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Effects of Think–Aloud Pair Problem Solving on Secondary–Level Students' Performance in Career and Technical Education Courses

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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 34 secondary–level career and technical education students. There was no significant difference in success rate between TAPPS students and students who worked alone (χ^2 (1) = .747, p = .39, ϕ = .148). There was no significant difference in completion time between students who successfully completed the troubleshooting task using TAPPS and those who were successful working alone (t (9) = –.74, p = .48, d = 0.45). The reserachers tentatively concluded that the use of TAPPS may not be an appropriate strategy at the secondary level if the agricultural instructors' focus is a higher success rate and a reduction in the time to complete the task. However, agricultural instructors may have other legitimate reasons for using TAPPS such as a way to facilitate collaborative learning or as a way for instructors to identify student misunderstandings that could be used to inform decisions about individualized or even group instructional interventions.

Keywords: metacognition, problem solving, experimental design, agricultural mechanics, troubleshooting

Introduction

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 secondary–level students' technical problem solving?

Theoretical Framework

The theoretical framework that guided this study was cognitive information processing learning theory (CIPLT). This theory postulates that learning and behavior develop through a person's interaction with the environment, previous experiences, and current knowledge (Andre & Phye, 1986). From a cognitive information processing perspective, learning is viewed as a series of active, constructive and goal–oriented mental processes that rely heavily on the presence of metacognition (Shuell, 1986). Individuals have the ability to adapt to novel problem situations, such as troubleshooting, through information processing (Phye, 2005). For example when secondary agricultural and industrial technology students are required to

troubleshoot engine faults, they must process information gathered from the engine as well as from previous experiences and knowledge that is relevant to the problem situation in order to develop a solution. Research shows (Schraw, 1998) that metacognitive instructional strategies, such as think–aloud pair problem solving (TAPPS), can assist students with the organization and regulation of their information processing to improve their problem solving performance. Conceptually, the current study focuses on the improvement of students' performance on a complex problem–solving activity (troubleshooting) by utilizing think–aloud pair problem solving as a strategy to invoke metacognitive thought. Relevant literature from the areas of troubleshooting, metacognition, and TAPPS was reviewed to inform this study.

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. An individual encounters a problem when an obstacle interferes with achieving a situational goal (Marzano & Kendall, 2007). Davidson, Deuser, and Sternberg (1994) described the process of solving problems as the direct behavior of individuals towards 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 may require testing a variety of possible solutions. 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 define the goal for the situation (e.g., establish a standard for the equipment to function correctly) and then test solutions (e.g., 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).

Novices often infuse systematic errors into procedures when solving problems (Brown & 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. During problem solving, it is important for students to know what knowledge to apply along with when and why to use it (Schunk, 2008). This suggests that the utilization of metacognitive thought would improve students' troubleshooting success.

Metacognition

Metacognition is the awareness of and ability 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). Schraw (1998) contended that metacognition involves two components: knowledge about cognition and regulation of cognition. The learner must have knowledge about how to perform a task and also how to plan, monitor, and evaluate their performance. The knowledge needed to perform

the task is comprised of three categories. The first is declarative knowledge or the knowing of facts, beliefs, opinions, generalizations, theories, hypothesis, and attitudes about ourselves, others, and the world. This is stored in memory as bits of information. Procedural knowledge refers to knowing how to do something involving the combination, refinement, incorporation, and accommodation of declarative knowledge so that it can be used in a course of action. Strategic or conditional knowledge refers to knowing when to use knowledge. This type of knowledge is demonstrated by understanding when and why to use forms of declarative and procedural knowledge.

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., 1994, p. 207). A model depicting a problem–solving process that incorporates metacognitive thought is presented in Figure 1.

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).

Individuals are often unaware of their own thought processes (Bloom & Broder, 1950). Lochhead (1981) stated that it is difficult 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 have 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, 1998, p. 87–88).

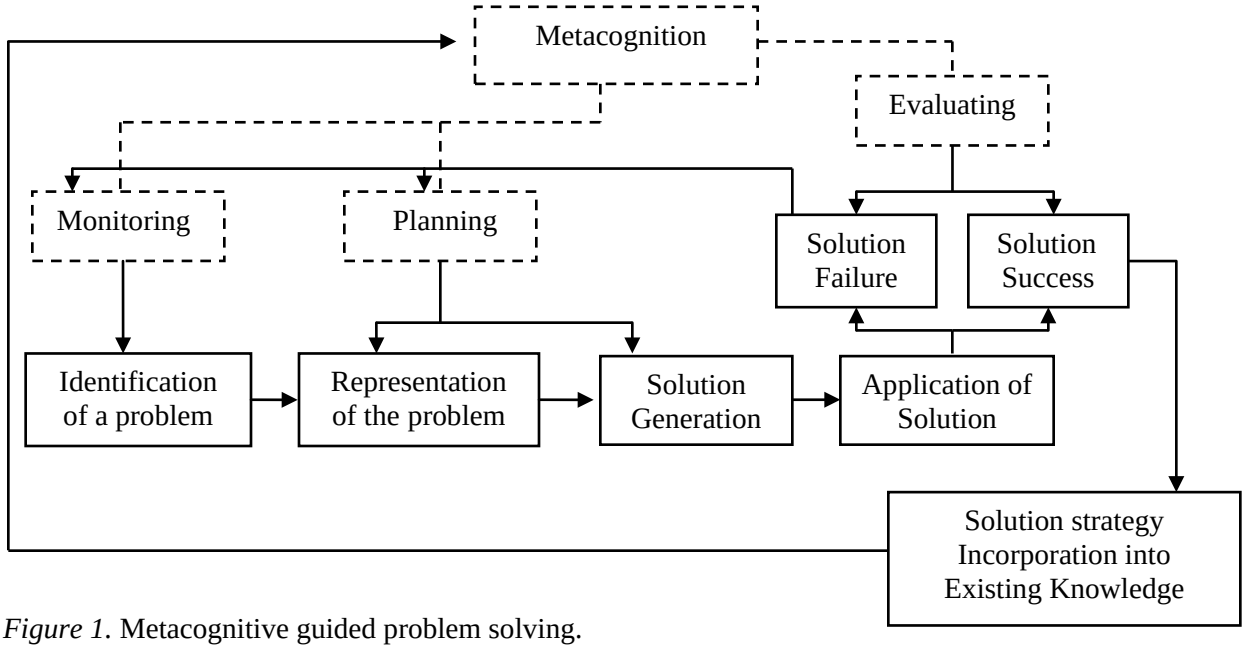

Figure 1. Metacognitive guided problem solving.

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). Results from previous studies have indicated that it might be reasonable to assume that individuals could develop metacognitive thinking through training and instruction (Borkowski, Chan, & Muthukrishna, 2000; Cardelle–Elawar, 1995; Pintrich, 2002; Schraw & Dennison, 1994). Whimbey and Lochhead (1986) offered TAPPS as an instructional technique that can improve 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, 1998). 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. Correct solution identification and implementation may increase as a result from problem solvers engaging in self–monitoring, clarifying their thinking, and considering useful solution strategies to reach their goals (Bransford, Sherwood, Vye, & Rieser, 1986; Silver, 1987). The TAPPS strategy may allow students to control or filter possible solutions to the problem during troubleshooting. Research in CTE has shown that TAPPS significantly improves postsecondary students' success at identifying and repairing faults during troubleshooting (Johnson & Chung, 1999; Pate, Wardlow, & Johnson, 2004). However, the TAPPS method has not been tested in the context of secondary–level CTE courses.

A variety of potential problems have been identified with the use of TAPPS. Ericsson and Simon (1993) noted that the act of verbalizing thoughts can interfere with the execution of the task. Requiring students to talk aloud may slow their progress due to the difficulty they may face to put their thoughts into words. Students' motivation to talk aloud or comfort level with discussing their thoughts with others may inhibit or slow their success rate (Kluwe, 1982). Students may have difficulty focusing their verbalization on the task. Veenman, Van Hout–Wolters, and Afflerbach (2006) suggested that the level of metacognitive thought in which students engaged is linked to their age or maturity. It is not apparent that the use of TAPPS will improve secondary–level CTE students troubleshooting success. Will secondary–level students who use TAPPS as a self–regulation strategy improve their troubleshooting performance?

Purpose

The purpose of this exploratory study was to determine the effect of TAPPS on 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 exploratory study involved five secondary schools from Iowa. Average school enrollment was 438 students (Iowa Department of Education, 2009a). On average, 22% of students enrolled at these schools were eligible for free and reduced–price lunch (Iowa Department of Education, 2009a). For these schools, the majority of students were White (95.7%) followed by Hispanic (1.7%), Black (1.1%), Asian (1.3%), and Native American (0.2%) (Iowa Department of Education, 2009b). The majority of students were male (51.9%). Students enrolled in selected agriculture and industrial technology education courses dealing with small engine technology were purposely selected to be participants in this study. The average class size was 15 students. Students' ages ranged from 14 to 17 years. Due to the sensitivity of using minors in the research, data were reported in aggregate form to insure the confidentially of individuals was protected. The study population consisted of a total of 34 students enrolled in the selected courses during the fall semester of 2008 and spring semester of 2009.

Research Design

This study used a randomized posttest–only control group experimental design (Campbell & Stanley, 1968; Figure 2). 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.

		Troubleshooting Small Engine Compression Fault		
R	C	Os, Ot		
R			TA	Os, Ot

Figure 2. 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.

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.

Procedure

Before the experiment, the lead 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 either 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 observe 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 solutions 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 solutions 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 time 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 (see Table 1).

Table 1
Student Performance on the Compression Troubleshooting Task by Group

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

[a] χ^2 (1) = .747, *p* = .39., ϕ = .148
[b] Data includes only students with a successful task outcome; *t* (9) = –.74, *p* = .48., *d = 0.45*

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 (χ^2 (1) = .747, *p* = .39). The effect size descriptor proposed by Rea and Parker (2005, p. 189), indicated that there was a "weak" association (ϕ=.14) between group and task outcome. 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 min. Successful students who used TAPPS had an average completion time of 16.5 min. 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). The calculated Cohen's *d* (0.45) indicated a moderate treatment effect (Cohen, 1992). Therefore, hypothesis 2 was also retained.

Limitations/Conclusions/Recommendations/ Implications

Caution should be exercised when generalizing the results of this study to other populations outside of the participants from this exploratory study. A limitation to this study was the limited number of participating students. For this study, secondary–level CTE students who used TAPPS while troubleshooting a small gas engine had a lower success rate than students who worked silently. However, the Chi–square test showed no significant difference between the groups, therefore we concluded that for students involved in this study there was no difference in troubleshooting success rates between students who used TAPPS and students who worked alone. 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%) is 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 in this study (25%) is drastically different from the proportion of successful postsecondary TAPPS students in Pate et al.'s study (89.9% and 83.3%). Veenman et al. (2006) argued that elementary levels of metacognitive thought develop during early childhood but become more sophisticated and academically oriented through instructional interventions requiring the explicit use of metacognition. 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. However, secondary–level students' knowledge of basic engine principles and operating theory was not formally assessed before this study. 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 and quality of a problem solver's domain–specific knowledge can be a limiting factor in their ability to reach a solution. Future research should investigate the relationship between secondary–level CTE students' knowledge of basic engine principles and their ability to use TAPPS successfully.

Average time to completion for the TAPPS students was four minutes longer than the average time to completion for students working alone. The *t* test comparing minutes to completion revealed no significant difference between students who successfully completed the troubleshooting task using TAPPS and those who were successful working alone. We concluded that for students involved in this study there was no difference in time to completion of the troubleshooting task between students using TAPPS and students working alone.

The reserachers tentatively conclude that the use of TAPPS may not be an appropriate strategy at the secondary level if the agricultural instructors' focus is a higher success rate and a reduction in the time to complete the task. However, agricultural instructors may have other legitimate reasons for using TAPPS such as a way to facilitate collaborative learning or as a way for instructors to identify student misunderstandings that could be used to inform decisions about individualized or even group instructional interventions.

To ensure the fidelity of the experimental design only one group of students from each school provided data that was used in the study. This strategy was necessary to enhance internal validity of the study, but resulted in smaller sample sizes. A recommendation for further research involving secondary–level students is the use of a clinical approach. A clinical setting would allow 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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