Compact Power Equipment Troubleshooting Training: Formative Assessment using Think-Aloud Pair Problem Solving

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Abstract

Think-aloud pair problem solving (TAPPS) was used to formatively assess agriculture students' problem solving during compact power equipment troubleshooting training. A total of 56 students were taught engine operational theory and a troubleshooting procedure followed by training in TAPPS. Sixty-six percent of students were successful at identifying and repairing the fault. The chi-square test of association showed no significant difference (χ^2 (1) = 0.08, p = 0.78, phi = 0.038) in success rate between students who worked alone and those who used TAPPS. A review of video recordings of TAPPS sessions revealed unsuccessful students were unfamiliar with valve clearance adjustment procedures, forgot possible faults and unable to interpret cylinder leak down test results. Unsuccessful students struggled to connect engine theory of operation to troubleshooting procedure. TAPPS served as a way for the instructor to identify student misunderstandings to inform individual instructional interventions to improve students troubleshooting skills. Suggestions for instruction included memory association exercises to help students linking engine components with possible faults.

Introduction

Over the last decade, educational psychology research has gone to great lengths in attempting to determine how educators can improve students' problem solving skills specifically in the content areas of mathematics and physics (National Research Council, 2000; Renkl and Atkinson, 2003). P-12 STEM education initiatives and the ever-increasing complexity of technology have generated a great need for educators to examine the methods used for teaching students technical problem solving (Brophy et al., 2008). Tier IV emission regulations have been met with aggressive engineering solutions that integrate complex controller networks as well as equipment, thereby creating greater challenges in technician training for diagnosing performance issues and making troubleshooting education an essential part of agricultural systems technology undergraduate programming. Research studies have shown mixed results regarding the success that think-aloud pair problem solving (TAPPS) may offer instructors at improving students troubleshooting. Pate and Miller (2011) found no significant difference between secondary students who used TAPPS and those who did not on troubleshooting success rate. Pate et al., (2004) found that using TAPPS during troubleshooting significantly improved post-secondary students' success rate at identifying and repairing an engine fault. With greater emphasis being placed on troubleshooting skills as an essential part of agricultural systems technology programming, the TAPPS strategy was selected for this study to determine if implementation would serve as a useful strategy for instructors seeking to improve students' technical problem solving skills.

The theoretical framework that guided this study was the cognitive information processing learning theory (CIPLT). This theory contends that learning and behavior develop through a person's interaction with the environment, previous experiences and current knowledge (Andre and 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 agricultural technicians 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.

In troubleshooting, students may have the technical knowledge but may lack the cognitive skill set necessary to access their knowledge under new and challenging conditions (Bandura, 1993). Research has shown (Schraw, 1998) that metacognitive instructional strategies,

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such as TAPPS, can assist students with the organization and regulation of their information processing to improve their problem solving performance. The TAPPS strategy involves an individual person solving a problem while a listener asks questions to prompt the problem solver to verbalize their thoughts and clarify their thinking (Whimbey and Lochhead, 1986). The focus is on having students express their thoughts aloud while engaging in problem-solving activities, allowing them to become more aware of their thinking processes or access knowledge from long-term memory.

TAPPS could assist agricultural systems technology troubleshooting instruction in two ways. First, the amount and quality of a problem solver's technical knowledge has been shown to limit students' abilities to reach solutions (Davidson et al, 1994). TAPPS may afford instructors the opportunity to identify areas for supplemental instruction such as correction of misconceptions regarding engine operation theory or faulty problem search strategies. Instructors engaging in this strategy could provide immediate feedback to students to improve their performance. However, having students think aloud may impede their problem solving. Ericsson and Simon (1993) pointed out that the act of verbalizing thoughts can interfere with the execution of a problem solving task. Requiring students to talk aloud may slow their progress due to the difficulty they may face by putting more focus on communicating 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). Yet additional research (Berardi-Coletta et al., 1995) has documented that students' performance improved when they were asked to give reasons for their actions during problem solving. Second, Wood and Bandura (1989) identified that students with higher perceptions of their abilities persisted through problems of increasing difficulty and used analytic strategies in more efficient ways. If students verbalize the belief they are poor problem solvers, they may make fewer attempts to examine their thinking which may lower the number of solutions examined (Hacker, 1998). TAPPS may allow instructors the opportunity to identify those students and provide a means of intervention such as scaffolding troubleshooting exercises based on level of difficulty to increase students' troubleshooting self-efficacy.

The purpose of this exploratory study was to determine the effectiveness of TAPPS as a formative assessment for improving agricultural systems technology students' problem solving during compact power equipment troubleshooting training.

Objectives

- Describe agricultural systems technology students' thoughts while using TAPPS to troubleshoot a small gas engine compression fault.
- Identify areas to improve instruction through assessment of students' statements during troubleshooting.

Hypothesis

- There will be no significant differences in success rate and completion time for troubleshooting a small engine compression system fault between students who use TAPPS and students who do not use TAPPS.
- There will be no significant difference for engine knowledge test scores between students who are successful and students who are not successful at troubleshooting.

Methodology

Participants

This project was approved through Utah State University's IRB under protocol #2834. Between the 2011 and 2012 spring semesters, 56 students participated in a postsecondary compact power equipment class at Utah State University. The majority of students were male (80.4%, f = 45). Most students (58.9%, f = 33) were attending their third or fourth year of school. These students were assigned randomly to either the experimental or control group for the troubleshooting exercise. There were 28 students assigned to the control group and 28 assigned to the experimental group.

Research Design

This study used a randomized posttest-only control group experimental design (Campbell and Stanley, 1968). The strengths of this design include high internal validity and fewer assumptions are made regarding external influences because randomization essentially produces equivalent treatment and control groups. A potential limitation of this design may include lack of generalizability and possible contamination of the control group however the study was conducted in an actual classroom environment and multiple measures were taken to ensure the experimental protocol was followed. Students were assigned randomly to two groups. The single difference between groups was the use of TAPPS during troubleshooting. All 56 students were video recorded. A wireless lapel microphone was used to capture students' verbalizations as they were video recorded. Individuals were video recorded to ensure the fidelity of the treatments and document students problem solving process. All students were asked to troubleshoot identical Briggs and Stratton single cylinder air-cooled horizontal shaft overhead valve engines. Students were asked to individually troubleshoot their engine's fault. As a deception technique to discourage students from discussing the activity, students were told that each engine had a different fault and not to discuss their troubleshooting exercise until all students had completed the activity.

Students were isolated away from other students in an area using panels to surround them so they could not be observed or heard by other students during the troubleshooting exercise and were not disturbed by outside distractions. There was no evidence that students violated protocol. Three engine faults were randomly assigned to students. The three engine faults were insufficient clearance between the rocker arm and the valve stem, a grounded ignition component or insufficient fuel delivery. Students assigned to the control group were recorded and were not asked to think aloud while troubleshooting but told they could talk to themselves if they wished. The experimental group used the TAPPS technique while troubleshooting. The undergraduate researcher acted as a participant observer and served as the listener partner for students assigned to TAPPS. The undergraduate researcher observed each individual student to ensure students followed protocol. The undergraduate researcher used a list of preapproved questions to prompt the TAPPS students to constantly verbalize their thoughts and clarify their thinking. Questions regarding their thinking included "What are you thinking now," "Tell me what you are thinking now," and "Tell me why you did that." The TAPPS students were required to orally verbalize their thoughts throughout the troubleshooting exercise.

Procedure

Students were randomly assigned to a treatment group at the beginning of the course. During the beginning weeks of the course students received instruction on basic engine operation theory. Prior to midterm, a standardize industry service exam developed by Briggs and Stratton Corporation was given to determine students' knowledge level regarding engine operation theory. It was assumed that the service exam for technician certification was content and face valid because it is utilized extensively by Briggs and Stratton Corporation to certify the proficiency of company master technicians. The test consisted of 50 questions, including multiple choice, multiple response and true/false items. Questions covered theory and general knowledge regarding compression, electrical theory, four cycle theory, fuel-carburetor and governors. Briggs and Stratton Corporation considers a score of 75% or greater to be passing.

Following the engine knowledge test, the research mentor provided each student with identical instruction regarding domain-specific knowledge on troubleshooting small gas engines via protocol adapted from Webster (2001). Students were presented technical information on the three major systems required for an engine to operate: compression, ignition and air/fuel intake. Following the troubleshooting instruction, the research mentor taught all students how to use TAPPS. Instruction regarding TAPPS included problems modified from Whimbey and Lochhead (1986) to provide practice for students with talking aloud during problem solving. Ericsson and Simon (1993) recommend this as a practice procedure to allow students to become comfortable with expressing their thoughts verbally. After instruction on troubleshooting and TAPPS, students individually went to the lab area to troubleshoot their engine problem. No hints were given regarding the engine fault. Students were instructed not to remove the cylinder head or crankcase cover.

Treatments

Each troubleshooter was given a 45-minute period in which to troubleshoot the engine fault and provided a complete set of basic engine repair tools which included: a compression gage, a cylinder leak down tester, a socket set, an engine repair manual, an ignition tester, torx bits, a set of metric and standard fractional combination end wrenches, screwdrivers and a supply of compressed air. During troubleshooting, students were asked to identify the correct fault, identify the engine system affected and correctly repair the fault. The undergraduate researcher was the listening partner for all of the TAPPS students and prompted each student to talk aloud as they were troubleshooting. If students paused for more than 10 seconds the undergraduate researcher asked them questions to probe their thinking. The undergraduate researcher did not ask questions regarding the engine or its possible faults. Students were instructed not to talk with each other regarding the exercise until the end of the data collection.

Troubleshooting solutions were checked to determine successfulness. A task outcome (successful or unsuccessful) was recorded for each student based on whether they were able to identify the correct fault, the engine system affected and correctly repair it in order for the engine to start and operate. Results were recorded for successfulness and time of completion for each student. The chi-square test of association was used to test for differences between the two groups in the nominal dependent variable, task completion for the 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. An alpha level of 0.05 was set *a priori*.

In order to describe students' thought processes during troubleshooting, students recorded verbalizations were transcribed and coded. Two additional undergraduate researchers were recruited to assist with transcript analysis. The undergraduate researchers independently transcribed the recordings of the TAPPS students and then compared transcriptions to the recordings to identify any errors in the transcripts. Transcriptions were compared using Microsoft Word Track Change's Compare feature to validate credibility of the transcripts as stated by Ericsson and Simon (1993). The researcher mentor instructed the research assistants on how to code students' troubleshooting transcripts. For the analysis of the transcriptions, coding categories of students' verbalizations were classified into statements regarding troubleshooting instruction, engine theory or metacognition. Verbalizations were considered focused on the troubleshooting instruction if students' verbalized concerns with order of operations for identifying engine problems. Statements focusing on principles of engine theory such as the operations of the four-stroke cycle and engine components were considered engine theory statements. For metacognitive statements, Ericsson and Simon's (1993) protocol coding of verbalizations was used. To be considered metacognitive, students' statements needed to involve planning, monitoring and evaluating to progress. Students' statements directed at judging themselves as performing poorly or well were identified as either negative self-assessment or positive self-assessment. Students' statements directed at judging the troubleshooting activity positively or negatively were coded as positive problem assessment or negative problem assessment. Students' verbalizations consisting of information irrelevant to solving the problem were coded as not on task.

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). There was no significant difference between the TAPPS group and the control group on the engine knowledge test (t (54) =0.332, p =0.741). The mean for students using TAPPS was 51.3 (SD = 11.05) and the mean for students working alone was 50.4 (SD = 7.02).

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

A total of 28 students completed the troubleshooting exercise alone. A total of 28 students completed the troubleshooting exercise using TAPPS. The number of successful students in the control group was 19. There were 18 successful students using TAPPS. Chi-square test of association showed no significant difference in success rate between students who worked alone and those who used TAPPS. The mean time to completion was 30.8 minutes (SD = 11.32) for students who worked alone. The mean time to completion was 30.6 minutes (SD = 9.44) for TAPPS. For students who were successful, there was no significant difference between the TAPPS group and the control group on time to completion (t (17) = 0.051, p = 0.960). Hypothesis 1 was retained.

Hypothesis 2: There will be no significant difference in engine knowledge test scores between students who are successful and students who are not successful at troubleshooting.

There were 37 successful students who completed the troubleshooting task. There were a total of 19 unsuccessful students participating in the troubleshooting task (see Table 2). There was a significant difference between the students who successfully completed the troubleshooting task and the unsuccessful students on the engine knowledge test (t (26)= 2.187 , p =0.038, d = 0.85). The mean percentage scored on the engine knowledge test for all successful students (n= 19) was 50.31 (SD = 8.52). The mean percentage scored on the engine knowledge test for unsuccessful students (n = 9) was 43.11 (SD = 7.21). The calculated Cohen's d (0.68) indicated a medium to large treatment effect (Cohen, 1992). Therefore, hypothesis 2 was rejected.

Differences in Verbalizations between Unsuccessful and Successful Students

All students began the troubleshooting exercise by checking engine fuel and oil levels and attempting to start the engine. Most successful students' verbalizations indicated a strict adherence to the troubleshooting protocol that was provided. Students worked using a systems approach checking through compression, ignition and air/fuel delivery as described in the instruction provided to them. Unsuccessful students did not check each system in order as presented in the troubleshooting protocol or indicated forgetting the troubleshooting procedure.

After attempting to start the engine, students began evaluating possible faults based on sensory data and then began planning test procedures for possible solutions. An example comment was, "When I pulled on the rewind starter, I didn't feel any resistance. It might be something wrong with the compression." One student stated "it sounds like it isn't getting fuel. That could mean something is wrong with the carburetor."

Comments classified for engine theory were directed at identification of engine components. Statements focused on pointing out engine components. Successful students' statements indicated a working knowledge of the function of primary systems such as timing of valves, air leaks, cylinder pressure/leakage and valve clearance. Additional comments were related to the ignition system and component functions. The component unsuccessful students most commonly focused on was the spark plug. These students rarely ventured into discussing other potential faults of the ignition system. Unsuccessful students had difficulty remembering how to use diagnostic tools properly.

Unsuccessful students often self-identified topics they needed to review to improve performance. Unsuccessful students discussed being unfamiliar with valve clearance adjustment procedures and indicated not knowing how to use the

Table 1. Student Performance by Group

Group	Engine Knowledge Test [z]	Task outcome [y]				Minutes to completion [x]	
		Successful		Unsuccessful			
	M (SD)	*n*	%	*n*	%	*n*	*M (SD)*
Control (n = 28)	50.42 (SD = 7.02)	19	67.9	9	32.1	19	28.46 (10.5)
TAPPS (n = 28)	51.25 (SD =11.05)	18	64.3	10	35.7	18	28.90 (11.5)

[z] (t (54) =.332, p =0.741)

[y] ÷2 (1) = .08, p = .78, ϕ = .038

[x] Data includes only students with a successful task outcome; (t (35) = .122, p = .904)

Table 2. Student Differences on Engine Knowledge Test by Troubleshooting Outcome

Troubleshooting Outcome	Engine Knowledge Test	
	M [z]	*SD*
Successful *(n =37)*	52.8	9.5
Unsuccessful *(n =19)*	47.1	7.3

[z] t (54) = 2.296, p = .026, d = *0.68,* test scores were given in percentage of correct answers.

compression leak down tester. A student mentioned "I wish I would have been here more when he was doing in the lab." Another student commented "I don't remember them [possible faults]. We covered it in class didn't we?" Two students made several negative self-assessment statements regarding their ability and level of content knowledge. Unsuccessful students' comments that indicated this were "I have no clue what I'm doing, I'm not good at this stuff" or "I don't even know where to start."

Conclusion, Implication and Recommendations

TAPPS served as a way for the research mentor to identify misunderstandings affecting students' troubleshooting skills. Unsuccessful students were unfamiliar with valve clearance adjustment procedures, forgot possible faults and unable to interpret cylinder leak down test results. Successful students using TAPPS were concentrated on planning test procedures and evaluating sensory data gathered from the engine. Suggestions for instruction included memory association exercises to help students linking engine components with possible faults.

There were 37 students who successfully completed the troubleshooting exercise. Yet, there was no significant difference between those students using TAPPS and those working alone. A significant difference was found in this study between students who successfully completed the troubleshooting task and those who did not on the engine knowledge test score. Students successfully troubleshooting the engine on average scored 5% higher than students who were not successful troubleshooting the engine. Analysis of student comments during troubleshooting with the research mentor identified engine operation theory and proper tool usage topics to review with unsuccessful students.

It is possible the high success rate that students experienced in this study may have been linked to the amount of instruction they received in how to use TAPPS. All students in this study received one class period of troubleshooting instruction and one class session how to use TAPPS for troubleshooting. Additionally, it is unknown if the higher success rate was linked to student self-efficacy. Students may have had a higher motivation to study and believed in their ability to complete the troubleshooting activity. This could have resulted in students increasing their study hours on troubleshooting and engine operation.

Instructors may benefit from using TAPPS to facilitate collaborative learning or as a formative assessment to identify student misunderstandings that could be used to inform decisions regarding instructional remediation. It is recommended that instructors utilize think-aloud sessions to determine quantity and quality of a problem solver's domain-specific knowledge. Suggestions for instructors of agriculture to incorporate this problem solving technique include livestock manure management planning, ventilation design for confined livestock operations and agribusiness planning. Future research should investigate the impact of using TAPPS to assess students' troubleshooting of equipment controller networks and automation programs. An implication for workforce employers could be that having technicians who are proficient in communicating their diagnostic procedures may reduce expenditures of company resources allocated to troubleshooting work orders such as technical maintenance and repairs.

Limitations

Caution should be exercised when generalizing the results of this study to populations outside of the participants from this exploratory study. A limitation of this study was the limited number of participating students. It is recommended that this study be replicated to ensure reliability of the results with a large sample. There was no difference between troubleshooting methods on improving students' troubleshooting success. There were no significant differences in average completion time for the students who used TAPPS compared to students in the control group. The chi-squared test of association 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 study utilized a clinical approach to allow one-on-one interaction between the researcher and student. This procedure increased the control over diffusion of information between students. However, it could have been possible for students to talk outside of class. Informal interactions with students did not indicate that this occurred.

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