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A Descriptive Interpretive Analysis of Students' Oral Verbalization During the Use of Think–Aloud Pair Problem Solving While Troubleshooting

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Researchers assert that the metacognitive nature of think–aloud pair problem solving (TAPPS) improves students' problem solving by focusing their attention on their own thinking. The purpose of this study was to identify and describe oral verbalizations indicating cognitive processes of secondary–level career and technical education students who used TAPPS while troubleshooting. A task outcome (successful or unsuccessful) was recorded for students who used TAPPS while troubleshooting a small gas engine fault on the basis of whether they were able to identify the correct solution to repair the fault. A qualitative interpretive approach was used to describe and interpret students' thoughts while they were engaged in TAPPS. A quantitative analysis was used to compare levels of oral verbalization between successful and unsuccessful TAPPS students. The total average percentage of oral verbalizations indicating metacognitive thought was 54% for successful students and 52% for unsuccessful students. The content of students' oral verbalizations revealed that the metacognitive nature of the TAPPS strategy does not improve problem–solving success when secondary–level career and technical education students do not possess enough domain–specific knowledge. TAPPS can provide school–based agricultural education instructors with a formative assessment tool for checking students thinking and understanding of technical information for problem solving.

Keywords: metacognition, problem solving, qualitative analysis, agricultural mechanics, troubleshooting

Introduction

The complexity of emerging technologies in agriculture has increased the difficulties that technicians might face when attempting to repair equipment problems. Employers want employees who can identify problems and find solutions to those problems (Johnson, 1991). In order to make informed decisions about repairs, individuals must be able to synthesize information about the problem, evaluate potential solutions, and execute their plans. School–based agriculture programs are in a prime situation to help students develop this type of higher order thinking. One of the research priority areas for the National Research Agenda of Agricultural Education and Communication (Osborne, 2007) has been to determine what teaching strategies most effectively and most efficiently yield desired student outcomes with particular groups of students. Ulmer and Torres (2007) argued that school–based agricultural education students should be taught not only content, but also how to improve their thinking. Cano and Newcomb (1990) recommended that school–based agricultural education instructors increase the levels of cognition of their students. Recent instructional efforts have focused on developing students' abilities to solve real–world problems (Technology for All Americans Project, 1996). Hill (1997) stated, "It is imperative that professionals in the field incorporate problem solving concepts and strategies as a significant element in curriculum design and implementation" (p. 32). Pasher, Bain, Bottage, Graesser, Koedinger, McDaniel, and Metcalfe (2007) recommended that teachers find opportunities to have students ask and answer questions to promote explanations that are metacognitive in nature to improve students' problem solving. Research has led to development of several techniques that have shown promise for improving student problem solving (Dunlosky & Metcalfe, 2009).

One of these techniques is the use of think–aloud pair problem solving (TAPPS) (Lochhead, 2001). Lochhead pointed out that the goal of TAPPS is the eventual development of students' ability to observe and control their cognitive behavior, but Glaser (1984) argued that transfer of thinking habits from using general strategies like TAPPS is limited because of a lack of a direct connection between thinking and problem solving during learning. Perkins, Simmons, and Tishman (1990) argued that general cognitive strategies have potential to be helpful in teaching problem solving, but only with deliberate effort. Salomon and Perkins (1989) concluded that the lack of transfer in thinking habits taught in general cognitive strategies is linked to the reliance on automatic triggering through practice rather than thoughtfully detaching strategies from one context and applying them to another. Results from previous studies 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).

Theoretical Framework

The theoretical framework for this study revolves around problem solving, the role of metacognition, the impact of verbalization on thinking, and TAPPS. Davidson, Deuser, and Sternberg (1994) described problem solving as "the active process of trying to transform the initial state of a problem into the desired one" (p. 207–208). This behavior is characterized by identification, evaluation, and utilization of potential solution paths that would accomplish the desired end result. The ability to monitor and control one's thinking to accomplish a desired goal is central to metacognition (Dunlosky & Metcalfe, 2009). According to Davidson et al., metacognition aids problem solving by helping an individual focus on identifying the problem, defining the problem space, generating a mental representation of the problem, planning how to proceed, and evaluating what is known about their own performance.

Nelson and Narens (1990) developed the theoretical model of metacognitive thought seen in Figure 1. The object–level represents an ongoing cognitive task such as problem solving. The meta–level contains a model of a person's understanding of the task they are performing and the knowledge that is needed to complete the task. The model is informed by the individual's monitoring of their progress towards completing the task. As the model is updated, the individual's problem–solving performance can be controlled to seek new information or test a solution.

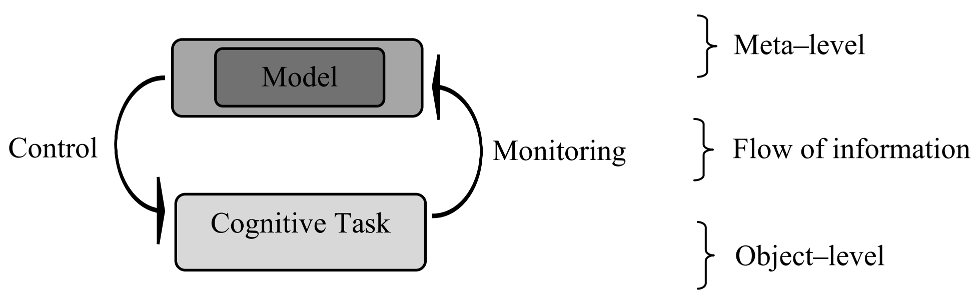

Figure 1. Metacognition framework. Adapted from "Metamemory: A Theoretical Framework and New Findings," by T. O. Nelson and L. Narens, 1990, *The Psychology of Learning and Motivation, 26*, p. 126. Copyright 1990 by Elsevier. Adapted with permission.

Hacker and Dunlosky (2003) suggested that having students explain their thoughts during problem solving through oral verbal reports helps invoke metacognitive thinking. Research has supported the use of self–explanations as a strategy for improving student problem–solving performance (Ahlum–Heath & Di Vesta, 1986; Berry, 1983; Stanley, Mathews, Buss, & Kotler–Cope, 1989; Stinessen, 1985). TAPPS is a method for invoking oral verbalization during problem solving with the goal of developing the problem solver's ability to monitor their thoughts (Gourgey, 1998). The TAPPS procedure involves a student solving a problem while a listener asks questions to prompt the student to verbalize their thoughts and clarify their thinking (Lochhead, 2000). Berardi–Coletta, Buyer, Dominowski, and Rellinger (1995) found that students who gave reasons for their actions during problem solving performed superior to students who were silent, asked to talk aloud, or asked problem–focused questions.

Using TAPPS during troubleshooting has been shown to double postsecondary career and technical education students' success rate at solving small engine faults (Pate et al., 2004), but the impact of using TAPPS during troubleshooting in school–based agricultural education is uncertain. Students may have difficulty focusing their verbalization on problem–oriented features rather than actively clarifying their own thinking. Students' motivation may inhibit their success (Kluwe, 1982). If students believe they are poor problem solvers, they may make fewer attempts to monitor and regulate their thinking, which, in turn, may lower the number of solutions examined (Hacker, 1998). Does TAPPS help secondary–level CTE students' invoke thinking that is metacognitive in nature?

Purpose

The purpose of this study was to identify and describe oral verbalizations indicating cognitive processes of secondary–level career and technical education students who used TAPPS while troubleshooting.

Objectives

1. Identify an optimum level of metacognitive statements conducive to successful troubleshooting.
2. Describe secondary–level career and technical education students' thought processes while using TAPPS to troubleshoot a small gas engine compression fault.

Methodology

Limitations

Although this study did not measure all of the students' thought processes, the researchers sought to ensure credibility of the qualitative data by transcribing directly from digital audio recordings of students' verbalizations during troubleshooting. Confirmability of the transcripts was checked by having a research assistant review the transcripts and compare them with the audio recordings. Transferability of the results from this study is limited by the number of students that were available to participate due to the limited numbers of CTE courses teaching a unit on small engine technology, student attendance, laboratory space, and amount of available equipment.

Research Design

This study design incorporated a mixed–methods approach. A qualitative interpretive approach was used to describe and interpret students' thoughts through their oral verbalizations while they were engaged in TAPPS. A task outcome (successful or unsuccessful) was recorded for students who used TAPPS while troubleshooting a small gas engine fault 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. A quantitative analysis was used to compare levels of oral verbalization between successful and unsuccessful TAPPS students.

Participants

The data source for this study was digital audio recordings of 16 secondary–level career and technical education students from four Iowa schools who engaged in TAPPS during a small engine troubleshooting task. Students enrolled in selected CTE courses dealing with small engine technology were purposely selected to be participants in this study.

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). Ericsson and Simon's (1993) techniques guided recording, transcription, and analysis of the verbal protocols. Students were randomly assigned to use the TAPPS approach while troubleshooting. TAPPS students were randomly assigned another student in class that was not in the TAPPS group to be a listening partner. Each listener was trained on the technique required for TAPPS questioning. Listening partners were asked to encourage problem solvers to verbalize their thoughts without giving any hints or assisting the problem solver in finding a solution. Following Ericsson and Simon's (1993) protocol, students assigned to the troubleshooting role completed a TAPPS practice session with two nonsensical word problems involving the ordering of letters in the alphabet and the order of the Great Lakes based on their depths. The practice task was designed to ensure problem solvers could verbalize their thoughts at an adequate level but was considered by the lead researcher to be sufficiently dissimilar from the troubleshooting task so as not to introduce bias into students' reports. Students assigned to use TAPPS were asked to troubleshoot a compression fault involving a missing valve spring retainer in a small engine. No hints were provided about the nature of the engine fault by the lead researcher to the students, except students were told the fault did not involve removal of the cylinder head or crankcase cover. This information was provided to prevent students from completely disassembling the engine. Each student troubleshooter was provided with a complete set of basic engine repair tools, a digital voice recorder, an attached lapel microphone, 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.

Analysis

For the analysis of the transcriptions, coding categories of oral verbalizations were developed *a priori* based on Ericsson and Simon's (1993) protocol. Responses from the problem solver were coded as level–one, level–two, or level–three verbal statements. Level–one verbalizations were statements describing contents of working memory. Level–two verbalizations were statements describing nonverbal sensory information. As indicated by Ericsson and Simon's protocol level–three verbalizations were considered metacognitive statements involving planning, monitoring, and evaluating. Students' statements directed at judging themselves as performing poorly or well were coded as negative self–assessment and positive self–assessment, respectively. Students' statements directed at judging the activity positively or negatively were coded as positive problem assessment or negative problem assessment, respectively. Students' verbalizations consisting of information irrelevant to solving the problem were coded as not on task. The number of oral verbalizations in each category was tabulated for students who were successful and unsuccessful at the troubleshooting task and then analyzed with descriptive statistics including frequencies and percentages.

In order to accomplish the second research objective which sought to describe students' thought processes while using TAPPS, students' recorded verbalizations were transcribed and coded. A volunteer was recruited to assist with transcript analysis. The lead researcher transcribed the recordings of the TAPPS students and then listened to the recordings to identify any errors in the transcripts. To ensure credibility of the transcripts as stated by Ericsson and Simon (1993), the research assistant also reviewed the transcripts and compared them with the audio recordings. The lead researcher instructed the research assistant on how to code the transcripts. The lead researcher and research assistant independently coded each transcript. Interrater reliability was 87% between the lead researcher and the research assistant. To ensure dependability of the analysis, intrarater reliability was assessed after a period of four days from the initial coding of the transcripts. Five transcripts were randomly selected to be recoded by the lead researcher and the research assistant. Intrarater reliability for the lead researcher was 92%. Intrarater reliability for the research assistant was 90%. Transcripts coded by the lead researcher were used for analysis. Statements from each coding category were used to describe students' cognitive processes.

Results/Findings

Quantitative Data

Objective 1 sought to identify an optimum level of metacognitive statements made by students using TAPPS that would be conducive for successful troubleshooting. Sixteen secondary–level career and technical education students used TAPPS while troubleshooting a small gas engine compression system fault. Four of the 16 students were successful at troubleshooting the compression system fault. Average time to completion for successful students was 15 minutes (*SD* = 6.7). Unsuccessful students spent an entire class period attempting to troubleshoot the engine fault. Class periods ranged from 30 to 35 minutes in length with an average of 31.2 minutes (*SD* = 2.7).

Successful students had slightly higher percentages of oral verbalizations in the categories of level–one working memory, level–two nonverbal sensory information, level–three planning, and level–three evaluating. Although the average percentages of oral verbalizations were similar between groups, there were differences between unsuccessful and successful students in standard deviations for the categories of level–three planning, level–three monitoring, and level–three evaluating (see Table 1). Successful students had an average of 10 level–three planning oral verbalizations (*SD* = 9.1) while unsuccessful students had an average of 9.8 (*SD* = 4.1). Successful students had an average of 15 level–three monitoring oral verbalizations (*SD* = 8.0) while unsuccessful students had an average of 18.3 (*SD* = 5.5). This would indicate a relatively high rate of variation in the number of metacognitive statements between successful students. Successful and unsuccessful students had similar standard deviations for level–one working memory oral verbalizations. On average, out of the total verbalizations for unsuccessful students there were higher percentages of oral verbalizations in the categories of negative self–assessment (*M* = 2.0, *SD* = 1.7), negative problem assessment (*M* = 3.0, *SD* = 3.0), and not on task (*M* = 3.0, *SD* = 4.7).

Table 2 shows frequencies and percentages of oral verbalizations for unsuccessful secondary–level CTE students who used TAPPS (*n* = 12). The average total number of verbalizations for unsuccessful students was 120 (*SD* = 56.1). The average rate of oral verbalizations per minute for unsuccessful students was 3.8 (*SD* = 1.5). Of all unsuccessful students, student H had the highest rates of oral verbalizations in all categories except level–three negative self–assessment, level–three positive self–assessment, level–three negative problem assessment, and level–three positive problem assessment. If student H is removed from the data set, the average total number of oral verbalizations given by unsuccessful students becomes 105 (*SD* = 27.0) and the average rate of oral verbalizations per minute given by unsuccessful students becomes 3.4 (*SD* = 0.8).

Table 3 shows frequencies and percentages of oral verbalizations for successful secondary–level CTE students who used TAPPS (*n* = 4). The average total number of verbalizations for successful students was 66 (*SD* = 32.7). The average rate of oral verbalizations per minute for successful students was 4.4 (*SD* = 1.0).

Patterns of verbalizations shown in Tables 2 and 3 were relatively equal when completion time was accounted for. Level–one working memory, level–three planning, level–three monitoring, and level–three evaluating accounted for the majority of oral verbalizations.

Table 1. *Average percentages of oral verbalizations by group*

	Successful[a]		Unsuccessful[b]	
Code	*M*	*SD*	*M*	*SD*
Level-one working memory	40.6	7.9	38.7	8.5
Level-two nonverbal sensory information	2.5	4.0	1.3	1.7
Level-three planning	10.0	9.1	9.8	4.1
Level-three monitoring	15.0	8.0	18.3	5.5
Level-three evaluating	29.0	4.4	23.7	6.1
Level-thee negative self-assessment	1.2	1.7	2.0	1.7
Level-three positive self-assessment	1.0	2.1	0.5	1.5
Level-three negative problem assessment	0.0	0.0	3.0	3.0
Level-three positive problem assessment	0.0	0.0	0.1	0.3
Not on task	1.5	2.1	3.0	4.0

[a] $n = 4$. Average time spent on troubleshooting = 15 minutes ($SD = 6.7$).
[b] $n = 12$. Average time spent on troubleshooting = 31.2 minutes ($SD = 2.7$).

Table 2.
Frequencies and Percentages of Oral Verbalizations for Unsuccessful Students Who Used Think–Aloud Pair Problem Solving

Student	L1	L2	L3P	L3M	L3E	L3NSA	L3PSA	L3NPA	L3PPA	NOT	Total[a]
B	32 (31.7%)	0 (0.0%)	9 (8.9%)	17 (16.8%)	36 (35.6%)	4 (4.0%)	1 (1.0%)	2 (2.0%)	0 (0.0%)	0 (0.0%)	101 (100.0%)
C	43 (40.6%)	0 (0.0%)	13 (12.3%)	22 (20.8%)	28 (26.4%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	106 (100.0%)
E	42 (43.8%)	1 (1.0%)	6 (6.3%)	19 (19.8%)	23 (24.0%)	1 (1.0%)	0 (0.0%)	3 (3.1%)	0 (0.0%)	1 (1.0%)	96 (100.0%)
F	36 (27.9%)	2 (1.6%)	19 (14.7%)	21 (16.3%)	33 (25.6%)	2 (1.6%)	0 (0.0%)	6 (4.7%)	0 (0.0%)	10 (7.8%)	129 (100.0%)
G	28 (26.7%)	1 (1.0%)	11 (10.5%)	31 (29.5%)	32 (30.5%)	0 (0.0%)	0 (0.0%)	2 (1.9%)	0 (0.0%)	0 (0.0%)	105 (100.0%)
H	109 (38.9%)	17 (6.1%)	21 (7.5%)	42 (15.0%)	60 (21.4%)	0 (0.0%)	1 (0.4%)	7 (2.5%)	0 (0.0%)	23 (8.2%)	280 (100.0%)
K	39 (30.2%)	2 (1.6%)	2 (1.6%)	33 (25.6%)	38 (29.5%)	7 (5.4%)	0 (0.0%)	6 (4.7%)	0 (0.0%)	2 (1.6%)	129 (100.0%)
L	40 (42.1%)	0 (0.0%)	12 (12.6%)	19 (20.0%)	20 (21.1%)	2 (2.1%)	0 (0.0%)	1 (1.1%)	1 (1.1%)	0 (0.0%)	95 (100.0%)
M	51 (34.9%)	1 (0.7%)	17 (11.6%)	25 (17.1%)	27 (18.5%)	4 (2.7%)	0 (0.0%)	16 (11.0%)	0 (0.0%)	5 (3.4%)	146 (100.0%)
N	42 (50.0%)	0 (0.0%)	14 (16.7%)	9 (10.7%)	17 (20.2%)	1 (1.2%)	0 (0.0%)	1 (1.2%)	0 (0.0%)	0 (0.0%)	84 (100.0%)
O	54 (46.2%)	2 (1.7%)	8 (6.8%)	12 (10.3%)	18 (15.4%)	3 (2.6%)	6 (5.1%)	1 (0.9%)	0 (0.0%)	13 (11.1%)	117 (100.0%)
P	26 (52.0%)	1 (2.0%)	4 (8.0%)	9 (18.0%)	8 (16.0%)	1 (2.0%)	0 (0.0%)	1 (2.0%)	0 (0.0%)	0 (0.0%)	50 (100.0%)

Note. L1 = level–one working memory; L2 = level–two nonverbal sensory information; L3P = level–three planning; L3M = level–three monitoring; L3E = level–three evaluating; L3NSA = level–three negative self–assessment; L3PSA = level–three positive self–assessment; L3NPA = level–three negative problem assessment; L3PPA = level–three positive problem assessment; NOT = Not on task.
[a] Average time spent on troubleshooting = 31.2 min (*SD* = 2.7).

Table 3.
Frequencies and Percentages of Oral Verbalizations for Successful Students Who Used Think–Aloud Pair Problem Solving

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

Note. L1 = level–one working memory; L2 = level–two nonverbal sensory information; L3P = level–three planning; L3M = level–three monitoring; L3E = level–three evaluating; L3NSA = level–three negative self–assessment; L3PSA = level–three positive self–assessment; L3NPA = level–three negative problem assessment; L3PPA = level–three positive problem assessment; NOT = not on task.
[a] Average time spent on troubleshooting = 15 minutes (SD = 6.7).

Qualitative Data

Objective two sought to describe secondary–level career and technical education students' thought processes while using TAPPS to troubleshoot a small gas engine compression fault. Most often students' level–one working memory verbalizations described their actions as they removed or returned parts to the engine. When describing their actions, successful student A and three unsuccessful students (E, K, and B) failed to use correct engine terminology to describe the engine parts. For example, successful student A stated, "Taking off ssss hold on I don't know what it is yet but I'm taking it off." Unsuccessful student E stated, "I'm gonna take off the something I don't know what it's called so yeah taking this thing off."

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

Students' level–three planning verbalizations were directed toward the order of tests to be made to the engine. When planning their next test, students described what they would do but offered little explanation for why they planned to conduct those tests. Successful student J started troubleshooting by checking the spark plug gap without first identifying if a fault existed in the ignition system. Unsuccessful student C commented that it seemed to have pretty good compression so the next thing to check was spark.

The content of level–three monitoring oral verbalizations given by students revealed shallow analysis of possible solutions. Students did not analyze the results of their tests before checking other engine components at random. Unsuccessful student C remembered to check valve springs but upon examination determined nothing was wrong with them. Unsuccessful student C stated, "Err look at the valve springs really quick just to see if anything is wrong there with the valve springs look good, there's nothing abnormal about them." Unsuccessful student C's listening partner asked, "How do you know that something's not wrong with those?" In response, unsuccessful student C stated, "Ah um they look pretty normal they didn't look anything out of the ordinary so just by the eye they looked fine to me." Afterward, unsuccessful student C's listening partner asked, "Could they be warped or disfigured if something was wrong?" Unsuccessful student C replied, "Yeah, they would but if they, they look pretty good to me." Unsuccessful students' level–three evaluating verbalizations indicated a lack of knowledge regarding the troubleshooting procedure and the functions of engine components. Unsuccessful student P stated, "Alright, then compression, crap I forgot what the other one's were alright, compression, crap something else and then the carburetor." Four unsuccessful students (F, L, N, and M) identified compression as the fault area but failed to identify a solution. Of these four students, two (M and F) verbalized that they could not remember what to check for compression. Unsuccessful student M stated, "I don't even remember everything we're supposed to check for compression, so, if, I can't even remember what to check there's no way I can get it fixed." Unsuccessful student F stated, "There's like no compression… I can't even remember."

Successful students' level–three evaluation verbalizations were focused on making judgments relevant to the cause of the engine fault based on the result of their engine test. Successful student I stated, "Ah, the compression system is wrong; the intake doesn't look to be moving." Successful students often verbalized what they had learned from working with the engine. These students made note of problem characteristics and related them to what they had learned. Successful student J stated,

> Well, I don't know how I'm suppose to fix it, but I think I figured the problem out, um the spring doesn't seem to be seated right, um, I'm not sure what I'd do to fix springs, the other one has a gap right there… It doesn't seem to be compressed, um make it so it would be compressed.

Negative self–assessment, negative problem assessment, and not on task verbalizations generally were given by unsuccessful students.

Unsuccessful student K stated, "I feel like a retard." Three unsuccessful students (K, M, and O) explained they did not like being recorded while they were working. Unsuccessful student M stated, "Umm, cause I don't like this talking through it, I'm not a talker anyway." Unsuccessful student B stated, "Thinking I'm probably didn't get this and I'm going to be the one failure in the class." Two students (E and H) seemed to view the activity as irrelevant to them. Unsuccessful student E stated, "…this is stupid I really don't care about these stupid engines..." Unsuccessful student H stated, "Subway eat fresh, ha ha we're talking about random bull."

Conclusions/Recommendations/Implications

When work time was accounted for, verbalization rates between unsuccessful and successful students were similar in all oral verbalization categories except level–three negative–self assessment, level–three negative problem assessment, and not on task. Successful students had no level–three negative problem assessment, whereas unsuccessful students had an average of three verbalizations for level–three negative problem assessment. Also, unsuccessful students gave almost twice as many negative self–assessment verbalizations as successful students. This could have been caused by students' frustration with not finding a solution toward the end of their troubleshooting activity. Students may have been uncomfortable talking aloud. This may have affected their motivation to complete the activity (Hacker, 1998; Kluwe, 1982). On average, unsuccessful secondary–level career and technical students gave twice the amount of not on task verbalizations as successful students. This can be explained by the number of not on task verbalizations given by unsuccessful students F, H, and O. These students' not on task oral verbalizations averaged 9% of their total oral verbalizations. The remaining unsuccessful students' not on task oral verbalizations averaged only 0.7% (*SD* = 1.2) of their total oral verbalizations.

Objective 1: Identify an optimum level of metacognitive statements conducive to successful troubleshooting.

Results did not indicate a minimum level of metacognitive statements during TAPPS that is conducive to successfully troubleshooting a small engine compression fault. This was indicated by the relatively high rate of variation in the number of metacognitive statements given by students. The total average percentage of oral verbalizations across the level–three planning, monitoring, and evaluating categories was 54% for successful students and 52% for unsuccessful students. These rates and the qualitative data indicate that TAPPS seemed to focus secondary–level students' thinking toward a process–oriented approach during troubleshooting (Berardi–Coletta et al., 1995). It is possible that the relatively short durations of the TAPPS instruction was not sufficient to affect the amount of metacognitive statements given by students. Extending the length of the practice with TAPPS may yield different results. Perkins et al. (1990) suggested contextualizing instruction of general cognitive strategies by teaching them in the target domain with vocabulary adjusted to suit the target domain. Future research should be conducted to determine the effect of allowing secondary–level students to practice using TAPPS with an engine problem before being tested. Additional investigation over an increased treatment period may provide insight into the effects of TAPPS on other outcomes such as students' self–efficacy and motivation.

Objective 2: Describe secondary–level career and technical education students' thought processes while using TAPPS to troubleshoot a small gas engine compression fault.

The content of students' oral verbalizations indicates the metacognitive nature of the TAPPS strategy does not improve problem–solving success when secondary–level career and technical education students do not possess enough domain–specific knowledge. Unsuccessful students' verbalizations in the level–three monitoring and evaluating categories often were concerned with their level of knowledge regarding troubleshooting and small engines. These students had difficulty remembering the troubleshooting process and the proper functions of engine components.

Unsuccessful secondary–level career and technical education students verbalized negatively about their ability or performance and the troubleshooting activity. A majority of level–three evaluating statements from unsuccessful students focused on assessing their knowledge of engine principles and troubleshooting. Unsuccessful students described their level of knowledge as low or nonexistent. In contrast, the content of successful students' level–three evaluating verbalizations focused on making judgments in relation to their monitoring of the effects of their engine tests and their evaluation of engine fault symptoms. TAPPS can provide school–based agricultural education instructors with a formative assessment for checking students thinking and understanding of technical information for problem solving. A recommendation for teaching troubleshooting with secondary–level CTE students would be to ensure that students possess the prerequisite knowledge for troubleshooting with the use of TAPPS prior to a summative assessment of students' troubleshooting skills.

It was assumed that curriculum and instruction provided by secondary classroom teachers regarding engine theory and operating principles did not vary between data collection sites prior to troubleshooting instruction. Students' concerns about their knowledge level could be connected to their rate of troubleshooting success. 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. An implication is that students' knowledge level could be connected to the amount of instruction they receive and the difficulty of the troubleshooting activity. All secondary–level students in this study received only one class period of troubleshooting instruction. Students were given notes and a demonstration on how to troubleshoot the air/fuel delivery, ignition, and compression systems. Students were told the engine needed all three systems to function correctly in order to run, and possible faults for each system were described to the students. To complete the troubleshooting activity, students had to identify the system at fault, identify the specific engine component that was malfunctioning, and correctly describe the appropriate repair. However, secondary–level students' knowledge of basic engine principles and operating theory was not formally assessed before this study. Although this exploratory study offers no support for using TAPPS at the secondary level, the reader is cautioned against making generalizations from this relatively small sample of 16 students. This study does not rule out the possibility that TAPPS could be useful with other secondary–level students, and we strongly recommended that future research incorporate a larger sample size.

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