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Effects of Regulatory Self–Questioning on Secondary–Level Students' Problem–Solving Performance

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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 asked to answer a list of regulatory questions as they solved their problems. The difference in test scores between the experimental and control groups was statistically significant ($t(62) = 1.96$; $p = .027$). On average, students who participated in the self–questioning group outperformed students in the control group by 10 percentage points. Cohen's d indicated a moderate effect size (0.5). 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 use of regulatory self–questioning may positively benefit teachers who teach principles of Ohm's Law. 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 secondary–level students. Further research should be conducted to investigate the effects of regulatory self–questioning when students are faced with increasingly complex problems.

Keywords: metacognition, problem solving, experimental design, agricultural mechanics, applied mathematics

Introduction/Conceptual Framework

Agricultural mechanics competencies have been shown to be linked with mathematical problem solving skills acquisition (Johnson, 1993, Parr, Edwards, & Lesing, 2006). However it has been shown that students engaged in learning principles of electricity often have difficulty understanding the abstract nature of the mathematical relationships involved with Ohm's Law, such as the relationships between voltage, current, and resistance in a circuit (Cheng & Shipstone, 2002). Students tend to implement localized reasoning when challenged with the task of analyzing a circuit. 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., 1983, p. 407). Students were also inconsistent in their reasoning when they analyzed circuits.

Research (Owen & Sweller, 1985; Sweller, Mawer, & Ward, 1983) suggests differences in ability to solve mathematical problems between novices and experts in physics lies in their development of solution schemas. Experts in physics tend to begin working forward by generating equations through utilization of the given information presented in the problem (Larkin, McDermott, & Simon, 1980a, 1980b; Simon & Simon, 1978). In contrast, novices tend to begin with a means–ends problem–solving approach which has shown to be ineffective by causing a reduction in the information obtained about the problem structure (Sweller, Mawer, & Ward). Davenport, Yaron, Koedinger, and Klaher (2008) found that undergraduate students failed to correctly choose which values to use in a mass action formula and did not display planning when attempting to solve the chemical equilibrium problem.

McDermott and Shaffer (1992) called for instruction that will promote students' active mental participation in the learning process. Recent efforts have been made to develop physics curriculum that assists in moving novices towards expert–like problem solving behavior (Beatty, Gerace, Leonard, & Dufresne, 2006; Shaffer & McDermott, 1992). Some researchers have suggested that a regulatory checklist is an instructional strategy that could improve students' problem solving by helping students work forward from the givens of a problem to develop an appropriate schema (King, 1991b; Schraw, 1998). Agricultural education curriculum continues to integrate contextualized learning of academic principles related to literacy, life sciences, physical sciences, and mathematics with technical skill acquisition. It is critical to determine what instructional approaches can be most effectively applied to career and technical education settings to assist students with learning contextualized academic competences (Connors & Elliot, 1995; Park & Osborne, 2007; Parr, Edwards, & Lesing, 2009; Thompson & Warnick, 2007).

Theoretical Framework

The theoretical framework for this study is built on 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, 1979, p. 908). Metacognition involves two components: knowledge about cognition and 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 by using Ohm's Law. Transforming the initial situation into the desired goal requires mental and behavioral activities (Chi & Glaser, 1985). The amount and level of mental operations that students use can vary depending on how difficult it is to formulate a solution (Andre, 1986).

The self–regulation model (see Figure 1) developed by Butler and Winne (1995) is composed of a progression of decisions made by the learner. This process is recursive in nature, where metacognition functions as the core of regulation within each stage. As learners engage in an academic task, they use knowledge and beliefs to establish the requirements and properties needed to complete the assignment. Once learners have defined the problem space, they set goals and then apply tactics and strategies to generate cognitive and behavioral products for accomplishing the goals. Monitoring allows the learner to compare the products against achievement of the goals. This comparison creates a set of cognitive evaluations that provide feedback on how to proceed (Dunlosky & Metcalfe, 2009).

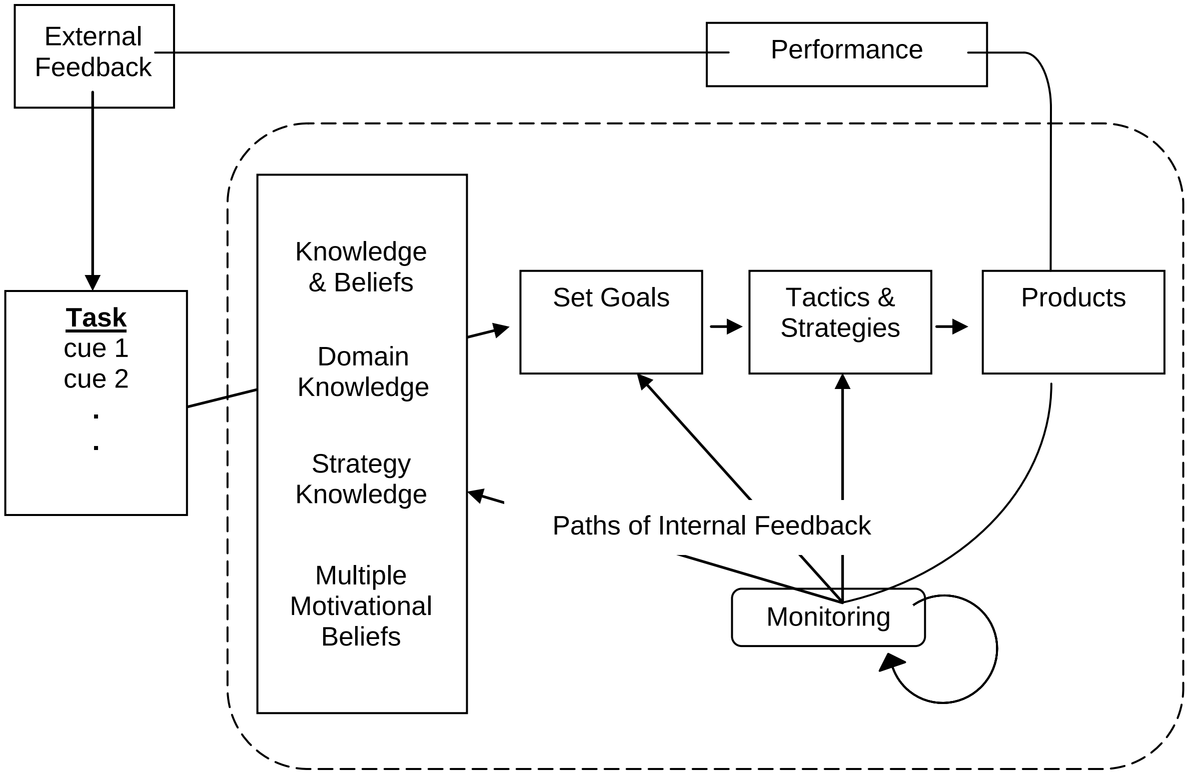

Figure 1. A model of self–regulated learning. From "Feedback and Self–Regulated Learning: A Theoretical Synthesis," by D. L. Butler and P. H. Winne, 1995, *Review of Educational Research, 65,* p. 248. Copyright 1995 by Sage Publications. Adapted with permission.

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., 1993; 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 to solve 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 examined its use in the context of secondary–level career and technical education programs teaching physics principals such as Ohm's Law.

Purpose

The purpose of this study was to determine if the incorporation of regulatory self–questioning improved test scores of secondary–level career and technical education students who were solving simple circuit problems through the use of algebraic manipulation of Ohm's Law.

Hypothesis

There will be a significant difference in test scores for solving simple circuit problems using Ohm's Law between students who used a regulatory self–questioning checklist and students who did not use a regulatory self–questioning checklist.

Methodology

Population/sample

The study involved four secondary–level schools in 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 2. Possible threats to internal validity are subject effects and diffusion. Researchers could unintentionally bias students' inclination to perform better if their behavior or explanations reveal that students are receiving a treatment. To control for subject effects, the lead 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 teachers were taught procedures to follow for their role in the project and 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 teachers' 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 2. 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" (CAERT, 2002). Instruction was given on basic electrical terminology including voltage, amperage, and resistance. The teacher 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 described in the treatments subsection. 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 min.

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 King (1998). The checklist included questions grouped into three metacognitive categories: planning, monitoring, and evaluating (Figure 3).

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. Practice worksheets completed by students were checked and collected to verify students followed protocol.

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 3. Regulatory self–questioning prompt card. From "Effects of training in strategic questioning on children's problem–solving performance," by A. King, 1991, *Journal of Educational Psychology, 83,* p. 309. Copyright 1991 by the American Psychological Association. Adapted with permission.

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 can 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 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 upon 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 courses in methods for teaching agricultural mechanics. Reviewers were asked to determine if the lesson plan was typical of an electrical circuit theory lesson, the test measured what was being taught in the lesson plan, the test items were at a median level of difficulty, 3 minutes was an appropriate time limit to solve the problems, and 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 minutes 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 received one point each 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. Students received zero points if they left the question blank.

Analysis

Data were analyzed with SPSS version 16.0. Means and standard deviations were used to describe problem–solving scores. A one–tailed independent t test was 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 before 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 *a priori* at .05. 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 (Ary, Jacobs, Sorensen, 2010). The audio recordings of the teachers and researcher were used to ensure the fidelity of the treatment and indicated the protocol was followed.

Results

The average percentage scored on Ohm's Law simple circuit test by students using a regulatory self–questioning checklist was 88.4 (SD = 19.9). Average percentage scored on Ohm's Law simple circuit test by students who did not use a regulatory self–questioning checklist was 72.8 (SD = 20.5). Table 1 shows the mean percentage test scores by group. The difference in electrical circuit theory test scores between the control group and experimental group was statistically significant (t (62) = 1.96, p = .027). 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 (0.5) indicated a moderate treatment effect (Cohen, 1992). The research hypothesis positing a significant difference in test scores for solving simple circuit problems using Ohm's Law between students who use a regulatory self–

questioning checklist and students who did not was supported by the data.

Frequency distributions of the control and experimental groups' test scores are shown in Tables 2, respectively. The control group (–1.06, *SE* = .403) and experimental group (–2.55, *SE* = .403) distributions were negatively skewed. The test score distributions clearly favor the regulatory self–questioning approach. Regulatory self–questioning students scored higher than students who did not use self–questioning. The proportion of regulatory self–questioning students with test scores between 90 and 100% was twice that of students who did not use self–questioning. 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
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		

Note. $t(62) = 1.96$, $p = .027$.

Table 2
Students' Test Score Distribution

	Control Group			Regulatory Self-Questioning Group		
Range in %	*f*	%	Cumulative %	*f*	%	Cumulative %
≤55	4	11.8	11.8	2	5.8	5.8
60 to 69	5	14.7	26.5	1	2.9	8.7
70 to 79	7	20.5	47.0	4	11.8	20.6
80 to 89	7	20.6	67.7	4	11.8	32.4
90 to 100	11	32.4	100.0	23	67.6	100.0
Total	34	100.0		34	100.0	

Conclusions/Recommendations/Implications

Students in the regulatory self–questioning group scored 10 percentage points higher than the control group. In addition to the *t* test detecting a statistically significant difference, the Cohen's *d* indicated a moderate effect for regulatory self–questioning. This suggests 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 Perkins 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. A recommendation for agricultural educators is to 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. Specifically by encouraging students to focus on task–appropriate, effective questioning and responding agricultural educators can overcome difficulties with delivering an integrated, contextualized curriculum that links academic competences and technical skill acquisition (Connors & Elliot, 1995; Park & Osborne, 2007; Parr, Edwards, & Lesing, 2009; Thompson & Warnick, 2007). 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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