

EFFECTS OF THINKING ALOUD PAIR PROBLEM SOLVING ON THE TROUBLESHOOTING PERFORMANCE OF UNDERGRADUATE AGRICULTURE STUDENTS IN A POWER TECHNOLOGY COURSE

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Abstract

A randomized, post-test only control group experimental design with a counter-balanced internal replication was used to determine the effects of thinking aloud pair problem solving (TAPPS) on the troubleshooting performance of college students in a power technology course. The experimental results were stable across two troubleshooting tasks. Students who participated in TAPPS groups were assigned a listening partner and verbalized their thought processes. They were significantly more successful ($p \leq .05$) at troubleshooting engine faults than were students in the work alone control groups. Among students who successfully completed the troubleshooting tasks across both groups, there were no significant differences in time required for completion. These findings indicate that the use of thinking aloud pair problem solving may be an important step in the development of metacognitive skills among students in technological troubleshooting.

Introduction/Theoretical Framework

All students, including those enrolled in colleges of agriculture, will encounter problems of increasing technological complexity over the course of their lives. The ability to effectively and efficiently solve these problems will become increasingly important. How efficient are undergraduate agriculture students in solving technological problems? Are problem solving strategies overtly used by students in courses? Are there teaching and learning practices that enable students to more effectively solve technical problems?

The theoretical framework for this study was built around metacognition, technical troubleshooting as a specialized problem solving process, and the thinking aloud pair problem solving approach as a mechanism to promote cognitive self-awareness and monitoring. Relevant literature from each of these areas was reviewed to inform this study.

Metacognition

Much recent work in education has focused on the development of students' metacognitive skills in order to enhance their abilities as learners and problem solvers (Zimmerman & Risemberg, 1997). According to Sternberg (1983), metacognitive skills are the executive thinking skills used by individuals to develop strategies for problem resolution. Flavell (1976) described metacognition as "the active monitoring and consequent regulation and orchestration of these [cognitive] processes in relation to . . . some concrete goal or objective" (p. 232). Berardi-Coletta, Buyer, Dominowski, and Rellinger. (1995) stated that metacognition is "an active reflective process that is explicitly and exclusively directed at one's own cognitive activity. It involves the self-monitoring, self-evaluating, and self-regulation of on-going tasks" (p. 206).

Son and Schwartz (2002), emphasized the closed-loop dynamic existing between the monitoring, evaluating, and regulating

functions involved in metacognition. Monitoring and evaluation enables an individual to regulate his or her mental processes, which, in turn, may produce new mental processes that must be subsequently monitored and evaluated.

From the foregoing, it is apparent, that self-awareness of one's underlying cognitive processes is fundamental to metacognition. According to Lochhead (1981), such self-awareness "is necessary for self-correction. Mental routines can only be 'de-bugged' and improved if we are sufficiently aware of their components to examine and change them" (p. 68). According to the National Research Council (2000), "competent . . . problem solvers monitor and regulate their own processing and change their strategies as necessary" (p. 238).

It seems somewhat intuitive that an individual would be aware of and have the ability to regulate his or her own cognitive processes. However, several researchers have found that this is not the case. Bloom and Broder (1950) conducted one of the earliest qualitative studies of problem solving among college students. In this study, students attempted to solve problems while verbalizing their thought processes. An unexpected limitation to the study occurred when Bloom and Broder (1950) found that, by and large, students were simply unaware of their own thought processes:

A further difficulty in a study of this kind is that of getting from the subject an accurate representation of the [thought] process. The subject is not always in a position to describe, or even to know, what his [sic] processes of thought are. In many cases the processes take place so quickly that the subject is unable to perceive them. In some cases they probably involve very deep-seated and practically 'unconscious' processes, such that the individual does something without knowing what he is doing or how (p. 90).

According to Lochhead (1981), "Learning to be aware of even isolated pieces in one's thinking is a difficult task (p. 68). Greenfield (1987) found that

unsuccessful problem solvers "might start the problem with a plan, then lose sight of it [the plan] as they worked toward an answer, seemingly distracted by some difficulty or irrelevancy" (p. 15). Griffiths (1976), provided insight on this phenomena based on his observations of an unsuccessful physics problem solver, stating:

More troublesome than the student's lack of knowledge is the fact that he doesn't know that he doesn't know. He has not developed the ability to monitor his knowledge and recognize the difference between scattering terms and understanding concepts. He has no awareness or self-monitoring process for his own knowledge (p. 81).

Technical Troubleshooting

According to Holyoak (1995), "A problem arises when we have a goal – a state of affairs we want to achieve – and it is not immediately apparent how the goal can be achieved" (p. 118). Given this definition of a problem, problem solving is simply the process of finding the best solution that allows movement from the present state to the goal state (Gobet & Simon, 1996).

Halpern (1984) further described the dimensions of problem solving by stating that problems have an anatomy consisting of (a) the initial state; (b) the goal state; and (c) the problem space, which contains all of the possible solution paths whereby one can move from the initial state to the goal state. According to Halpern (1984), the key to effective problem solving is the ability to recognize and select the most efficient solution path from the myriad of potential solution paths present in the solution space.

MacPherson (1998), indicated that technical troubleshooting is a special category of problem solving. Morris and Rouse (1985), defined technical troubleshooting by describing the role of the troubleshooter. According to Morris and Rouse (1985), when a system "is not functioning properly, the troubleshooter must attempt to locate the reason for the malfunction and then must repair or replace the faulty component" (p. 503).

Morris and Rouse (1985) indicated that three skill sets are essential in technical

troubleshooting: (a) the ability to make tests, (b) the ability to replace or repair faulty components, and (c) the “*ability to employ some kind of a strategy* [italics in original] in searching for the source” of the fault (p. 504). Jereb (1996) emphasized the importance of strategy in troubleshooting, when he stated that, “The question of how to come from a given starting situation to a desired end situation is usually the essence of each technical problem” (p.2). This is congruent with Halpern (1984) who indicated that the key component of the problem solving process was the ability to recognize and select the most efficient solution path from among all possible solution paths. Morris and Rouse (1985) concluded that identifying and employing an effective strategy was the most difficult skill set for troubleshooters to develop.

Morris and Rouse (1985) stated that troubleshooting strategies range from simply starting with the component nearest the troubleshooter to “generating hypotheses based on knowledge of the system and symptoms and identifying tests to confirm or reject those hypotheses” (p. 504). The authors further stated that the strategic performance of poor troubleshooters “was characterized by incomplete and inappropriate use of information, ineffective hypotheses generation and testing, and . . . less strategic flexibility” (p. 505). Conversely, proficient troubleshooters employed more efficient strategies for identifying and testing hypotheses.

Johnson (1989) reviewed the literature and confirmed that proficient technical troubleshooters use a hypothesis testing process when diagnosing and repairing system faults. Based on his review, Johnson developed the technical troubleshooting model presented in Figure 1. The model divides the technical troubleshooting process into two primary components, hypothesis generation and hypothesis testing, each of which has several sub-components. The recycling, iterative nature of the troubleshooting process is indicated by the arrows on each side of the model.

Johnson’s (1989) model incorporates and provides a higher level of specificity concerning the relationship between the three troubleshooting skill sets identified by Morris and Rouse (1985). The skill set of making tests would be required during the “acquire information” sub-component of both the hypothesis generation and hypotheses testing phases of Johnson’s model. Likewise, the repair or replace faulty components skill set would often be necessary during the “is hypotheses correct” sub-component of the hypothesis evaluation phase. Finally, and most obviously, the overall heuristic of Johnson’s model is the use of hypothesis generation and testing as a solution strategy (third skill set) in technical troubleshooting. The technical troubleshooting model is also consistent with problem anatomy as described by Halpern (1984).

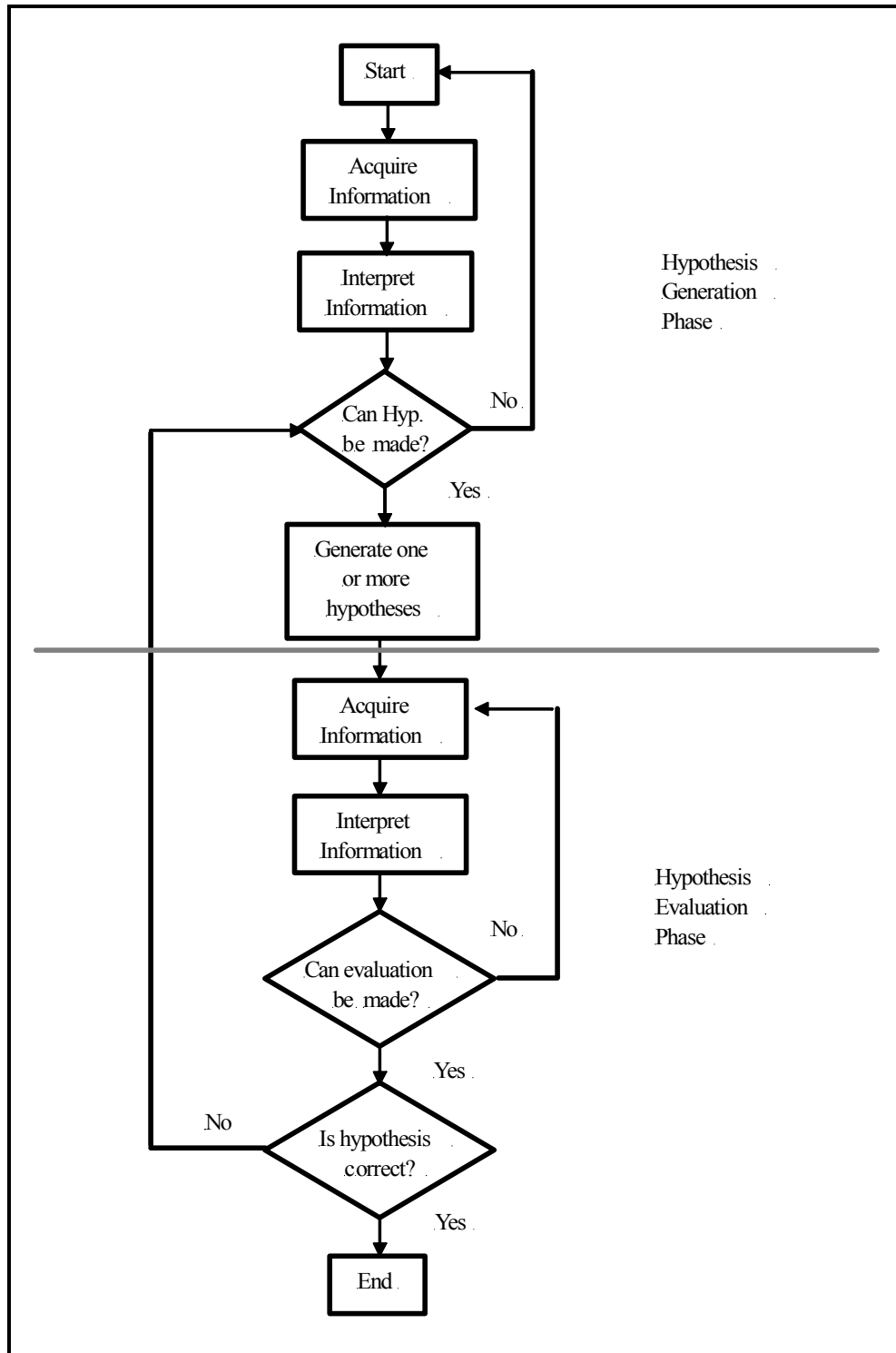


Figure 1. Technical troubleshooting model.

Note. From “A description of expert and novice performance differences on technical troubleshooting tasks” by S.D. Johnson, 1989, *Journal of Industrial Teacher Education*, 26(3), 19-37. Copyright 1989 by *Journal of Industrial Teacher Education*. Reprinted with permission.

Johnson's (1989) model also points out the potential complexity of the technical troubleshooting process and its consequent metacognitive demands. As an example, consider a malfunctioning technical system consisting of only five components, each of which can be diagnosed with a single test. In determining the cause(s) of the malfunction, the troubleshooter would be confronted with 120 ($5! = 120$) potential test sequences which could be used in identifying the faulty component(s). Obviously, more complex systems present more components, more potential component and sub-system interactions, and greater metacognitive demands (Halpern, 1984; Morris and Rouse, 1985).

Thinking Aloud Pair Problem Solving

The thinking aloud pair problem solving (TAPPS) technique is a strategy for improving problem solving performance through verbal probing and elaboration. According to Lochhead and Whimbey (1987), TAPPS requires two students, the problem solver and the listener, to work cooperatively in solving a problem, following strict role protocols. The problem solver attempts to solve the problem, while fully verbalizing his or her thoughts and thought processes. The listener's goal is to develop a detailed understanding of every step, strategy, and assumption of the problem solver. The listener makes certain that the problem solver continues talking by meeting even the shortest silence with statements such as, "Tell me what you are thinking now." The listener also queries the problem solver any time that the problem solver's thinking is unclear to the listener, 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).

Several researchers have found that TAPPS and similar thinking aloud techniques result in increased levels of student metacognition (Berardi-Coletta, et al., 1995; Flaherty, 1975; Hogan, 1999) and problem solving success (Chi, De Leeuw,

Chui, & LaVancher, 1994; Johnson & Chung, 1999). Berardi-Coletta, et al. (1995), hypothesized that this is due to the explanation demands made during the thinking aloud process which "shifts the focus of the problem solver to the solver's actions, thoughts, and reasoning and asks the solver to examine them" (p. 222).

Johnson and Chung (1999) studied the effectiveness of the TAPPS technique in an electronics troubleshooting task, using students at the University of Illinois. In this quasi-experimental study, Johnson and Chung found that TAPPS students were significantly more successful in fault detection, identification of faulty components, and evaluation of fault hypotheses than were students in the control group. Because the Johnson and Chung study used a non-equivalent control group design (Campbell & Stanley, 1966), the researchers acknowledged that several threats to both internal and external validity existed. Thus, while Johnson and Chung's (1999) findings suggest that the TAPPS technique improves technical troubleshooting performance, true experimental research and subsequent replication across a variety of settings and technical subject domains are needed.

Purpose

The purpose of this study was to determine if employing the TAPPS technique improved student effectiveness when troubleshooting small gasoline engine faults. Since the literature was somewhat inconclusive regarding the efficacy of the TAPPS technique in troubleshooting technological problems, non-directional research hypotheses were posited.

1. There will be significant differences in success rate and time to completion for troubleshooting a small gasoline engine electrical system fault between students who employ the TAPPS technique and students who do not employ the TAPPS technique.

2. There will be significant differences in success rate and time to completion for troubleshooting a small gasoline engine air/fuel delivery system fault between students who employ the TAPPS technique and students who do not employ the TAPPS technique.

Methods

This study utilized a post-test only control group design (Campbell & Stanley, 1966), with a counter-balanced internal replication. This design, which is inherently resistant to threats to internal validity, is illustrated in Figure 2.

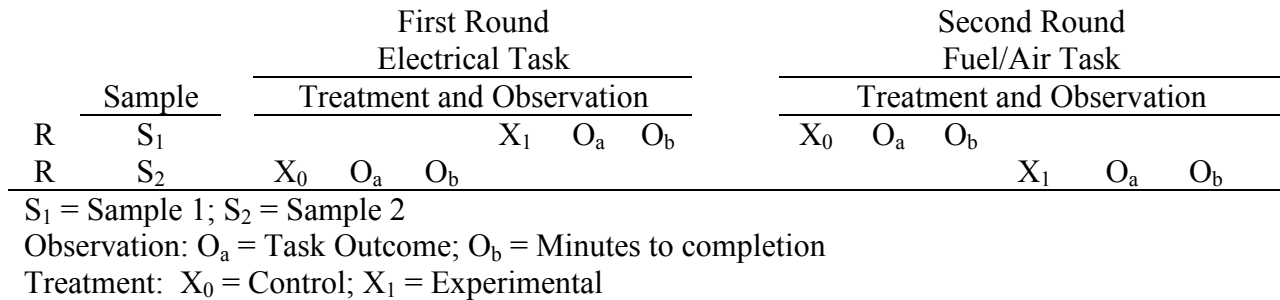


Figure 2. Illustration of post-test only control group design, with internal replication.

Thirty students in a college course on small power technology during the spring 2003 semester comprised the subjects in the study. Prior to the experiment, the students received instruction and laboratory practice on engine theory and operation, engine overhaul, and engine troubleshooting protocols. For the study, students were randomly assigned to either of two groups: experimental or control.

Identical small gasoline engines were prepared, each with the identical fault to their primary electrical system, for each subject in the study. No clues were given, even about the general engine system in which the fault existed, only that the fault was not an internal component fault. Each troubleshooter was provided with a complete set of basic engine repair tools and a 50 minute period in which to troubleshoot the engine, identify and repair the fault, and test run the engine. A task outcome (successful or unsuccessful) was recorded for each troubleshooter based on whether or not he/she was able to repair the fault and start the engine. For successful troubleshooters, the time (minutes) required for task completion was also recorded.

Students in the control group worked alone to troubleshoot their respective

engines, identify the fault, repair the fault, and test run the engine. Control group students were instructed that they would be audio recorded for any overt verbalization of their thought processes but were neither encouraged or discouraged to do so. During the exercise they were observed to insure that they worked independently on the troubleshooting exercise. Students in the experimental group participated in the thinking aloud pair problem solving treatment (TAPPS). Each subject in the experimental group was paired with a listening partner, presented with an engine, and asked to complete the troubleshooting task. Individuals in the control group completed their troubleshooting task prior to the experimental group, and then served as the listening partners for the experimental group during the next class period two to four days later. The role of the listening partner was to continually encourage the troubleshooter to verbalize their thought processes throughout the activity using such statements and questions as, "What are you doing now?" and "Tell me what you are thinking." All students were audio taped as they completed the troubleshooting tasks.

The listening partners were specifically instructed, both verbally and in written form,

that they were only allowed to ask questions or make statements to get the thinking aloud troubleshooters to verbalize their thought processes; the instructions specifically prohibited the listening partners from asking questions or making statements that might lead the troubleshooters toward a possible fault solution. Two research monitors were present during all treatments and ensured that the listening partners complied with these instructions. Additionally, the audio recordings provided no evidence that the listening partners violated their instructions.

In order to reduce the likelihood that students would observe other students during the troubleshooting task, or that successful troubleshooters would provide assistance to others, individual workstations were isolated by distance and two researchers monitored the students during the experiment. No violations of the experimental protocol were detected. Additionally, prior to each troubleshooting task, the students were told that no two engines necessarily had the same fault. This was done in order to reduce the perceived benefit of observing another student troubleshooter and to eliminate the perceived benefit of any potential discussions among the students between classes. While it is possible that students discussed their troubleshooting tasks with classmates between classes, no evidence arose to suggest that this occurred. Monitors observed no indication that students had prior knowledge of their specific fault.

For the second round of the study, the groups were reversed and treatments were administered the following week. The subjects in the control became the experimental group, and the experimental group became the control. The engines were returned to working order and a new fault in the air/fuel delivery system was created in each. The subjects in the experimental group completed the troubleshooting activity with a listening partner, and the control group completed the task without the aid of a listening partner. The same research procedures as before were used in the second round of the study.

The test for differences between groups on the nominal dependent variable, task

completion (successful or unsuccessful), was the Chi-square test of association. Independent t-tests were used to determine if there were significant differences in completion times between successful students in the experimental and the control groups.

Since the junior-level course in which the experiment was conducted requires a prerequisite agricultural technology course where basic engine principles are taught, students were given a written cognitive pre-test to determine if differences existed between the experimental and control groupings with regard to their levels of subject matter knowledge. This cognitive test was a graded evaluation as part of the course and was based on the course objectives. It had been used in previous semesters. It was therefore deemed to possess content validity.

Results

Prior to testing the null hypotheses, student pre-test scores were analyzed to determine if differences existed between the two student groups on their knowledge of basic engine principles and operating theory. No significant differences were found, $t(28) = 1.35$, $p = .19$. Therefore, the groups were assumed to be equal in their levels of engine knowledge and pre-existing differences between groups on level of subject matter knowledge were not assumed to be a confounding factor in this counter-balanced design.

Table 1 presents descriptive statistics on student performance in the electrical troubleshooting task, by group. Students using the thinking aloud paired problem solving (TAPPS) technique (experimental group) had a significantly higher success rate than did those students who did not use the TAPPS technique (control group), $\chi^2(1) = 5.56$, $p = .02$. Therefore, Part A of null hypothesis one, positing no relationship between group and task outcome, was rejected. Using the effect size descriptors proposed by Rea and Parker (1992, p. 203), the magnitude of the phi coefficient ($\phi = .50$) indicated that there was a "relatively strong" association between group and task outcome.

For those students successfully completing the electrical troubleshooting task, there was no significant difference between groups in the mean time (minutes) required, $t(19) = -.34, p = .74$. The

assumption of equal variances was met ($F(4,15) = 2.12; p = .26$). Part B of null hypothesis one, positing no relationship between group and completion time, was not rejected.

Table 1
Student Performance on the Electrical Troubleshooting Task by Group

Group	Task outcome ^a				Minutes to completion ^b			
	Successful		Unsuccessful		M	Mdn	SD	Skewness
	n	%	n	%				
Control ($n = 12$)	5	41.7	7	58.3	33.6	33.0	19.8	0.23
Experimental ($n = 18$)	16	88.9	2	11.1	30.9	30.0	13.6	-0.08

^a $\chi^2(1) = 5.56, p = .02$.

^bBased on only students with a successful task outcome; $t(19) = -.34, p = .74$.

Table 2 presents descriptive statistics on student performance in fuel/intake task, by group. Students using the thinking aloud paired problem solving (TAPPS) technique (experimental group) had a significantly higher success rate than did those students who did not use the TAPPS technique (control group), $\chi^2(1) = 4.54, p = .03$. Therefore, Part A of null hypothesis two, positing no relationship between group and task outcome, was rejected. Using the effect size descriptors proposed by Rea and Parker (1992, p. 203), the magnitude of the

phi coefficient ($\phi = .39$) indicated that there was a “moderate” association between group and task outcome.

For those students successfully completing the electrical troubleshooting task, there was no significant difference between groups in the mean time (minutes) required, $t(16) = -.45, p = .66$. The assumption of equal variances was met ($F(9,7) = 1.02, p = 1.0$). Part B of null hypothesis two, positing no relationship between group and completion time, was not rejected.

Table 2
Student Performance on the Fuel/Intake Troubleshooting Task by Group

Group	Task outcome ^a				Minutes to completion ^b			
	Successful		Unsuccessful		M	Mdn	SD	Skewness
	n	%	n	%				
Control ($n = 18$)	8	44.4	10	55.6	33.0	33.0	18.3	0.00
Experimental ($n = 12$)	10	83.3	2	16.7	29.1	29.0	18.5	0.31

^a $\chi^2(1) = 4.54, p = .03$.

^bBased on only students with a successful task outcome; $t(16) = -.45, p = .66$.

The audio recordings of the experiment were used to insure the fidelity of the treatment. Recordings of the experimental (TAPPS) group individuals yielded narrative data. The audio tapes for the control group, across each troubleshooting task, were largely blank. Although control group subjects were afforded the opportunity to think aloud during their troubleshooting exercise, none did so, as evidenced by the tape recordings. This is especially interesting in light of the fact that for the second round of the study the control group subjects had already participated as the experimental group thinking aloud subjects in the first round, and should have been accustomed to verbalizing their thoughts during the troubleshooting task.

Conclusions/Recommendations/ Implications

For both iterations of the study, significantly higher proportions of the subjects in the treatment groups (thinking aloud pair problem solving) successfully completed the troubleshooting tasks. Effect sizes ranged from moderate to relatively strong. This finding indicates that students engaged in troubleshooting small gasoline engine faults are more likely to be successful if they overtly verbalize their cognitive problem solving processes. This supports the findings of Johnson and Chung (1999) as well as assertions by researchers who indicated that the thinking aloud process assists the problem solver in avoiding skipping steps in reasoning, skipping over important information, or being unaware of getting bogged down in a component of the problem (Heiman & Slomianko, 1987).

Successful small gasoline engine troubleshooters who participated in the thinking aloud paired problem solving (TAPPS) groups were not significantly different in the time it took to complete the tasks compared to successful troubleshooters in the control groups. Thus, it can be concluded that the time required to elicit metacognitive skills through verbalization does not adversely affect time for completion. This finding of no difference in

time required for task completion, coupled with higher success rates for the TAPPS groups, indicates that the TAPPS process yields a higher efficiency rate for technical troubleshooting.

Since the control group subjects in the replication were thinking aloud participants (experimental group) in the first round of the study and were largely successful in task completion by using the thinking aloud strategy, one might assume that the subjects would transfer this strategy to their second round troubleshooting task. This does not appear to be the case. While students can successfully use the thinking aloud technique when externally prompted, they do not appear to do so when the external prompt is removed. Metacognition is the self-regulation or executive control of one's thinking skills – one overtly thinks through his/her own thought processes. The data indicate that students in this study do not possess these metacognitive skills, or if they do possess them their level of metacognitive functioning is low.

Further research should be conducted to investigate why students are unsuccessful at utilizing and transferring metacognitive skills without benefit of an external prompt. Additionally, if thinking aloud pair problem solving results in more efficient troubleshooting through elaboration of the thought process, research is needed to determine strategies to invoke this process when the external prompt is removed. This would allow students to exhibit independent metacognitive skills, and to become successful independent problem solvers. More specifically, educators may be able to overtly teach these skills to students.

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