using TAPPS during troubleshooting has significantly increased postsecondary students' success at solving technical problems (Johnson & Chung, 1999; Pate et al., 2004). Pate et al.'s results revealed that a significantly higher proportion of postsecondary students who used TAPPS successfully completed a troubleshooting task compared with students who did not use TAPPS. This indicates that students who concentrate on explaining their thinking

should be more successful at solving similar problems, such as troubleshooting a small gasoline engine fault. Previous research suggests that TAPPS students who have difficulty successfully completing a troubleshooting task may focus their verbalization on problem-oriented features rather than actively clarifying their own thinking and that students' negative self-assessment of their thinking may inhibit their success. The cognitive impact of TAPPS oral verbalization during troubleshooting is uncertain. Are TAPPS students' verbalizations conducive to improving their problem-solving abilities?

Purpose and Objective

The purpose of this study was to identify and describe oral verbalizations indicating cognitive processes of secondary-level career and technical education students who used TAPPS while troubleshooting. The objective was to analyze secondary-level career and technical education students' oral statements made while engaging in TAPPS to describe students' cognitive process while troubleshooting.

Methodology

Research Design

This study design incorporated a mixed-methods approach. A qualitative interpretive approach was used to describe and interpret students' thoughts while they were engaged in TAPPS. A quantitative analysis was used to compare levels of oral verbalization between successful and unsuccessful TAPPS students.

Participants

The data source for this study was digital audio recordings of 16 secondary-level career and technical education students from four Iowa schools who engaged in TAPPS

during a troubleshooting task. The researcher assigned a code to each transcript to match participants to their troubleshooting results after coding was complete.

Procedure

Students were asked to use the TAPPS approach while troubleshooting a compression fault involving a missing valve spring retainer in a small engine. No hints were given to the students, but they were told the fault did not involve removal of the cylinder head or crankcase cover. This information was provided to prevent students from completely disassembling the engine. Each problem solver was provided with a complete set of basic engine repair tools and a 45-minute period in which to identify the correct fault, identify the correct engine system affected, and correctly describe how to repair the fault. Ericsson & Simon's (1993) techniques guided recording, transcription, and analysis of the verbal protocols. Each student was equipped with a digital voice recorder and an attached lapel microphone. Students were required to orally verbalize their thoughts throughout the troubleshooting exercise. Each problem solver was randomly assigned a listener. Each listener was trained on the technique required for questioning. The researcher explained the TAPPS procedure to the listeners and provided a list of sample questions. Listeners were asked to encourage problem solvers to verbalize their thoughts without giving any hints or assisting the problem solver in finding a solution. Whenever the problem solver was quiet for a few seconds, the listener asked for verbalization by asking a question such as, "What are you thinking?" Listeners also asked for clarification whenever they were unsure of how the problem solver was thinking and pushed for greater detail in the verbalized thoughts by asking a question such as, "Now, why did you look at the carburetor, what do you mean?" Prior to troubleshooting, students assigned to the problem solver role completed a TAPPS

practice session with an unrelated word problem. The practice task was designed to ensure

problem solvers could verbalize their thoughts at an adequate level but was sufficiently

dissimilar so as not to introduce bias into students' reports during the troubleshooting task.

A volunteer was recruited to assist with transcript analysis. This research assistant

earned a bachelor's degree in accounting. Her qualifications to serve as a research assistant

included a 3.48 cumulative grade point average, completion of a statistical analysis course,

and 2 years of work experience analyzing and preparing detailed written reports. The

researcher transcribed the recordings of the TAPPS students and then listened to the

recordings to identify any errors in the transcripts. To ensure credibility of the transcripts, the

research assistant also reviewed the transcripts and compared them with the audio recordings.

The researcher instructed the research assistant on how to code the transcripts. The

researcher and research assistant independently coded each transcript. Coded transcripts were

compared to determine inter-rater reliability. There was 87% agreement between the

researcher and research assistant. After 4 days, five transcripts were randomly selected to be

recoded by the researcher and research assistant. Intra-rater reliability for the researcher was

92%. Intra-rater reliability of the research assistant was 90%. Therefore, transcripts coded by

the researcher were used for analysis.

Transcripts were segmented into verbal interactions consisting of a question from the

listener and a response from the problem solver. Responses from the problem solver were

coded as level-one, level-two, or level-three verbal statements. Level-one verbalizations were

statements describing contents of working memory. These included descriptions of

representing the problem (e.g., "The engine has no compression") or reporting concurrent

behavior (e.g., "I'm loosening this bolt"). Level-two verbalizations were statements

describing nonverbal sensory information (e.g., "This smells funny"). Level-three

verbalizations were statements involving planning (e.g., "First I need to check the spark"),

monitoring (e.g., "What did I just do? Oh I checked the carburetor"), and evaluating (e.g., "I

pulled on the rope but I don't think I felt any resistance").

The code "negative self-assessment" was given to students' statements directed at

judging themselves as performing poorly (e.g., "I can't do this"). The code "positive self-

assessment" was given to students' statements directed at judging themselves as performing

well (e.g., "I think this is easy"). The code "positive problem assessment" was given to

students' statements directed at judging the activity positively (e.g., "I think this is an easy

problem.") The code "negative problem assessment" was given to students' statements

directed at judging the activity negatively (e.g., "This is too hard, this is stupid"). The code

"not on task" was used for student verbalizations consisting of information irrelevant to

solving the problem. For example, a listener asked, "What are you thinking about?" The

thinker responded, "about getting high." This response was coded as "not on task."

Analysis

The number of oral verbalizations at each level per student was tabulated for students

who were successful and unsuccessful at the troubleshooting task and then analyzed with

descriptive statistics including frequencies. Codes were used to develop common themes for

students' cognitive processes.

Results/Findings

Quantitative Data

Sixteen secondary-level career and technical education students used TAPPS while

troubleshooting a small gas engine compression system fault. Four of the 16 students were

successful at troubleshooting the compression system fault. Average time to completion for successful students was 15 minutes ($SD = 6.7$). Unsuccessful students spent an entire class period attempting to troubleshoot the engine fault. Class periods ranged from 30 to 35 minutes in length with an average of 31.2 minutes ($SD = 2.7$).

Table 1 shows frequencies and percentages of oral verbalizations for successful secondary-level career and technical education students who used TAPPS. The average total number of verbalizations for successful students was 66 ($SD = 32.7$). The average rate of oral verbalizations per minute for successful students was 4.4 ($SD = 1.0$).

Table 2 shows frequencies and percentages of oral verbalizations for unsuccessful secondary-level career and technical education students who used TAPPS. The average total number of verbalizations for unsuccessful students was 120 ($SD = 56.1$). The average rate of oral verbalizations per minute for unsuccessful students was 3.8 ($SD = 1.5$). Of all unsuccessful students, student H had higher rates of oral verbalizations in all categories except level-three negative self-assessment, level-three positive self-assessment, level-three negative problem assessment, and level-three positive problem assessment. When student H was removed from the data set, the average total number of oral verbalizations given by unsuccessful students was 105 ($SD = 27.0$) and the average rate of oral verbalizations per minute given by unsuccessful students was 3.4 ($SD = 0.8$)

Patterns of verbalizations in Tables 1 and 2 were relatively equal when completion time was accounted for. Level-one working memory, level-three planning, level-three monitoring, and level-three evaluating accounted for the majority of oral verbalizations.

Averages for the percentages of oral verbalizations by group are shown in Table 3. Successful students had slightly higher percentages of oral verbalizations in the categories of

level-one working memory, level-two nonverbal sensory information, level-three planning, and level-three evaluating. There were differences between unsuccessful and successful students in the standard deviations for the categories of level-three planning, level-three monitoring and level-three evaluating. Successful students had a higher standard deviation (9.1) for level-three planning oral verbalizations than unsuccessful students ($SD = 4.1$). Successful students also had a higher standard deviation (8.0) for level-three monitoring oral verbalizations than unsuccessful students ($SD = 5.5$). Successful and unsuccessful students had similar standard deviations for level-one working memory oral verbalizations. Unsuccessful students had higher percentages of oral verbalizations in the categories of negative self-assessment, negative problem assessment, and not on task.

Qualitative Data

Qualitative data were the content within students' oral verbalizations. The majority of this content that indicated cognitive processing was found in the categories of level-three planning, level-three monitoring, and level-three evaluating. The remaining content was in the categories of level-three negative self-assessment, level-three negative problem assessment, level-one working memory, and level-two nonverbal sensory information. Content for the categories of level-three positive self-assessment and level-three positive problem assessment was essentially nonexistent.

Level-three planning oral verbalizations

For both successful and unsuccessful students, level-three planning verbalizations were directed toward the order of tests to be made to the engine. Most students did not describe what they believed to be causing the engine to malfunction before attempting repairs. Unsuccessful student L stated, "Ah, check compression first, okay." Unsuccessful

student F stated, "So, we're going to start off by taking these bolts off here." Successful student J started troubleshooting by checking the spark plug gap without first identifying if a fault existed in the ignition system. Successful student A began troubleshooting by removing the air filter without identifying the problem with the engine.

When planning their next test, students described what they would do with little explanation for why they planned to conduct those tests. Successful student J stated, "Now I'm going to check my carburetor next soon as I get my top cover put back together." Unsuccessful student C commented that it seemed to have pretty good compression so the next thing to check was spark. When the listening partner asked, "What are you doing now?" Unsuccessful student F stated, "I'm gonna check for spark in the spark plug and make sure we've got that."

Level-three monitoring oral verbalizations

The content of level-three monitoring oral verbalizations given by successful and unsuccessful students revealed shallow analysis of possible solutions. After checking an engine component, students failed to progress in their troubleshooting. Students did not analyze the results of their tests before moving randomly to check other engine components. Successful student J stated, "I was going to check the armature gap because it seem to have a real easy pull but it still has compression so I had to check armature gap to make sure we were get'n enough through." Four unsuccessful students (C, F, G, and L) checked and rechecked the ignition armature air gap as well as the spark plug electrode gap. Unsuccessful student C remembered to check valve springs but upon examination determined nothing was wrong with them. Unsuccessful student C stated, "Err look at the valve springs really quick just to see if anything is wrong there…the valve springs look good, there's nothing abnormal

about them." Unsuccessful student C's listening partner asked, "How do you know that something's not wrong with those?" In response, unsuccessful student C stated, "Ah um they look pretty normal they didn't look anything out of the ordinary so just by the eye they looked fine to me." Afterward, unsuccessful student C's listening partner asked, "Could they be warped or disfigured if something was wrong?" Unsuccessful student C replied, "Yeah, they would but if they, they look pretty good to me."

Level-three evaluating oral verbalizations

Unsuccessful students' level-three evaluating verbalizations indicated a lack of knowledge regarding the troubleshooting procedure and the functions of engine components. Unsuccessful student P stated, "Alright, then compression, crap I forgot what the other one's were alright, compression, crap something else and then the carburetor." Unsuccessful student O stated, "I don't know what I'm doing." Four unsuccessful students (F, L, N, and M) identified compression as the fault area but failed to identify a solution. Of these four students, two (M and F) verbalized that they could not remember what to check for compression. Unsuccessful student M stated, "I don't even remember everything we're supposed to check for compression, so, if, I can't even remember what to check there's no way I can get it fixed." Unsuccessful student F stated, "There's like no compression… I can't even remember. Probably check to see if there's any spark, I've already checked the gas and there's gas in there right now already, so I've got that covered." Student N identified compression as the problem but linked the cause of the fault to the ground wire. Student L also identified that the engine had a compression fault and then attempted a solution by making adjustments to the ignition armature air gap.

Successful students' level-three evaluation verbalizations were focused on making judgments relevant to the cause of the engine fault based on the result of their engine test. Successful student I stated, "Ah, the compression system is wrong; the intake doesn't look to be moving." Successful students often verbalized about what they had learned from working with the engine. These students made note of problem characteristics and related them to what they had learned. Successful student J stated, "Well, I don't know how I'm suppose to fix it, but I think I figured the problem out, um the spring doesn't seem to be seated right, um, I'm not sure what I'd do to fix springs, the other one has a gap right there… It doesn't seem to be compressed, um make it so it would be compressed."

Level-three negative self-assessment, level-three negative problem assessment, and not on task oral verbalizations

Negative self-assessment, negative problem assessment, and not on task verbalizations generally were given by unsuccessful students. Unsuccessful students judged themselves as poor problem solvers. Unsuccessful student K stated, "I feel like a retard." Three unsuccessful students (K, M, and O) explained they did not like being recorded while they were working. Unsuccessful student M stated, "Umm, cause I don't like this talking through it, I'm not a talker anyway." Unsuccessful student B stated, "Thinking I'm probably didn't get this and I'm going to be the one failure in the class." Two students (E and H) seemed to view the activity as irrelevant to them. Unsuccessful student E stated, "…this is stupid I really don't care about these stupid engines..." Unsuccessful students often verbalized about irrelevant information characteristic of being not on task. These verbalizations often focused on activities of the day or other student events. Unsuccessful student H stated, "Subway eat fresh, ha ha we're talking about random bull."

Level-one working memory oral verbalizations

Most often students' level-one working memory verbalizations described their actions as they removed or returned parts to the engine. When describing their actions, successful student A and three unsuccessful students (E, K, and B) failed to use correct engine terminology to describe the engine parts. Successful student A stated, "Taking off ssss hold on I don't know what it is yet but I'm taking it off." Unsuccessful student E stated, "I'm gonna take off the something I don't know what it's called so yeah taking this thing off."

Level-two nonverbal sensory information oral verbalizations

There were no differences in content of level-two nonverbal sensory information oral verbalizations between successful and unsuccessful students. Across groups, level-two nonverbal sensory information verbalizations revealed sensations in smell and touch that were attended to by students during troubleshooting. These verbalizations described perceptions of these sensations. Successful student D stated, "Ugh that smells." Unsuccessful student H stated, "Smells good."

Table 1. *Frequencies and percentages of oral verbalizations for successful students who used think-aloud pair problem solving*

Student	L1	L2	L3P	L3M	L3E	L3NSA	L3PSA	L3NPA	L3PPA	NOT	Total
A	31	0	6	18	32	1	0	0	0	4	92
	(33.7%)	(0.0%)	(6.5%)	(19.5%)	(34.8%)	(1.1%)	(0.0%)	(0.0%)	(0.0%)	(4.3%)	(100.0%)
D	19	1	6	11	16	2	0	0	0	1	56
	(33.9%)	(1.8%)	(10.7%)	(19.6%)	(28.6%)	(3.6%)	(0.0%)	(0.0%)	(0.0%)	(1.8%)	(100.0%)
I	11	2	0	4	6	0	1	0	0	0	24
	(45.8%)	(8.3%)	(0.0%)	(16.7%)	(25.0%)	(0.0%)	(4.2%)	(0.0%)	(0.0%)	(0.0%)	(100.0%)
J	45	0	20	3	24	0	0	0	0	0	92
	(48.9%)	(0.0%)	(21.7%)	(3.3%)	(26.1%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(100.0%)

Note. L1 = level-one working memory, L2 = level-two nonverbal sensory information, L3P = level-three planning, L3M = level-three monitoring, L3E = level-three evaluating, L3NSA = negative self-assessment, L3PSA = positive self-assessment, L3NPA = negative problem assessment, L3PPA = positive problem assessment, NOT = not on task.

Table 2. *Frequencies and percentages of oral verbalizations for unsuccessful students who used think-aloud pair problem solving*

Student	L1	L2	L3P	L3M	L3E	L3NSA	L3PSA	L3NPA	L3PPA	NOT	Total
B	32	0	9	17	36	4	1	2	0	0	101
	(31.7%)	(0.0%)	(8.9%)	(16.8%)	(35.6%)	(4.0%)	(1.0%)	(2.0%)	(0.0%)	(0.0%)	(100.0%)
C	43	0	13	22	28	0	0	0	0	0	106
	(40.6%)	(0.0%)	(12.3%)	(20.8%)	(26.4%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(0.0%)	(100.0%)
E	42	1	6	19	23	1	0	3	0	1	96
	(43.8%)	(1.0%)	(6.3%)	(19.8%)	(24.0%)	(1.0%)	(0.0%)	(3.1%)	(0.0%)	(1.0%)	(100.0%)
F	36	2	19	21	33	2	0	6	0	10	129
	(27.9%)	(1.6%)	(14.7%)	(16.3%)	(25.6%)	(1.6%)	(0.0%)	(4.7%)	(0.0%)	(7.8%)	(100.0%)
G	28	1	11	31	32	0	0	2	0	0	105
	(26.7%)	(1.0%)	(10.5%)	(29.5%)	(30.5%)	(0.0%)	(0.0%)	(1.9%)	(0.0%)	(0.0%)	(100.0%)
H	109	17	21	42	60	0	1	7	0	23	280
	(38.9%)	(6.1%)	(7.5%)	(15.0%)	(21.4%)	(0.0%)	(0.4%)	(2.5%)	(0.0%)	(8.2%)	(100.0%)
K	39	2	2	33	38	7	0	6	0	2	129
	(30.2%)	(1.6%)	(1.6%)	(25.6%)	(29.5%)	(5.4%)	(0.0%)	(4.7%)	(0.0%)	(1.6%)	(100.0%)

Table 2. (*continued*)

Student	L1	L2	L3P	L3M	L3E	L3NSA	L3PSA	L3NPA	L3PPA	NOT	Total
L	40	0	12	19	20	2	0	1	1	0	95
	(42.1%)	(0.0%)	(12.6%)	(20.0%)	(21.1%)	(2.1%)	(0.0%)	(1.1%)	(1.1%)	(0.0%)	(100.0%)
M	51	1	17	25	27	4	0	16	0	5	146
	(34.9%)	(0.7%)	(11.6%)	(17.1%)	(18.5%)	(2.7%)	(0.0%)	(11.0%)	(0.0%)	(3.4%)	(100.0%)
N	42	0	14	9	17	1	0	1	0	0	84
	(50.0%)	(0.0%)	(16.7%)	(10.7%)	(20.2%)	(1.2%)	(0.0%)	(1.2%)	(0.0%)	(0.0%)	(100.0%)
O	54	2	8	12	18	3	6	1	0	13	117
	(46.2%)	(1.7%)	(6.8%)	(10.3%)	(15.4%)	(2.6%)	(5.1%)	(0.9%)	(0.0%)	(11.1%)	(100.0%)
P	26	1	4	9	8	1	0	1	0	0	50
	(52.0%)	(2.0%)	(8.0%)	(18.0%)	(16.0%)	(2.0%)	(0.0%)	(2.0%)	(0.0%)	(0.0%)	(100.0%)

Note. L1 = level-one working memory, L2 = level-two nonverbal sensory information, L3P = level-three planning, L3M = level-three monitoring, L3E = level-three evaluating, L3NSA = negative self-assessment, L3PSA = positive self-assessment, L3NPA = negative problem assessment, L3PPA = positive problem assessment, NOT = Not on task.

Table 3. *Average percentages of oral verbalizations by group*

Code	Successful		Unsuccessful	
	M	*SD*	*M*	*SD*
L1	40.6	7.9	38.7	8.5
L2	2.5	4.0	1.3	1.7
L3P	10.0	9.1	9.8	4.1
L3M	15.0	8.0	18.3	5.5
L3E	29.0	4.4	23.7	6.1
L3NSA	1.2	1.7	2.0	1.7
L3PSA	1.0	2.1	0.5	1.5
L3NPA	0.0	0.0	3.0	3.0
L3PPA	0.0	0.0	0.1	0.3
NOT	1.5	2.1	3.0	4.0

Note. L1 = level-one working memory, L2 = level-two nonverbal sensory information, L3P = level-three planning, L3M = level-three monitoring, L3E = level-three evaluating, L3NSA = negative self-assessment, L3PSA = positive self-assessment, L3NPA = negative problem assessment, L3PPA = positive problem assessment, NOT = not on task.

Conclusions/Recommendations/Implications

When work time was accounted for, verbalization rates between unsuccessful and successful students were similar in all oral verbalization categories except level-three negative-self assessment, level-three negative problem assessment, and not on task. Successful students had no level-three negative problem assessment, whereas unsuccessful students had an average of three verbalizations for level-three negative problem assessment. Also, unsuccessful students gave almost two times the amount of negative self-assessment

verbalizations as successful students. This could have been caused by students' frustration with not finding a solution toward the end of their troubleshooting activity. On average, unsuccessful secondary-level career and technical students gave twice the amount of not on task verbalizations as successful students. This can be explained by the number of not on task verbalizations given by unsuccessful students F, H, and O. These students' not on task oral verbalizations averaged 9% of their total oral verbalizations. The remaining unsuccessful students' not on task oral verbalizations averaged only 0.7% ($SD = 1.2$) of their total oral verbalizations. The total average percentage of oral verbalizations across the level-three planning, monitoring, and evaluating categories was 54% for successful students and 52% for unsuccessful students. These rates indicate that TAPPS focuses secondary-level students' thinking toward a process-oriented approach during troubleshooting.

However, the content of students' oral verbalizations indicates the metacognitive nature of the TAPPS strategy does not improve problem-solving success when secondary-level career and technical education students do not possess enough domain-specific knowledge. Unsuccessful students' verbalizations in the level-three monitoring and evaluating categories often were concerned with their level of knowledge regarding troubleshooting and small engines. These students had difficulty remembering the troubleshooting process and the proper functions of engine components. Unsuccessful secondary-level career and technical education students verbalized negatively about their ability or performance and the troubleshooting activity. A majority of level-three evaluating statements from unsuccessful students focused on assessing their knowledge of engine principles and troubleshooting. Unsuccessful students described their level of knowledge as low or nonexistent. In contrast, the content of successful students' level-three evaluating

verbalizations focused on making judgments in relation to their monitoring of the effects of their engine tests and their evaluation of engine fault symptoms.

Students' concerns about their knowledge level could be connected to their rate of troubleshooting success. An implication is that students' knowledge level could be connected to the amount of instruction they receive and the difficulty of the troubleshooting activity. All secondary-level students in this study received only one class period of troubleshooting instruction. Students were given notes and a demonstration on how to troubleshoot the air/fuel delivery, ignition, and compression systems. Students were told the engine needed all three systems to function correctly in order to run, and possible faults for each system were described to the students. To complete the troubleshooting activity, students had to identify the system at fault, identify the specific engine component that was malfunctioning, and correctly describe the appropriate repair. Postsecondary students in Pate et al.'s (2004) study were enrolled in a college course that required a prerequisite agricultural technology course in which basic engine principles were taught, and the high success rate of postsecondary students who used TAPPS in Pate et al.'s study could be associated with the level of instruction provided. The course requirements may have caused the postsecondary students' domain specific knowledge to be stronger than that of the secondary-level students. Davidson et al. (1994) observed that amount and quality of a problem solver's domain-specific knowledge can be a limiting factor in their ability to reach a solution. However, secondary-level students' knowledge of basic engine principles and operating theory was not formally assessed prior to this study. Analysis of the qualitative data indicates that students' domain-specific knowledge was not strong enough to support troubleshooting. Secondary-level career and technical education teachers should ensure their students possess the prerequisite

knowledge before performing troubleshooting. Researchers should determine if students possess strong domain-specific knowledge before testing the effects of TAPPS on troubleshooting success.

Lochhead (2001) pointed out that the goal of TAPPS is the eventual development of students' ability to observe and control their cognitive behavior, but Glaser (1984) argued that transfer of thinking habits from using general strategies like TAPPS is limited because of a lack of a direct connection between thinking and problem solving during learning. Perkins, Simmons, and Tishman (1990) argued that general cognitive strategies have potential to be helpful in teaching problem solving but only with deliberate effort, and Salomon and Perkins (1989) concluded that the lack of transfer in thinking habits taught in general cognitive strategies is linked to the reliance on automatic triggering through practice rather than thoughtfully decontextualizing principles from one context and applying them to another. Thus, implementation of the TAPPS strategy should be modified for use with secondary-level career and technical education students. Perkins et al. suggested contextualizing instruction of general cognitive strategies by teaching them in the target domain with vocabulary adjusted to suit the target domain. For example, secondary-level students could practice using TAPPS with an engine problem before being tested.

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CHAPTER V. EFFECTS OF REGULATORY SELF-QUESTIONING ON SECONDARY-LEVEL STUDENTS' PROBLEM-SOLVING PERFORMANCE

A paper prepared for the submission to the Journal of Agricultural Education

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Abstract

A randomized, posttest-only control group experimental design was used to determine the effects of regulatory self-questioning on secondary-level career and technical education students' electrical circuit theory test scores. Students who participated in the self-questioning group were given a list of regulatory questions and asked to answer them as they solved their problems. Differences in test scores between the experimental and control groups were *not statistically significant (p = .053). On average, students in the treatment group outperformed students in the control group by 10 percentage points. Cohen's d indicated a moderate effect size (0.5). Findings from this study suggest that students who engage in regulatory self-questioning are more likely to solve electrical circuit theory problems correctly. Educators could assist students in achieving greater problem-solving outcomes by requiring use of regulatory self-questioning. This study should be replicated to determine the effects of regulatory self-questioning with other students*, and *further research should be conducted to investigate the effects of regulatory self-questioning when students are faced with increasingly complex problems.*

Background

Students engaged in learning principles of electricity often have difficulty understanding the abstract nature of the mathematical relationships involved with Ohm's law. Students have difficulty understanding the relationships between voltage, current, and resistance in a circuit. Students tend to implement localized reasoning when challenged with

the task of analyzing a circuit (Cheng & Shipstone, 2002). McDermott and Shaffer (1992) found that students computing electrical circuit problems often ignored or modified the mathematics when their results contradicted their expectations.

Cohen, Eylon, and Ganiel (1983) examined high-school students' understanding of the relationships between the variables in an electrical circuit and found that students often used Ohm's law incorrectly. "Students have difficulties in analyzing the effect which a change in one component has on the rest of the circuit" (Cohen et al., p. 407). Students also were inconsistent in their reasoning when they analyzed circuits. McDermott and Shaffer (1992) called for instruction that will promote the active mental participation of students in their learning process. Some researchers have suggested that a regulatory checklist is an instructional strategy that could improve students' problem solving (King, 1991b; Schraw, 1998).

Theoretical Framework

The theoretical framework for this study is built around metacognition and its relationship to problem solving.

Metacognition and Problem Solving

Active mental participation is called metacognition (Flavell, 1979). Metacognition has been defined as actively attending to one's thinking. Metacognitive knowledge "can lead you to select, evaluate, revise, and abandon cognitive tasks, goals, and strategies in light of their relationships with one another and with your own abilities and interests with respect to that enterprise" (Flavell, p. 908). Metacognition involves two components: knowledge about cognition and the regulation of cognition (Schraw, 1998). The learner must have knowledge about how to perform a task and also how to plan, monitor, and evaluate their performance.

A problem occurs when an individual has identified an initial situation with a goal in mind but has no clear means of achieving the end result (Chi & Glaser, 1985). Problems generally consist of three components: givens, obstacles, and a goal state (Anderson, 1985). Givens are limitations and characteristics that define the initial state of the problem. Obstacles are known and unknown givens that make it difficult to reach the desired solution. The goal state is simply the desired outcome or solution. Problem solving encompasses the individuals' efforts toward achieving a situational goal for which there is no direct solution path. Depending on the level of difficulty of the problem, these problem-solving efforts are organized into hierarchical tasks; subordinate goals must be achieved before the final goal can be reached. When students compute electrical circuit problems, they must identify the correct mathematical algorithm before computing the solution using Ohm's law. Transforming the initial situation into the desired goal requires mental and behavioral activities (Chi & Glaser). The amount and level of mental operations that students use can vary depending on how difficult it is to formulate a solution (Andre, 1986).

Swanson (1990) suggested that students engaged in problem solving typically have only partial knowledge about a problem and its solution. This creates a situation in which the student initiates a general search for information and possible solutions. This search is guided and controlled by the student's metacognition. "Metacognition is especially important because it affects acquisition, comprehension, retention and application of what is learned, in addition to affecting learning efficiency, critical thinking, and problem solving" (Hartman, 1998, p. 1). In Swanson's study, high metacognitive ability positively influenced students' problem-solving performance. The high-metacognitive students' advantage in problem-solving performance was linked to increased hypothetico-deductive reasoning and

prioritization of strategies. High-metacognitive students demonstrated efficient and effective information processing by correctly monitoring right and wrong answers.

Pintrich (2002) argued that novices need to have a repertoire of different general strategies for learning and thinking to master new or challenging tasks. Metacognitive instruction would enable students to perform better and learn more in the classroom. This instruction needs to be taught explicitly by embedding it within content-driven lessons in different subject areas. Explicit metacognitive instruction helps students connect the strategies to other knowledge they may already have. According to Cardelle-Elawar (1995), metacognitive training through self-questioning induces students to self-regulate their learning. The metacognitive questioning encourages students to activate prior knowledge, analyze information, reconceptualize the problem space by integrating information into a coherent representation, and self-monitor their progress by evaluating and correcting their mistakes.

Most research documenting positive effects of metacognitive strategies has been limited to content areas of reading and mathematics (King, 1991a; Royer, Cisero, & Carlo, 1993). This creates contention as to whether metacognition is domain specific or domain general in nature (Royer et al.; Schraw, 1998). Glaser (1984) suggested general metacognitive problem-solving strategies have little benefit for teaching specific skill sets and argued that general problem-solving methods are less powerful because of a lack of domain specificity. Novices' difficulties in problem solving are said to be linked to the inadequacies of their knowledge base rather than their ability to use problem-solving strategies. Riley, Greeno, and Heller (1983) concluded that children's success at solving simple word problems that require the use of addition and subtraction principles was

influenced by their knowledge of efficient counting procedures. This suggests that implementation of a general metacognitive problem-solving strategy during electrical circuit theory instruction will have little effect on students who possess knowledge of algebraic principles.

Another point of concern with explicitly teaching metacognitive strategies within content-driven lessons is that this may generate competition within cognitive capacities such as memory and attention. Perkins, Simmons, and Tishman (1990) argued that adding a metacognitive strategy during instruction may disrupt performance because of a cognitive overload. For example, use of a regulatory checklist during instruction may generate greater demands on attention and working memory. Explicit metacognitive training during instruction could be detrimental to students' acquisition of content knowledge, which could lead to a decrease in problem-solving performance.

Regulatory Checklist

Schraw (1998) suggested use of an instructional strategy called regulatory checklist to improve student's regulation of cognition while attending to instruction and problem solving. The regulatory checklist is considered a metacognitive strategy because it functions to help learners keep a continuous check on their progress (King, 1991b). The questions are designed to help students clarify the problem and access their existing knowledge and strategies when relevant. King (1991b) stated that "truly self-regulated learners eventually learn and study alone" (p. 334) without the advantage of an external prompter. King (1991b) found that ninth graders who used self-questioning to review had greater history lecture comprehension than students who used discussion groups and students who used independent study sessions on both practiced and unpracticed lecture material. King (1991a) found that fifth graders trained

in guided questioning had greater problem-solving processes and outcomes when attempting to solve computer-assisted problems. This method may have taught students how to internally ask for and obtain the explanations, justifications, information and methods needed for solving the problem. Cardelle-Elawar (1995) found that low-achieving elementary and junior-high students who were instructed in and practiced monitoring themselves during the act of problem solving by using guided questioning were more successful on achievement tests than students who were not engaged in guided questioning.

Self-questioning during problem solving may hold promise for enhancing student performance, but no studies have been done in the context of secondary-level career and technical education programs teaching the use of Ohm's law.

Purpose

The purpose of this study was to determine if the use of regulatory self-questioning improved success rates of secondary-level career and technical education students asked to solve simple circuit problems by using algebraic manipulation of Ohm's law.

Hypothesis

There will be no significant difference in test scores for solving simple circuit problems using Ohm's law between students who are taught to use a regulatory checklist and students who are not taught how to use the regulatory checklist.

Methodology

Participants

The study involved four secondary-level schools from Iowa. The schools were chosen on the basis of their accessibility to Iowa State University and the curriculum taught in their career and technical courses. Students enrolled in selected agriculture and industrial

education courses dealing with electricity were selected to be the subjects for this study. The study population consisted of 68 students whose ages ranged from 14 to 17 years.

Research Design

This study used a randomized, posttest-only experimental design (Campbell & Stanley, 1966)*.* This design, which is inherently resistant to most threats to internal validity, is illustrated in Figure 1. Possible threats to internal validity are subject effects and diffusion. The researcher could unintentionally bias students' inclination to perform better if his behavior or explanations revealed that students were receiving a treatment. To control for subject effects, the researcher explained that the activity was a research project to try out two teaching methods to improve the course and stated that both methods were believed to have the same effect. To control for situational variables such as teaching efficiency and enthusiasm, the regular classroom instructor was taught procedures to follow for their role in the project. The classroom instructor was instructed to follow the given lesson plan. During the practice sessions and test administration, the teacher and researcher gave the same instructions, used the same practice problems and tests, and tried to assume the same attitudes with the students. The instructor's and researcher's interactions with students were audio recorded for comparison and to verify the protocol was followed.

R	C	O_s
R	X	O_s

Figure 1. Illustration of randomized, posttest-only experimental design. R = random assignment, O_s= observation of test score, X = experimental group, C = control group.

All students received instruction from their regular classroom teacher via a lesson plan adapted from the Center for Agricultural and Environmental Research and Training, Inc. (CAERT) titled "Measuring and Calculating Electricity" (CARET, 2002). Instruction was given on basic electrical terminology including voltage, amperage, and resistance. The instructor also taught the components of Ohm's law and how to solve simple circuit problems by manipulating Ohm's law. During the class meeting following instruction, the researcher randomly assigned students to either the experimental or control group for a practice session on how to use Ohm's law. The groups received identical materials, except the experimental group students also received a regulatory checklist as part of the metacognitive treatment. The metacognitive treatment involved instruction on how to regulate thinking via a regulatory checklist adapted from Schraw (1998). Details of treatments for each group are detailed in the treatment section. For the practice sessions, one group was selected randomly to be relocated to another classroom to prevent diffusion of information between the groups. Two of the experimental groups were relocated, and two of the control groups were relocated. The groups remained separate until completion of the test.

Each student in each group was given an example problem worked by either the teacher or researcher, depending on which group the student was assigned to, and a set of two practice problems to work independently. During the practice sessions, the teacher and researcher assisted students via individualized coaching while students worked on the two

practice problems. The individualized coaching involved discussion with the student regarding possible manipulations of Ohm's law. The teacher was provided an answer key for the practice problems to check students' answers. Students' answers were confirmed as correct by the teacher or researcher, depending on which group the student was assigned to. If a student's answer was incorrect, the teacher or researcher told the individual student the answer was incorrect and explained that the answer was either given in the incorrect units, calculated incorrectly, or calculated for the wrong component of the circuit. Students were told to redo the problem. When the student finished reworking the problem, the teacher or researcher confirmed whether the new answer was correct. Practice sessions were uniformly scheduled for 40 minutes.

Treatments

The only difference between groups was that students in the control group received no training, modeling, or instruction on how to use regulatory questioning. The teacher provided the control group with a demonstration on how to use Ohm's law. This allowed students to review what they learned from the lesson on Ohm's law. Students worked the example problem on their worksheet while following directions from their teacher. After the teacher's demonstration, students practiced independently by solving two simple circuit practice problems. During the control group's practice session, the teacher monitored students, assisted students via individualized coaching while they worked on the two practice problems, answered questions regarding correct answers, and reminded students to work on their questions independently.

Students assigned to the experimental group received instruction from the researcher on how to regulate their thinking via a regulatory checklist adapted from Schraw (1998). The

checklist included questions grouped into three metacognitive categories: planning,

monitoring, and evaluating (Figure 2).

Planning

What is the problem?

What am I trying to do here?

What do I know about the problem so far?

What information is given to me?

How can this help me?

What is my plan?

Is there another way to do this?

What would happen if …?

What should I do next?

Monitoring

Am I using my strategy?

Do I need a different strategy?

Has my goal changed?

What is my goal now?

Am I on the right track?

Am I getting closer to my goal?

Evaluating

What worked?

What didn't work?

What would I do differently next time?

Figure 2. Regulatory checklist questions.

Students in the experimental group were given a regulatory checklist question card.

The researcher read and explained the card and demonstrated how to use regulatory questions

with Ohm's law. This allowed students to practice what they learned from the lesson on

Ohm's law. Students in the experimental group worked the example problem on their

worksheet while following directions from the researcher. During the demonstration, the

researcher verbalized his thought processes to answer the regulatory checklist questions

while solving the example problem. Students followed along by observing their question cards. After the researcher's demonstration, students practiced independently by solving the two simple circuit practice problems while using their regulatory checklist.

Students in the experimental group were told that question asking and question answering is a way of managing and checking their thinking while problem solving. The researcher explained that this was a way of keeping themselves aware of what they are doing during problem solving so they could monitor their path toward a solution. During the practice session, the researcher monitored students, assisted students via individualized coaching while students worked on the two practice problems, provided assistance regarding the use of the regulatory checklist, answered questions regarding correct answers, and reminded students to work on their questions independently.

Instrumentation

The researcher developed a test based on information in the CAERT (2002) lesson plan "Measuring and Calculating Electricity" to assess students' performance. The test involved only single-load circuits. The questions were theoretical in nature and did not include voltage drop. The test contained six word problems: two for unknown voltage, two for unknown amperage, and two for unknown resistance. The test and lesson plan were reviewed for content and face validity by five professors who taught methods for teaching agricultural mechanics courses. Reviewers were asked to determine whether the lesson plan was typical of an electrical circuit theory lesson, if the test measured what was being taught in the lesson plan, if the test items were at a median level of difficulty, if 3 minutes was an appropriate time limit to solve the problems, and if the items would be clear and unambiguous for students. The reviewers determined the test and lesson plan were content

and face valid and deemed the time limit appropriate. The time limit of 3 minutes is

consistent in research examining mathematical word problem solution times (Mwangi &

Sweller, 1998; Sweller, & Cooper, 1985).

A pilot test was conducted with eight undergraduates at Iowa State University

enrolled in an agricultural mechanics teaching methods course taught by the researcher to

determine any unforeseen problems with the experimental protocol and internal consistency

of the electricity test. No problems were detected with implementation of the experimental

protocol. Cronbach's alpha for the experimental group ($n = 4$) was .88. Cronbach's alpha for

the control group ($n = 4$) was 1.0.

Data Collection

After they completed the two practice problems, students were given the test to assess

their performance. Students were allowed 3 minutes to complete each problem and received a

nonprogrammable calculator to compute basic arithmetic. Students in the experimental group

were asked to use the regulatory checklist procedure as they completed the test. Each student

worked independently. Students were separated by distance and monitored by either the

teacher or the researcher, depending on which group they were assigned to, to reduce the

likelihood that students would observe other students answers during the test. Each student

received each question separately. After 3 minutes, the question was collected by either the

teacher or the researcher and the next question was given to the students. Questions were

handed out face down. Students were instructed not to turn the question over until they were

given permission to start. Students who finished a question before the 3-minute time limit

were asked to raise their hand to have their paper collected by the researcher or teacher.

Students were told to wait quietly until the next question was handed out.

Correct answers were tabulated and recorded by the researcher for each student. Each problem was assigned a point value of three points. Students were given one point for correct manipulation of Ohm's law to isolate the unknown property of the problem, the correct mathematical answer, and correct units of measure for the answer. No points were given if students left the question blank.

Analysis

Data were analyzed with SPSS version 16.0. Means and standard deviations were used to describe problem-solving scores. Independent *t*-tests were used to determine any significant differences in test scores between students in the experimental and control groups. The unit of analysis was the student. To check for scoring errors, the researcher recalculated students' scores prior to data entry. To check for data entry error, the researcher compared students' scores recorded on the data collection forms with values entered in the computer to determine if any discrepancies existed. No data entry errors were detected. The alpha level was set at .05.

Results

Because students were assigned randomly to groups, it was assumed that any preexisting differences would fall within the range of expected statistical variation and would not confound the results. The audio recordings of the teacher and researcher were used to ensure the fidelity of the treatment and indicated the protocol was followed. Frequency distributions of the control and experimental group's test scores are shown in Tables 1 and 2, respectively. The control group and experimental group distributions were negatively skewed. The test score distributions clearly favor the regulatory self-questioning approach. Regulatory self-questioning students scored higher than students who worked silently. The

proportion of regulatory self-questioning students with test scores between 90 and 100% was twice that of students who worked silently. In addition, the proportion of control students with test scores of 69% and below was three times that of students who used regulatory self-questioning.

Table 1
Control group students' test score distribution

Range in %[a]	f	%	Cumulative %
≤55	4	11.8	11.8
60 to 69	5	14.7	26.5
70 to 79	7	20.5	47.0
80 to 89	7	20.6	67.7
90 to 100	11	32.4	100.0
Total	34	100.0	

Table 2
Regulatory self-questioning group students' test score distribution

Range in %	f	%	Cumulative %
≤55	2	5.8	5.8
60 to 69	1	2.9	8.7
70 to 79	4	11.8	20.6
80 to 89	4	11.8	32.4
90 to 100	23	67.6	100.0
Total	34	100.0	

Table 3 shows the mean percentage test scores by group. On average, the regulatory self-questioning group's test scores were 10 percentage points higher than those of the control group. The calculated Cohen's *d* (.5) indicated a medium treatment effect (Cohen, 1992). The difference in electrical circuit theory test scores between the control group and experimental group was not statistically significant (t (62) = 1.96, p = .053). Therefore, the hypothesis positing no significant difference in test scores for solving simple circuit problems using Ohm's law between students who use a regulatory checklist and students who do not was not rejected.

Table 3
Differences between groups for percentage scored on Ohm's law simple circuit test

Group	M	SD	% Difference	d
Control (n = 34)	78.8	20.5	10.0	0.5
Experimental (n = 34)	88.4	19.9		

t (62) = 1.96, p = .053.

Conclusions/Recommendations/Implications

Students in the regulatory self-questioning group scored 10 percentage points higher than the control group. Although the *t*-test did not detect a statistically significant difference, Cohen's *d* indicated a moderate treatment effect of regulatory self-questioning on students' test scores for solving simple circuit problems using Ohm's law. The test score distributions suggest that students who use regulatory self-questioning are more likely to solve Ohm's law simple circuit problems correctly than students who do not use regulatory self-questioning. Findings from this study support assertions made by Cardelle-Elawar (1995), King (1991a, 1991b), and Swanson (1990) that use of regulatory self-questioning helps students learn difficult material. Test scores from the regulatory self-questioning group do not support

Perkin et al.'s (1990) conclusion that adding a metacognitive strategy during instruction would disrupt students' problem-solving performance. Regulatory self-questioning is a promising instructional tool for improving secondary-level students' problem-solving performance.

The skewed distribution for each group of test scores suggests this activity may not have been at a level of difficulty that required a high level of problem-solving activity. In the control group, 53% of students achieved a test score of 80% or better on the Ohm's law test, whereas 79% of students in the regulatory self-questioning group scored 80% or better. The content of the test required secondary-level students to find and use the appropriate mathematical algorithm to produce the correct solution. Anderson (1985) noted that problem solving can involve various amounts and levels of challenging tasks, which can vary the mental effort needed to find a solution and apply it (Andre, 1986). Further research should be conducted to investigate the effects of regulatory self-questioning when students are faced with increasingly complex electrical circuit theory problems.

Considered along with the percentage of students in the regulatory self-questioning group with high test scores, the effect size between treatments suggests that use of regulatory self-questioning may positively benefit teachers who teach principles of Ohm's law. This also may have implications for educators in other content areas that rely heavily on problem solving, such as science and technology. According to Pintrich (2002) and Royer et al. (1993), these content areas rely heavily on specific skill sets such as troubleshooting and hypothesis testing. There is controversy regarding the effectiveness of teaching students general thinking strategies to improve problem solving. One camp argues that using general problem-solving strategies is less powerful because of a lack of domain specificity (Glaser,

1984). Another camp argues that teaching general thinking strategies allows students to monitor and improve their cognitive performance (Schraw, 1998). This study tends to support the latter argument. Educators could incorporate regulatory self-questioning into their instruction by calling on students to answer regulatory questions during class. This would benefit students by encouraging expert-like problem-solving behavior. Because this sample consisted of only 68 secondary-level career and technical students, this study should be replicated to determine if the effects of regulatory self-questioning are consistent across subject matter and populations.

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CHAPTER VI. GENERAL CONCLUSIONS

General Discussion/Implications/Recommendations

This dissertation contains three papers that explore the effects of metacognitive instructional strategies on secondary-level career and technical education students' problem solving. One article reports the effects of think-aloud pair problem solving (TAPPS) on secondary-level students' success rate and time to completion for troubleshooting small engine faults in career and technical education courses. The second article analyzes secondary-level career and technical education students' cognitive processes indicated by their oral verbalizations during the use of TAPPS while troubleshooting. The third article reports the effects of using a regulatory checklist on secondary-level students' success rate for solving simple circuit problems using algebraic manipulation of Ohm's law in career and technical education courses. Three overall conclusions can be drawn.

Even though success rates were not statistically different between treatment groups, secondary-level career and technical education students who orally verbalized their thoughts while troubleshooting a small gas engines had a lower success rate than students who did not. Among students across both groups who successfully completed the troubleshooting task, there were no significant differences in completion time. Even so, average completion time for successful TAPPS students was 4 minutes longer than for successful students in the control group. Twenty-five percent of students who used TAPPS and 38% of students in the control group were able to successfully identify the correct fault, identify the correct engine system affected, and correctly describe how to repair the fault in order for the engine to operate. A key difference between secondary-level students in this study and postsecondary students in Pate, Wardlow, and Johnson's (2004) study is the level of instruction provided to

students. Secondary-level students received one class period of instruction, whereas postsecondary students in Pate et al.'s study were enrolled in a junior-level college course that required a prerequisite agricultural technology course in which basic engine principles were taught. Although this exploratory study offers no support for using TAPPS at the secondary level, the reader is cautioned against making generalizations from this relatively small sample of 34 students. This study does not rule out the possibility that TAPPS could be useful with other secondary-level students. This study should be replicated to determine if the effects of TAPPS are consistent across subject matter and populations, and further research should include a larger number of subjects to improve the power of the statistical tests.

The content of students' oral verbalizations indicates the metacognitive nature of the TAPPS strategy does not improve problem-solving success when secondary-level career and technical education students do not possess enough domain-specific knowledge. Unsuccessful students described their level of knowledge as low or nonexistent. Students' concerns with their knowledge level were connected to their rate of troubleshooting success. The level of instruction provided to secondary-level students may be linked to their low success rate. However, secondary-level students' knowledge of basic engine principles and operating theory was not formally assessed prior to this study. The positive benefits of metacognitive instructional strategies may be correlated to the knowledge level of students within a content area. Davidson, Deuser, and Sternberg (1994) observed that amount and quality of a problem solver's domain-specific knowledge can be a limiting factor in their ability to reach a solution. When students do not possess the prerequisite knowledge, metacognitive instructional strategies will have little effect on students' problem-solving success. Future research should investigate the relationship between troubleshooting

instruction time and secondary-level career and technical education students' ability to use TAPPS successfully.

Implementation of the TAPPS strategy should be modified for use with secondary-level career and technical education students. Because secondary-level students who successfully completed a troubleshooting task seemed to shift their focus toward a more process-oriented approach rather than focusing on what they did not know, one recommendation is to allow secondary-level students to practice using TAPPS with an engine problem before being tested. Perkins, Simmons, and Tishman (1990) suggested contextualizing instruction of general cognitive strategies by teaching them in the target domain with vocabulary adjusted to suit the target domain. To this end, TAPPS could be incorporated into daily activities and students could be deliberately encouraged to practice direct, goal-oriented, rational thinking during problem solving. Future research should investigate the effects of providing listeners with focused instruction and practice on how to ask questions to elicit metacognitive thinking.

Regulatory self-questioning is a promising instructional tool for improving secondary-level students' problem-solving performance. Secondary-level career and technical students who used regulatory self-questioning were more likely to solve Ohm's law simple circuit problems correctly than students who worked without using the regulatory self-questioning technique. On average, students who used regulatory self-questioning scored 10 percentage points higher than students who did not use regulatory self-questioning. Considered along with the percentage of students in the regulatory self-questioning group with high test scores, the effect size ($d = 0.5$) suggests that use of regulatory self-questioning may positively benefit teachers who teach principles of Ohm's law. This may have

implications for educators in other content areas that rely heavily on problem solving, such as science and technology. According to Pintrich (2002) and Royer, Cisero, and Carlo (1993), these content areas rely heavily on specific skill sets such as troubleshooting and hypothesis testing. Educators could incorporate regulatory self-questioning into their instruction by calling on students to answer regulatory questions during class. This would benefit students by encouraging expert-like problem-solving behavior. Because this sample consisted of only 68 secondary-level career and technical students, this study should be replicated to determine if the effects of regulatory self-questioning are consistent across subject matter and populations.

There is controversy regarding the effectiveness of teaching students general thinking strategies to improve problem solving. One camp argues that using general problem-solving strategies is less powerful because of a lack of domain specificity (Glaser, 1984). Another camp argues that teaching general thinking strategies allows students to monitor and improve their cognitive performance (Schraw, 1998). This study tends to support the latter argument. It appears that benefits of metacognitive instructional strategies are evident only when secondary-level career and technical students are provided domain-specific modeling on how to use the strategy and participate in practice sessions that intentionally modify their thought path and structure.

This study raises several questions about the use of metacognitive instructional strategies for improving secondary-level career and technical students' problem-solving performance. Questions for further research include:

1. Are effects of regulatory self-questioning consistent across subject matter and populations?

2. What impact does level of student content knowledge have on effectiveness of metacognitive instructional strategies?

3. What impact does level of listener instruction and practice have on effectiveness of TAPPS?

4. What types of questions prompt students to monitor and regulate their thoughts?

5. What impact does TAPPS have on secondary-level career and technical education students outside this study?

6. What impact does incorporation of TAPPS into daily classroom activities have on students' ability to invoke metacognitive thoughts during problem solving?

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    Instructional Science, 26, 113-125.

APPENDIX A. INSTITUTIONAL REVIEW BOARD STUDY APPROVALS

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Institutional Review Board
Office of Research Assurances
Vice President for Research
1138 Pearson Hall
Ames, Iowa 50011-2207
515 294-4566
FAX 515 294-4267

DATE: 10 July 2008

TO: Michael Pate
217 Curtiss Hall

CC: Dr. Greg Miller
201 Curtiss Hall

FROM: Jan Canny, IRB Administrator
Office of Research Assurances

TITLE: **Effects of Cognitive Learning Strategies**

IRB ID: 08-187

Approval Date: 9 July 2008
Date for Continuing Review: 8 July 2009

The Institutional Review Board of Iowa State University has reviewed and approved this project. Please refer to the IRB ID number shown above in all correspondence regarding this study.

Your study has been approved according to the dates shown above. To ensure compliance with federal regulations (45 CFR 46 & 21 CFR 56), please be sure to:

- **Use the documents with the IRB approval stamp** in your research

- **Obtain IRB approval prior to implementing <u>any</u> changes** to the study by completing the "Continuing Review and/or Modification" form.

- **Immediately inform the IRB of** (1) **all serious and/or unexpected adverse experiences** involving risks to subjects or others; and (2) **any other unanticipated problems involving risks** to subjects or others.

- **Stop all research activity if IRB approval lapses**, unless continuation is necessary to prevent harm to research participants. Research activity can resume once IRB approval is reestablished.

- **Complete a new continuing review form** at least three to four weeks prior to the **date for continuing review** as noted above to provide sufficient time for the IRB to review and approve continuation of the study. We will send a courtesy reminder as this date approaches.

Research investigators are expected to comply with the principles of the Belmont Report, and state and federal regulations regarding the involvement of humans in research. These documents are located on the Office of Research Assurances website [www.compliance.iastate.edu] or available by calling (515) 294-4566.

Upon completion of the project, please submit a Project Closure Form to the Office of Research Assurances, 1138 Pearson Hall, to officially close the project.

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

DATE: 25 June 2009

TO: Michael Pate
217 Curtiss Hall

CC: Dr. Greg Miller
206 Curtiss Hall

FROM: Jan Canny, IRB Administrator
Office of Research Assurances

IRB ID: 08-187

Approval Date: 25 June 2009   **Date for Continuing Review: 8 July 2010**

The Co-Chair of the Institutional Review Board of Iowa State University has conducted the annual continuing review of the protocol entitled: "Effects of Cognitive Learning Strategies." Your study has been approved for a period of one year. The continuing review date for this study is no later than **8 July 2010**.

Based on the information you provided in Section II of the documents submitted for continuing review, we have coded this study in our database as being permanently closed to the enrollment of new subjects, where all subjects have completed all research related activities and the study remains open only for data analysis. To open enrollment or initiate research-related interaction with subjects you must submit a modification and receive IRB approval prior to contacting subjects.

Even though enrollment of subjects has ended, federal regulations require continuing review of ongoing projects. Please submit the form with sufficient time (i.e. **three to four weeks**) for the IRB to review and approve continuation of the study, prior to the continuing review date.

Failure to complete and submit the continuing review form will result in expiration of IRB approval on the continuing review date and the file will be administratively closed. As a courtesy to you, we will send a reminder of the approaching review prior to this date.

Any **changes in the protocol or consent form** should not be implemented without prior IRB review and approval, using the "Continuing Review and/or Modification" form.   These documents are located on the Office of Research Assurances website or available by calling (515) 294-4566, www.compliance.iastate.edu.

You must promptly report any of the following to the IRB: (1) **all serious and/or unexpected adverse experiences** involving risks to subjects or others; and (2) **any other unanticipated problems involving risks** to subjects or others.

Upon completion of the project, please submit a Project Closure Form to the Office of Research Assurances, 1138 Pearson Hall, to officially close the project.

ORA 06/07

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Institutional Review Board
Office of Research Assurances
Vice President for Research
1138 Pearson Hall
Ames, Iowa 50011-2207
515 294-4566
FAX 515 294-4267

DATE:	February 27, 2009
TO:	Michael Pate 217 Curtiss Hall
CC:	Dr. Greg Miller 201 Curtiss Hall
FROM:	Jan Canny, IRB Administrator Office of Research Assurances
TITLE:	**Effects of metacognitive instruction on secondary students problem solving performance**
IRB ID:	**09-037** **Study Review Date:** 23 February 2009

The Institutional Review Board (IRB) Chair has reviewed this project and has declared the study exempt from the requirements of the human subject protections regulations as described in 45 CFR 46.101(b). The IRB determination of exemption means that:

- **You do not need to submit an application for annual continuing review.**

- **You must carry out the research as proposed in the IRB application,** including obtaining and documenting (signed) informed consent if you have stated in your application that you will do so or if required by the IRB.

- **Any modification of this research should be submitted to the IRB on a Continuing Review and/or Modification form, prior to making <u>any</u> changes,** to determine if the project still meets the Federal criteria for exemption. If it is determined that exemption is no longer warranted, then an IRB proposal will need to be submitted and approved before proceeding with data collection.

Please be sure to **use the documents with the IRB approval stamp** in your research.

Please note that you must submit all research involving human participants for review by the IRB. **Only the IRB may make the determination of exemption**, even if you conduct a study in the future that is exactly like this study.

APPENDIX B. TROUBLESHOOTING INSTRUCTION

ISU IRB # 1	08-187
Approved Date:	9 July 2008
Expiration Date:	8 July 2009

Small Engine Technology
Troubleshooting a small gasoline engine
Adapted from, Webster (2001).

Internal combustion engines need 3 things to run:
    Air/fuel mix, compression, Spark
If the engine will not start:
1.   Check compression
      Crank engine over, note resistance which indicates compression. If there is compression go on to "Check ignition." If there is no compression, check for:
      - Loose spark plug
      - Loose cylinder head bolts
      - Blown head gasket
      - Burned valves, seats
      - Insufficient tappet clearance
      - Warped Cylinder head
      - Warped valve stems
      - Worn cylinder bore and/or rings
      - Broken connecting rod
      - Improperly timed valves
      - Missing valve spring retainer
2.   Check ignition
      Attach spark plug tester, crank. If spark occurs, go on to "Check carburetion."
If spark does not occur, check for:
      - incorrect armature gap
      - sheared flywheel key
      - incorrect breaker point gap (if so equipped)
      - dirty or burned breaker points (if so equipped)
      - breaker plunger worn or stuck (if so equipped)
      - shorted ground wire (if so equipped)
      - shorted stop switch (if so equipped)
      - condenser failure (if so equipped)
      - worn cam bearings and/or cam gear (if has breaker points)
      - improperly operating interlock system
      - incorrect spark plug gap
3.   Check carburetion
      - Visual inspection
        remove breather, crank engine, look for fuel at choke plate.
      - Check condition of spark plug, if wet:
        - overchoking
        - excessively rich mixture

- water in fuel
-float needle valve stuck open
-      if spark plug is dry:
     - leaking carburetor mounting gaskets
     -gummy or dirty carburetor
     -float needle valve stuck closed
     - Inoperative fuel pump (if so equipped)
-      Simple test
     remove spark plug, pour very small quantity of gas in cylinder, crank
         engine.
-      if it attempts to run, see section "if spark plug is dry"
     if it does not attempt to run, see section "check ignition"

APPENDIX C. TAPPS INSTRUCTIONS FOR LISTENERS

1.) Continually Check Accuracy
        A) Every step that a problem solver takes should be checked
        B) Do not let the problem solver get ahead of you
        C) You should not work the problem separately from the problem solver

2.) Demand Constant Vocalization
        A) Make sure that the problem solver vocalizes all of the major steps they take to solve the problem

Examples of Listener Probing Questions

If the problem solver is silent for more than 3 seconds...
        Ask: "What are you thinking?" or "What are you doing?"

If you are not sure what the problem solver said...
        Ask: "What do you mean?" or "What did you say?"

If the problem solver performs a task without saying what they were thinking or what they were doing...
        Ask: "Why did you do ...?" or "What was your reasoning for doing...?"

If you are unsure why a step was taken
        Ask: "Why did you do ...?"

To keep the problem solver talking after a they have completed a thought or a task
        Ask: "What are you going to do now?" or "What are you thinking now?"

If the problem solver looks puzzled or gives up...
        Ask: "Now, What did you do before...?" or "What seems to be the trouble?"

If the problem solver states that they have found the answer to the problem
        Ask: "How do you know this? Or "Are you sure?"

Once a solution has been identified by the problem solver and you as a listener are satisfied that they justified their reasoning, I will check the solution of the problem. The problem solver may continue until the solution is reached or time has expired for the class session. If a solution has not been correctly identified then you and the problem solver will restart the process and you will continue to probe for their thinking.

APPENDIX D. THINK-ALOUD PRACTICE PROBLEMS

1.)   If the second letter of the word *best* comes after the fourth letter in the alphabet, circle the letter A below. If it does not, circle the B. (Lochhead, 2000, p. 10)

A   **B**

2.)   The Great Lakes differ in both their areas and depths. Lake Michigan is exceeded in depth only by Lake Superior, but it is exceeded in area by both Lakes Superior and Huron. Lake Superior is by far the largest and deepest of the Great Lakes, but Lake Ontario, which is the smallest in area, is deeper that both Lakes Huron and Erie. Lake Erie is larger than Lake Ontario but is not only shallower than Huron; it is also shallower than Ontario. (Lochhead, 2000, p. 34)

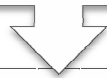Show the order of the Great Lakes from deepest to the shallowest.

1. _____
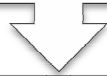
2. _____
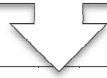
3. _____
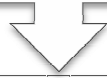
4. _____

5. _____

APPENDIX E. ORAL VERBALIZATION CODING INSTRUCTIONS

Coding should be segmented into verbal interactions consisting of a question from the listener and a response from the thinker. (See Example 1)

Coding Segment Example 1: Listener: Okay, why would you do that?

Thinker: Make sure there's nothing inside of there blocking the air

1. Responses (a complete statement) from the thinker should be coded for one of the

    following:

    - *Level One verbalizations* are characterized as statements describing working memory. included descriptions of representing the problem (e.g. "The engine has no compression" **L1**) or reporting current behavior (e.g., "I'm loosening this bolt" **L1**).

    - *Level Two verbalizations* are characterized as statements describing nonverbal sensory information (e.g., "This smells funny" **L2**).

    - *Level Three verbalizations* are characterized as statements involving:

        Planning (e.g., "First I need to check the spark, Then I will…" **L3P**)

        Monitoring (e.g., "What did I just do? Oh I checked the carburetor" **L3M**)

        Evaluation (e.g.,"I pulled on the rope but I don't think I felt any resistance" **L3E**)

        - Code *Negative Self-Assessment* is given for students' statements directed at judging themselves as performing poorly (e.g., "I can't do this" "I'm not a mechanic" **L3-NSA**).

        - Code *Positive Self-Assessment* is given for students' statements directed at judging themselves as performing well (e.g., "This is easy for me, I can do this" **L3-PSA**).

        - Code *Positive Problem-Assessment* is given for students' statements directed at judging the activity productively (e.g., "I think this is an easy problem" **L3-PPA**).

- Code *Negative Problem-Assessment* is given for students' statements directed at judging the activity negatively (e.g., "This is too hard, This is stupid" **L3-NPA**).

Code "*Not on Task*" was used for student verbalization consisting of information irrelevant to solving the problem.

> Listener: "What are you thinking about?"
> Thinker: "About getting high." **NOT**

2. Place code at the statement towards the right margin

3. At the end tally all codes for each category

APPENDIX F. STUDENT TROUBLESHOOTING RECORD SHEET

Name: _____   Group code: _____
Year in School: _____
Engine Number: _____   Beginning Time: _____ Time Fault Corrected: _____

Describe Fault and Correction:
_____

Instructions:

1.   You are assigned a small gas engine with a specific fault
        -        You are to **troubleshoot this engine**, using the troubleshooting procedures
                 discussed in class, **identify the system at fault**, **identify the malfunctioning
                 engine part** and **describe the procedure to correct the fault**.
        -        You have ONE CLASS PERIOD TO COMPLETE THIS TASK
2.   When you have successfully finished, **record the time** that you accomplished this in
        the blank above.
3.   No internal diagnoses are needed for the fault in your engine. You **will not need to
        open the crankcase or remove the cylinder head**. All diagnoses can be completed
        without "tearing into" the engine.
4.   You will absolutely **do your own work**. Do not talk to or listen to anyone else during
        this exercise. Do not look at the progress of anyone else. **Do not assume that any
        other engine is faulted the same as yours**; this could result in wasted time for your
        efforts.
5.   Do not use your notes or any reference for this exercise.
6.   An audio recorder will be assigned to you as you work. Please be sure that it is
        recording as you work. Otherwise, ignore it.
7.   When you have finished, either successfully or when the instructor tells you to stop:
        -        Please **DO NOT discuss your experience** with any other member of the class
                 until all everyone has completed the exercise.
        -        The instructor will tell you when it's all right to discuss it.
        -        If any other student asks you about what you did in class, just respond "You
                 have to do a troubleshooting exercise."
        -        There are a limited number of faults which can be set up for this exercise, so
                 the one you experience may (or may not) be similar to one that someone else
                 may draw.
8.   Upon completion of this activity, **please reset the engine to exactly the same
        condition** that it was in when you started, including the same fault. If you made any
        alterations to the engine other than the fault, be sure to correct them too.

APPENDIX G. LESSON PLAN AND TEST FOR CALCULATING ELECTRICITY

Course: (Dependent on Curriculum)

Unit: Electricity

Lesson: Calculating Unknown Electrical Circuit Values

Learning Goal: Understand the fundamental concepts, principles and interconnections of the life, physical and earth/space sciences.

Instructional Time: 40 minutes

Student Learning Objectives: Instruction in this lesson should result in students achieving the following objectives (Criteria may be set by teacher):

1. Define voltage, amperage, and resistance.

2. Solve for an unknown property of a simple circuit problem when given two known properties of that circuit via manipulation of Ohm's law.

List of Equipment, Tools, Supplies, and Facilities
Writing surface
Overhead projector
Transparencies from attached masters
Copies of student worksheets
Copies of student tests
Calculators

Interest Approach. Use an interest approach that will prepare the students for the lesson.

Ask students if they or one of their parents have ever been using several appliances in the kitchen and had a circuit breaker trip or a fuse blow.

Call on students if they don't answer right away.

Perform demonstration with 6V battery, 0.5A fuse, 15 6V light bulbs, and 15 6V lamp bases.
Connect battery to fuse using alligator clips. (See diagram)
Then wire lamp bases in parallel using the alligator clips. (See diagram)
Add blubs until fuse blows.
Ask students why this happened.

Call on students if they don't answer right away.

If overload is mentioned ask what that means.

If they say current or amps are too great ask what is current/amps.
After students answers are given transition to a discussion of electrical circuit components.
Ask what the components of an electrical circuit are.

Wrap up with a discussion of the learning objectives. The primary objective is learn how circuits function so that we can make sure we don't have a breaker trip or fuse blow. This is also to help keep ourselves safe when working with electricity. Explain to students they need to take notes.

Summary of Content and Teaching Strategies

(Write Objective 1 on the white board): <u>Define voltage, amperage, and resistance.</u>

Anticipated Problem:
Ask students to define voltage, amperage, and resistance.

Write answers on board and then transition to correct definitions. Explain that we want to use correct industry-accepted definitions so we can communicate with others and they understand what we are talking about.

Provide examples showing there is a direct relationship between voltage, amperage, and resistance.

Using TM: A4–3A and the notes below, discuss the various terms associated with measuring electricity. It may be helpful to students to compare electricity to a water system, where voltage would be like the pressure causing the water to flow through the pipes. Amperage would be comparable to the number of gallons flowing through a particular point at a given time. Resistance would be comparable to the resistance in the pipe that would interfere with the flow of water in that pipe.

A. *(Write on the board or show TM: A4–3A on overhead)* <u>Voltage is the **electromotive force** (**emf**) that causes electrons to flow through a conductor. It can be thought of as the pressure that causes the electrons to flow.</u>

(Write on the board or show TM: A4–3A on overhead)<u>The unit of measurement for voltage is the **volt**. One volt is defined as the amount of electrical pressure required for one ampere of current to flow in a circuit having one ohm of total resistance.</u>

B. *(**Write on the board or show TM: A4–3A on overhead**) Electrical current is the flow of electrons through a circuit. The rate of electrical current flow is measured in **amperes** or **amps**. One ampere of electrical current flows in a circuit when 6.28×10^{18} electrons flow past a certain point each second.*

C. (***Write on the board or show TM: A4–3A on overhead*) Resistance** is the characteristic of any material that opposes the flow of electricity. Resistance is measured in units called ***ohms***.

(Verbally explain to students)
All materials, even conductors, have some resistance to the flow of electrons. Conductors, such as copper and aluminum, have very low resistance, while insulators, such as rubber and porcelain, have very high resistance. Resistance of a specific conductor will vary based on its length, cross-sectional area, and temperature. The longer the conductor, the more resistance in that conductor. The smaller the cross-sectional area of a conductor, the more resistance in that conductor. As the temperature of a conductor increases, so does the resistance in that conductor.
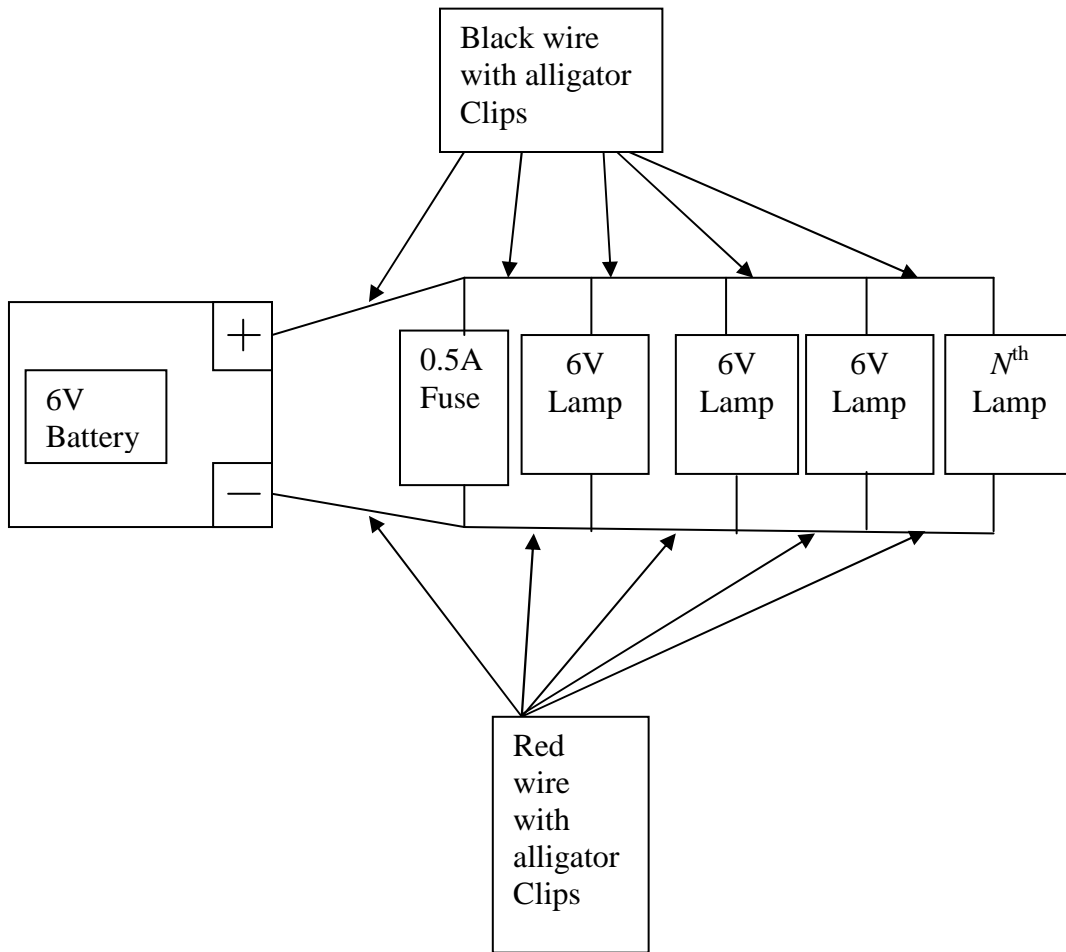
ELECTRICAL TERMS

1. Electromotive force—electrical pressure that causes electrons to flow, often called voltage, Units = V

2. Amperes—the rate of electrical current flow, Units = A

3. Ohms—units used to measure resistance within a conductor, Units =Ω

Interest Approach Diagram

(Write Objective 2 on the white board): Solve circuit problems using Ohm's law.

Anticipated Problem:
Ask students, how do you figure out the relationship between voltage, current, and resistances in a circuit?

If students answer use a meter, explain that they can be used only when the circuit's already installed. It would be a lot of work to go back and pull wire that wasn't the right size or reinstall a bigger circuit breaker, or reduce the number of receptacles in a circuit.

It would be easier to plan ahead. Electricians use Ohm's law or use references to Ohm's law to plan their circuits so that they are safe and don't trip the breaker.

Teach students the appropriate symbols used to represent volts, amps, and resistance. Write the equation of Ohm's law on the board and discuss the relationship of each part of the equation. Use the examples given in the notes to help students work with the various equations.

II. *(Write on the board or overhead)*
Ohm's law is a formula defining the relationship between voltage, current, and resistance. Ohm's law will allow you to determine an unknown value if two of the values are known or can be measured. Ohm's law is written in a formula like you use in algebra class.

In order to use Ohm's law we need to use symbols that will be used in the formula.

(Write on the board or overhead)
Let **V** represent voltage measured in volts, (V is short for Volts).
Let **A** represent current measured in amperes.
Let **Ω** represent resistance measured in ohms.
The relationship is given between **V, A, and Ω** in the formula: $V = A \times \Omega.$

(Work this example on the white board or projector)
Assume that 10 A of current flows in circuit having a total resistance of 11 ohms.
What is the source voltage?
Using the formula: $V = A \times \Omega$,
$V = 10$ amps $\times 11$ ohms.
Thus, $V = 110$ volts.

(Work this example on the white board or projector)
Assume that you know amps and volts, you can calculate resistance by rearranging the formula to be $\Omega = V \div A$.

Assume that there are 6 amps of current flowing through a 120 volt circuit.
What is the resistance?
Using the formula,
$\Omega = 120$ volts $\div 6$ amps $= 20$ ohms.

Review/Summary: *Summaries the various terms associated with measuring electricity. Reiterate to students that electricity can be compared to a water system, where voltage would be like the pressure causing the water to flow through the pipes. Amperage would be comparable to the number of gallons flowing through a particular point at a given time. And resistance would be comparable to the resistance in the pipe that would interfere with the flow of water in that pipe.*

Ask students, how do you figure out the relationship between voltage, current, and resistances in a circuit? Re-explain Ohm's law is a formula defining the relationship between voltage, current, and resistance. Ohm's law will allow you to determine an unknown value if two of the values are known or can be measured. Ohm's law is written in a formula like you use in algebra class $V = A \times \Omega$. Ask what V, A, and Ω represent and their appropriate unit representation.

40 minute Practice session: Follow the directions below for the practice session.

1. Half of the students will be randomly assigned to practice working Ohm's law using the attached practice problem worksheets: Electrical Problems Using Ohm's law.

2. You will demonstrate how to solve the *example problem* using Ohm's law to half of the students.

    a. The other half of the students will work with the researcher. It will be randomly determined which half of the students will go to another classroom to work on their practice problems.

3. All students will work two practice problems.
    a. They may use the calculators provided. Students will be given problems face down. They are not to turn it over until everyone has the worksheet and you instruct them to begin. Once you have handed out the problems to each student, tell the students they may begin solving the problems using Ohm's law independently. Remind them to work by themselves.

4. During the practice sessions you are to assist students via individualized coaching while they are working on their two practice problems. An answer key is provided for the practice problems.

    a. You are to check students' answers for correctness. If students' answers are correct please confirm this with the student by telling them that it is correct. If students' answers are incorrect explain to the individual student that the answer is incorrect. Only explain that the answer is either given in the incorrect units, their arithmetic was incorrect, or that they solved for the wrong component of the circuit.

    b. Have students redo the problem. When the student is finished reworking the problem confirm if the new answer is correct.

5. Allow the students to work on the problems until the end of the period.
    a. If a student completes the problem prior the end of the period they are to raise their hand quietly and you will collect their paper. They should not disturb any other students.

Practice Session Instructions for Researcher
Regulatory Questions Model Practice Problem

1.) Determine how many amps of current are flowing through a 120 volt circuit that is using 16 ohms of resistance.

Regulatory Questions to ask:

Planning

- What is the problem?
    - I don't know the current.

- What am I trying to do here?
    - I am trying to figure out the number of amps flowing through the circuit.

- What do I know about the problem so far?
    - I have a circuit with two know properties and one unknown. I know Ohm's law is $V = A \times \Omega$.

- What information is given to me?
    - I know Voltage is 120 and Resistance is 16 ohms

- How can this help me?
    - I can plug the known voltage and resistance into Ohm's law
    - $120V = A \times 16$ ohms.

- What is my strategy?
    - I need to get "I" by itself so I can solve for amperage. I do this by dividing both sides by 16Ω

- Is there another way to do this?
    - It could be measured directly, but we are focusing upon the mathematical relationship.

Monitoring

- Am I using my strategy?
    - Yes, I got 7.5 amps

- Am I on the right track?
    - My math looks right. I will re-input it back into the calculator.

- Do I need a different strategy?
    No, after re-entering it into the calculator I'm still getting 7.5amps.

- Do I need a new strategy?
    I could check my math by re-arranging the formula and using the value I have calculated. $\Omega = 120V \div 7.5A = 16\Omega$. So now I know that I don't need a new strategy. My answer works.

Evaluating

- What worked?
    My math worked and when I checked my plan my answer worked.

- What didn't work?
    Everything checked out right but I could have typed in a wrong number or symbol.

- What would I do differently next time?
    If I had to solve for either ohms or voltage I might have to rearrange the formula. I could double check my math by plugging in my answer to make sure my known values match.

18 minute Evaluation: Follow the directions below to administer the test.

1. Once the practice session has ended, you will monitor the students assigned to you for the test.

   a. They are to finish the test prior to going to their next class. You are to give out the test provided to your students. Do not help or assist during the test. Only monitor students to ensure they do not cheat. You will give out each problem separately.

2. Hand out problem one to each student.

   a. They may use the calculators provided. Students will be given each problem face down. They are not to turn it over until everyone has the worksheet and you instruct them to begin.

   b. Once all the students have received the problem, tell the students they may begin working the problem using Ohm's law independently. Remind them to work by themselves.

   c. You are to give the students 3 minutes to work the problem. If a student completes the problem prior the time limit they are to raise their hand quietly and you will collect their paper. They should not disturb any other students. You are to record the time in seconds on their paper when a student completes the problem.

   d. After the 3 minute time limit or everyone has completed the problem, collect students' papers. You are to record the time on their paper when a student completes the problem.

3. Next hand out the second problem worksheet faced down.

   a. Remind them they are not to turn it over until everyone has the worksheet and you instruct them to begin.

   b. Once all the students have received the problem, tell the students they may begin working the problem using Ohm's law independently. Remind them to work by themselves.

   c. You are to give the students 3 minutes to work the problem. If a student completes the problem prior the time limit they are to raise their hand quietly

and you will collect their paper. They should not disturb any other students. You are to record the time in seconds on their paper when a student completes the problem.

d. Collect all students' papers after the 3 minute time limit. You are to record the time on their paper when a student completes the problem.

4. Next hand out the third problem worksheet faced down.

a. Remind them they are not to turn it over until everyone has the worksheet and you instruct them to begin.

b. Once you have handed out problem three to each student, tell the students they may begin working the problem using Ohm's law independently. Remind them to work by themselves.

c. You are to give the students 3 minutes to work the problem. If a student completes the problem prior the time limit they are to raise their hand quietly and you will collect their paper. They should not disturb any other students. You are to record the time in seconds on their paper when a student completes the problem.

d. Collect all students' papers after the 3 minute time limit. You are to record the time on their paper when a student completes the problem.

5. Next hand out the fourth problem worksheet faced down.

a. Remind them they are not to turn it over until everyone has the worksheet and you instruct them to begin.

b. Once you have handed out problem four to each student, tell the students they may begin working the problem using Ohm's law independently. Remind them to work by themselves.

c. You are to give the students 3 minutes to work the problem. If a student completes the problem prior the time limit they are to raise their hand quietly and you will collect their paper. They should not disturb any other students. You are to record the time in seconds on their paper when a student completes the problem.

   d. Collect all students' papers after the 3 minute time limit. You are to record the time on their paper when a student completes the problem.

6. Next hand out the fifth problem worksheet faced down.

   a. Remind them they are not to turn it over until everyone has the worksheet and you instruct them to begin.

   b. Once you have handed out problem five to each student, tell the students they may begin working the problem using Ohm's law independently. Remind them to work by themselves.

   c. You are to give the students 3 minutes to work the problem. If a student completes the problem prior the time limit they are to raise their hand quietly and you will collect their paper. They should not disturb any other students. You are to record the time in seconds on their paper when a student completes the problem.

   d. Collect all students' papers after the 3 minute time limit. You are to record the time on their paper when a student completes the problem.

7. Next hand out the sixth problem worksheet faced down.

   a. Remind them they are not to turn it over until everyone has the worksheet and you instruct them to begin.

   b. Once you have handed out problem six to each student, tell the students they may begin working the problem using Ohm's law independently. Remind them to work by themselves.

   c. You are to give the students 3 minutes to work the problem. If a student completes the problem prior the time limit they are to raise their hand quietly and you will collect their paper. They should not disturb any other students. You are to record the time in seconds on their paper when a student completes the problem.

   d. Collect all students' papers after the 3 minute time limit. You are to record the time on their paper when a student completes the problem.

Name: _____

Date: _____

Practice Problem Worksheet
Electrical Problems Using Ohm's law

Purpose: Students will learn the relationships between volts, amps, and ohms by using Ohm's law to calculate various electricity problems.

<u>Example Problem:</u>
Determine how many amps of current are flowing through a 120 volt circuit that is using 16 ohms of resistance. (Show your work!)

Name: _____

Date: _____

Practice Problem Worksheet
Electrical Problems Using Ohm's law

Purpose: Students will learn the relationships between volts, amps, and ohms by using Ohm's law to calculate various electricity problems.

1. How many volts are required in a circuit that has 12 ohms of resistance and 40 amps of current flow? (Show your work!)

2. How many ohms of resistance are in a toaster on a 120 volt circuit that has 6.7 amps of current flow? (Show your work!)

Name: _____

Date: _____

Calculating Electricity Test

Lesson: Calculating Electricity

Problems to Solve
Instructions: Solve for each of the following questions. Show your work. To get full credit for your answer you must show the correct isolation of the unknown property using Ohm's law, your answer must be mathematically correct, and you must have the correct units of measure.

1. Given a 120 volt circuit with 12 ohms of resistance, how many amps of current are flowing through the circuit?

2. How many volts would be in a circuit that has an electrical device with 12 ohms of resistance and draws 13 amps of current?

3. Given a 240 volt circuit with 6 ohms of resistance, how many amps of current are flowing through the circuit?

4. How many ohms of resistance are in a 220 volt circuit that draws 30 amps of current?

5. How many ohms of resistance are in a 115 volt circuit that draws 14 amps of current?

6. How many volts would be in a circuit that has an electrical device with 4 ohms of resistance and draws 20 amps of current?

Electricity Test Key

1.) $120V= A \times 12\Omega$
$120V/12\Omega =A$
$A= 10$ amps

2.) $V= 13A \times 12\Omega$
$V= 156$ volts

3.) $240V= A \times 6\Omega$
$240V/6\Omega= A$
$A= 40$ amps

4.) $220V= 30A \times \Omega$
$220V/30A= \Omega$
$\Omega= 7.3$ ohms

5.) $115V= 14A \times \Omega$
$115V/14A= \Omega$
$\Omega= 8.2$ ohms

6.) $V= 20A \times 4\Omega$
$V= 80$ volts

Practice Problems Key

1.) $V= 40A \times 12\Omega$
$V= 480$ volts

2.) $120V= 6.7A \times \Omega$
$120V/6.7A= \Omega$
$\Omega= 17.9$ ohms

Example Problem Key

1.) $120V= A \times 16\Omega$
$120V/16\Omega= A$
$A= 7.5$ amps

APPENDIX H. REGULATORY SELF-QUESTIONING CARD

Directions: Use these questions to keep yourself aware of what you are doing during problem solving so that you can monitor your path toward a solution.

Planning

What is the problem?
What am I trying to do here?
What do I know about the problem so far?
What information is given to me?
How can this help me?
What is my plan?
Is there another way to do this?
What would happen if …?
What should I do next?

Monitoring

Am I using my strategy?
Do I need a different strategy?
Has my goal changed?
What is my goal now?
Am I on the right track?
Am I getting closer to my goal?

Evaluating

What worked?
What didn't work?
What would I do differently next time?