

Utility of Post-Hoc Audio Reflection to Expose Metacognition and Strategy Use by First-Year Engineering Students for Different Problem Types

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Abstract

This work-in-progress paper identifies metacognitive activities and problem solving strategies utilized by first-year engineering students to solve different types of problems. Our research question is: What problem solving strategies and metacognitive activities are revealed by students' post-hoc audio reflections on their solutions to three different types of engineering problems (story, open-ended, exercise)?

This study was conducted with first-year engineering students at our institution over two semesters. Students solved problems using tablets and custom-designed software that recorded student written work and erasures. Students then would watch playback of their problem solution and insert verbal comments into their work (post-hoc audio reflection). Analysis of students' written data did not reveal much about metacognition and only afforded minimal insight into strategy use. Audio data was then analyzed for strategy use and types of metacognitive activity for the three problem types.

Our analysis suggests that students do employ different strategies for different problems; open-ended and story problems are more likely to elicit metacognition in general, and few students articulated their thinking for exercise problems. Most metacognition occurred in the form of monitoring and evaluating, with little evidence of planning. Several strategies are used by students for all problems, but some are unique to specific types of problems. These findings demonstrate the usefulness of post-hoc audio reflection in engineering education research to better assess and address students' metacognition and problem solving strategies.

Introduction

This work-in-progress paper identifies metacognitive activities and problem solving strategies utilized by first-year engineering students to solve different types of problems. Our research question is: What problem solving strategies and metacognitive activities are revealed by students' post-hoc audio reflections on their solutions to three different types of engineering problems (story, open-ended, exercise)? Post-hoc audio reflection is defined as verbal student commentary recorded as students watch a play-back of their work after solving a problem.

It is difficult to discern cognitive problem-solving skills that are developed and those lacking in engineering students based only on their written work. Although studies have been done to explore the value of metacognition through think-alouds and post-hoc *written* reflection,^{1,2} little research exists exploring what can be gleaned about student strategy use and metacognition through post-hoc *audio* reflection. Moreover, existing research has largely overlooked the potential for different problem types to elicit diverse strategies and metacognitive activities from students. Research in this area could help address difficulties faced by first-year engineering students with diverse backgrounds and needs. Students who begin the program with weak mathematics preparation already find themselves at a disadvantage compared to their peers with more experience in mathematics. By identifying strategies and metacognitive activities that are most essential for success in solving engineering problems, we can advise ways to mediate these

discrepancies between students and help retain engineering students who are still developing math proficiency.

Prior research that focuses on differences between experts and novices based on the ability to know and apply core principles of a field asserts that engineering education often fails to provide students with opportunities to solve authentic problems³. Consequently, students are not given practice utilizing metacognitive strategies that are necessary for solving ill-structured problems. The goal of this study is to differentiate metacognition in terms of planning, monitoring and evaluation during problem solving for different problem types.

This study was conducted with first-year engineering students at our institution over two semesters. Three different problem types, story, open-ended, and exercise⁴, were selected for this study, with the understanding that different problem types elicit different problem-solving processes⁵. Students solved the problems using tablets and custom-designed software that recorded students' written work and erasures. Students then would watch playback of their problem solution and record verbal comments at relevant points within their work (self-selected based on what they wanted to reflect on). Although analysis of students' written data allowed detailed documentation of students' problem solving processes⁶, it did not reveal much about metacognition and only afforded minimal insight into strategy use. Audio data was then analyzed for strategy use and types of metacognitive activity for the three problem types. The implications of this research concern scaffolding for metacognition, strategy use and skill development in engineering education. Educators benefit from considering these findings when developing interventions for struggling students or when trying to develop approaches to solving problems that more closely align with those used by practicing engineers.

Literature Review

An issue of concern for post-secondary engineering educators is that of retention; only about half of the incoming freshmen in engineering graduate with a degree in the field⁷. Particularly noteworthy is the attrition of students from nontraditional backgrounds. Studies aimed at understanding student characteristics that correlate with leaving the field produce mixed results, probably because student outcomes are the result of a confluence of factors, although students who leave are more likely to feel less prepared in math and science than their peers^{8,9}. For retention rates to improve, barriers to completion need to be identified and addressed. Among identified barriers is the lack of awareness young scholars have regarding what work in their selected field actually looks like and a paucity of resources for students who need help transitioning to the demands of engineering education¹⁰. Because attitudes at the end of the first year in the program have strong predictive value in successful outcomes⁷, it is valuable to find ways to make the college experience a more successful transition between high school and the workforce. One way to do that may be to focus on the self-management skills and strategies needed by engineers, identify those that are lacking in freshman engineering students, and develop classroom experiences that address this discrepancy⁹.

Problems faced by engineers are typically ill-structured, meaning that they do not have a clear-cut answer or single approach to finding a solution¹¹. However, engineering education has failed to provide students with authentic experiences with these types of problems; instead, students see problems that are highly structured¹². To prepare students for what they will encounter after college, engineering educators need to emphasize deeper understanding of the core concepts

underlying the field of engineering³. A metacognitive basis for instruction may help students to develop problem solving approaches that will prepare them for success in dealing with ill-structured problems¹³. However, many students enter their post-secondary engineering studies with poorly-developed metacognitive skills, and in its current state, educational experiences do little to address this shortcoming¹⁴. Explicit education on strategies addressing metacognition have been shown to be beneficial in improving outcomes for students^{15, 16}, even in cases where content-specific knowledge is weak¹⁷.

Some work has already been done to test the idea of using metacognitive interventions in college science settings. For example, Sandi-Urena et al¹⁸ found that small-group discussions that prompted for metacognition helped chemistry students solve ill-structured problems. Remedial math students improve through explicit instruction on thinking strategies and frequent teacher feedback^{19, 20}. Various forms of metacognitive intervention have been tried as well. Hanson and Williams¹ saw gains in student performance through written metacognitive assignments, and McLaughlin²¹ suggested that the use of student-created podcasts fosters skill development.

Existing research has left a few important questions about approaches to problem solving unanswered. Problem solving can be studied in the phases of planning, monitoring, and evaluating¹⁷. Schraw defined planning as identifying resources needed to solve the problem, monitoring as assessing how well the task is understood and approached, and evaluating as determining the overall value of the work done. Ku and Ho²² studied activity in the three stages using general critical-thinking tasks, which they defined as tasks requiring “strategic use of cognitive skills that best suit a particular situation, as well as active control of one’s own thinking processes for well-justified conclusions” (p. 253). Using think-aloud to measure metacognitive activity, they found discernable differences between students with more critical thinking aptitude and activity in each of these stages. Students with high performance had more advanced planning strategies, more frequent monitoring activity, and a greater tendency to evaluate their work. However, similar work has not been done to examine activity in relation to problems specifically designed for engineers. Moreover, literature differentiating metacognitive activity in solving ill-structured versus well-structured problems in engineering classes is notably sparse; research largely neglects to differentiate the diversity of problem types and how they may elicit unique metacognitive activity. Research aimed at addressing these gaps could provide engineering educators with information to help them better serve students entering the program, particularly those with weak content foundations, to develop skills to become successful engineering students and to be more prepared for the workforce.

Methods and Analysis

Data collection for this study took place in first-year engineering class over two semesters: Fall 2009 ($n = 27$) and Spring 2011 ($n = 36$). Students used custom-designed software²³ to solve three different problem types (story, open-ended, and exercise). Each problem was semi-structured in a way to be accessible for first-year engineering students yet ill-defined enough to approximate eliciting problem solving skills that would be utilized in an actual workplace setting (although none would actually be defined as ill-defined). Table 1 details the data collection for the study. Student commentary was coded by researchers for evidence of metacognition and strategy use. Students were included in the count for contributing codes if their work was coded for either metacognition or strategy use.

Table 1: Data collection by semester

Semester	Total students in sample	Number of students contributing codes for story problem	Number of students contributing codes for open-ended problem	Number of students contributing codes for exercise problem
Fall 2009	27	18 (67%)	12 (44%)	8 (30%)
Spring 2011	36	19 (53%)	18 (50%)	10 (27%)

The story problem asked students to calculate the efficiency of a multi-stage solar energy conversion system. This problem was considered a *story* problem because it was embedded in a situational context. The open-ended question required students to determine resistance and current of a circuit comprised of multiple resistors. Students were then asked to develop an equivalent circuit within certain parameters. This problem was considered *open-ended* because the second part did not have a single correct outcome. The exercise problem required students to use unit conversions and physics principles to make calculations involving a pressurized tank. This problem was considered an *exercise* because it simply required students to apply the correct calculations to a particular situation.

The custom-designed software recorded student work, including erasures and revisions. Students would then watch a playback of their problem-solving and their verbal commentary on their work was audio recorded. Students were asked specifically to reflect on their thinking processes, and to identify where in the problem their thinking processes occurred. Audio data was then analyzed and coded for evidence of strategy use and metacognitive activity. A team of three researchers coded audio files individually then met as a team to come to a consensus on applied codes. Codes for strategy use were decided on based on the work of Nickerson²⁴. The most frequently observed codes, and the ones referenced in this paper, are summarized in Table 2 along with example quotes of segments collected by students during their reflection.

Table 2: Strategy codes and meanings

Strategy Code	Descriptor	Example quotes
Plug and chug	Plugs numbers into equations without planning or knowing why	<i>I figured I had to calculate something</i>
Guess and check	Guesses values or approaches and uses trial and error	<i>I'm going to keep on playing with other parallel circuits</i>
Segmentation	Recognizes a problem has multiple parts without being told explicitly by the problem	<i>I had to stop and think of the problem piece-by-piece</i>
Use an external resource	Refers to something outside of the problem for reference (peer, instructor, or text)	<i>I realized my mistake when I checked my answer with the people at my table</i>

The metacognitive domains of planning, monitoring, and evaluating were used to code data for metacognitive activity¹⁷. Within these domains, sub-codes were identified. These sub-codes more specifically describe what the students are doing as they reflect. Table 3 contains a summary of the most frequent sub-codes, which are the ones referenced in this paper, along with examples of audio segments contributed by participating students.

Table 3: Metacognitive codes

Major code	Sub-code	Descriptor	Example
Planning	Identify unknown value	Acknowledging what they needed to solve for	<i>It was clear that the problem was wanting to find out the resistance</i>
Monitoring	Acknowledge prior error	Notice that a mistake was made in calculation leading up to the solution	<i>Then I realized I was doing it wrong</i>
	Acknowledge importance	Explain how a strategy, such as drawing a diagram, helps	<i>I wanted to visualize what was going on with the problem. So I decided to draw a picture</i>
Evaluating	Evaluate performance Hi/Lo	Assess correctness or appropriateness of problem-solving action	<i>So after a quick glance I was satisfied and then I felt more confident, a little bit more confident as I would move forward into the next step of the problem</i>
	Acknowledge confusion Hi/Lo	State degree to which they felt they knew what they were doing	<i>And first I had no clue what to do</i>

Researchers then tabulated the codes by problem type to discern which problems were more or less likely to elicit particular strategies or types of metacognitive activity, as evidenced by post-hoc audio reflection.

Results

Problem type and metacognition

We grouped and reviewed codes for the three problem types within the broad metacognitive categories of planning, monitoring, and evaluating. Table 4 and the accompanying graphs display a frequency count of metacognitive activity for each problem type and percentages for each problem type. These counts reflect data pooled from both semesters.

Table 4: Frequency of metacognition by problem type ($N = 63$)

Metacognitive domain	Total number of codes	Story	Open-ended	Exercise
Planning	3	1 (33%)	2 (67%)	0 (0%)
Monitoring	109	39 (36%)	37 (33%)	33 (30%)
Evaluating	119	36 (30%)	61 (51%)	22 (29%)

This analysis suggests that in both the planning and evaluating phases, the open-ended problems elicit more metacognitive activity than the exercise or story and that activity during monitoring was relatively equal in all problem types. Overall, the most diverse metacognitive activity was recorded for the open-ended problem.

Planning. Little evidence of planning was revealed for any problem type. In total only three segments of audio data were coded for planning activity (1.3% of all codes), and no audio segments were coded for planning for the exercise problem. The only planning activity coded in audio reflection was to identify an unknown value. For example, as part of the open-ended question, students had to calculate the resistance and current for a “mystery” circuit and design a circuit to match the current in that mystery circuit. As evidence of planning by identifying an unknown value, a student said “After looking at the problem from the sheet it was clear that the problem was wanting to find out the resistance of the actual mystery circuit that we have to find out.”

Monitoring. In monitoring progress, the most common activity was acknowledging prior error (46% of all codes); this management strategy was common for the story type problem (56% of all story codes). Prior error may be attributed to an incorrect assumption, as one student solving the story problem commented “I was assuming 100% efficiency but later on I realized that that’s not the correct efficiency so I was using a different one.” The open-ended question involved applying knowledge or rules for resistors in parallel or series, and some student commentary reflected a failure to correctly recall those rules. In solving the exercise problem, students may acknowledge being misdirected by failing to notice the need for converting units. Acknowledging the importance of using metacognitive or problem-solving strategy was also a frequent activity in the monitoring domain, comprising 38% of all monitoring codes. Students solving the story problem spoke of finding it helpful to draw a diagram, and when approaching the open-ended and exercise problem, students mentioned they strategized by referring to previous equations or writing out the relevant equation prior to solving.

Evaluating. Evaluating was most commonly observed in the open-ended question and least present in the exercise problem; 51% of evaluating codes were linked with open-ended question and 18% with exercise. Within this domain, students were likely to evaluate their performance as either high or low while solving the open-ended problem. One student evaluated performance in the open-ended problem, saying “I’m not sure if I did this right or not but um, I tried my best and I think I got close to the right answers,” appearing to suggest that trying and calculating values that approximated the correct ones would be adequate. Students solving the story problem frequently acknowledged a high level of confusion. For example, one student

commented “Then I did not know what to do so I figured there was more so I figured I had to calculate something so I was seeing different places you can rearrange output and input equals efficiency to calculate whatever I needed but I wasn’t sure.”

Problem type and strategy use

As with the metacognitive codes, the exercise problem elicited the fewest codable audio segments regarding strategy use. During both semesters, only three students’ commentary on the exercise problem could be coded for strategy use. Also as with the metacognitive evidence, students showed more evidence of strategy use in their commentary on solving the open-ended question. Table 5 shows the relative frequencies of strategy use for each problem type, pooling data from both semesters. Because strategy use was not further partitioned into sub-domains, as was with metacognition, this table only shows data in aggregate.

Table 5: Frequency of strategy use by problem type

Total codes	Story	Open-ended	Exercise
79	30 (38%)	43 (54%)	6 (7.6%)

In both data collection years, the open-ended question was associated with more than half of the strategy codes and the exercise problem with the least number of strategy codes.

Within problem types, particular strategies were prevalent. The guess-and-check strategy was by far the most common for the open-ended problem, comprising more than half (56%) of all coded segments for this problem type. One student revealed the guess-and-check approach, commenting, “I’m going to keep on playing with other parallel circuits and then just ah, determine the current for each of them afterwards.”

Segmentation was most common for the story problem; just under half (40%) of the coded segments for this problem type were for segmentation. For example, a student said that when faced with the problem “I realized that this problem would have to be worked forwards and backwards in order to get the middle part which is what we wanted.”

All problem types elicited plug-and-chug strategies and utilizing an external resource, though plug-and chug was more common in solving the story problem. In a representative example, a student admitted “When I start I just take these numbers and I just start plugging them in, not really thinking about what they’re asking for, what my graph is looking like, the picture at the bottom, so I don’t know what I’m solving for.”

Use of an external resource was more evidenced in reflection on the open-ended problem, with students indicating that they referenced the textbook or a peer.

Discussion

Our research purpose was to discern the problem solving strategies and metacognitive activities revealed by first year engineering students’ post-hoc audio reflections on three different problem types (story, open-ended, and exercise). By studying the relationship between these two activities

and how they differ for problem types, engineering instructors can better understand what activities are natural for students, compare those to what research suggests is most effective, and mediate any discrepancy between the two.

Across problem types, evidence of planning by students was minimal. Although this lack of data may be attributed to the audio protocol, which may have prompted student reflection beginning after the planning phase, the paucity of planning may deserve further attention. Considering that a distinguishing factor between experts and novices is careful planning, possibly because experts have a more developed tool kit of strategies²⁵, engineering educators may be well-advised to address this gap by modeling and emphasizing the value of this metacognitive step to help students transition to a more expert approach.

Also common to all problem types was the reliance on strategies such as guess-and-check and plug-and-chug. In cases where guess-and-check accompanies references to metacognition, credit for self-management may be overly generous. In segments coded for both acknowledging prior error and guess-and-check, students merely recognized that the value they guessed was incorrect:

“So I, ah, I put that into the equation and realized it was the wrong efficiency so I restarted.”-Story problem

“I was trying to figure out how I could get my units to cancel out”-Exercise problem

In segments coded for evaluating performance, students also may have revealed their tendency to rely on the guess-and-check strategy:

“I’m sure after looking back at it now if I had just had a little bit more time to guess and check I could have come up with the right ohm combination of the resistors”-Open-ended problem

“Then I did not know what to do so I figured there was more so I figured I had to calculate something so I was seeing different place you can rearrange output and input equals efficiency to calculate whatever I needed but I wasn’t sure” –Story problem

“To the best of my calculations it would simply be trial and error. I think this is maybe what the problem was asking for.” –Story problem

In each of these examples, the student’s commentary seems to suggest that the student assumed the problem is *supposed* to be solved using guess-and-check.

Considering the research that exists discrediting the utility of plug-and-chug and guess-and-check as sustainable strategies²⁶, exposing student reliance on these approaches suggests a pedagogical need to explicitly define and discredit their effectiveness. Reliance of strategies such as guess-and-check and plug-and-chug expose naivety in problem solving awareness, which is an established discrepancy between novices and experts who approach a task²⁵. Coding of segments where students identify prior error or confusion can help instructors see where initial false starts were; instructors can use this information to develop awareness of common traps students fall into when approaching a particular type of problem and explicitly mediate.

Although few, there were some areas where particular problem types elicited specific strategies at disproportionate levels as compared to other problem types. For example, the segmentation approach was common to the story problem. Given that this strategy is a natural recourse to solving this type of problem, educators may want to consider using segmentation to scaffold problem solving skills.

Differences between problem types for metacognitive activity are more pronounced. The exercise problem had far fewer codes, monitoring was most common for the story problem than for other problem types, and evaluating for the open-ended problem. These distinctions could be attributed to the problems selected and the strategies students were most prone to utilize. For the open-ended resistor problem, students needed to calculate resistance and current and design a circuit. Because these students often approached this problem with a guess-and-check strategy, it would make sense that they often review their work to see if their answer makes sense. Students often approached the story problem using a segmentation strategy because they recognized that the problem had multiple parts. Thus, it follows that they would frequently check the progress they are making towards the answer. More research is needed to determine if these differences would still exist in other examples of these problem types. The findings based on these examples suggest that instructors interested in teaching metacognition may be most effective by using examples from these problem types to scaffold metacognitive development.

The utility of audio reflection cannot be understated. Much of what was observed through the audio was not revealed by examining written work alone. As one student solving the open-ended problem wrote: “After some guess and check with various resistors *that I failed to write down*, I found that the best combination, or a possible combination was to use the 40 ohm resistor and the 70 ohm resistor in parallel” (emphasis added). Additionally, strategies such as use of a textbook or peers for help would not be discerned through study of student written work. Even if professors do not have access to software that allows recording and annotating of students’ work, or do not have the time themselves to review audio data, the think-aloud process itself could help students develop metacognitive and problem solving strategies that will improve their task performance²⁷. The results from this research suggest recommending finding a place for explicit metacognitive and strategy-use instruction, specifically through an audio reflection protocol.

Conclusions

Implications

Engineering students enter their major from an array of backgrounds and experiences²⁸. Some may begin the program with an academic background that is more aligned with engineering education than others. Because metacognitive prowess and fluency with strategy use has been linked with problem solving success, developing a program for including instruction on these skills in engineering education classrooms may be beneficial^{9, 15, 17}. This research suggests that students tend to apply some strategies, such as plug-and-chug, to all problem types, and others are more specific to particular problems, such as segmentation with story problems. Awareness of these tendencies may suggest a starting point for engineering educators to scaffold metacognitive and strategy-use skill development.

Future work

Future work will delve into relationships between evidence of audio reflection and problem correctness. Students with more coded units will be considered highly metacognitive; students with no coded units will be classified as minimally metacognitive. Scores on each problem will be examined alongside audio commentary data to discern whether problem outcomes correlated with evidence of metacognition in post-hoc audio reflection. Because counting codes may be misleading, as students may evidence surface-level metacognition in multiple instances, further analysis will invoke the work of Ko and Ho²². In their study, they analyzed metacognition

through differentiation of “low-level” and “high-level” strategies. Low-level strategies are those which raise a question but do not necessarily indicate action; high-level strategies involve awareness of specific steps or ways of thinking necessary to solve the problem. This work will also consider the characteristics of students who did not contribute any codeable units. These students may not have contributed noteworthy audio segments because of a preference to express their thinking in writing or because of a legitimate dearth of metacognitive activity. Additional future work will explore correlations of student background and history with metacognitive activity and strategy use. Background variables that will be considered include prior math experience, gender, and ethnicity.

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