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USING A HYBRID OF ARGUMENTATION AND PROBLEM SOLVING PROMPTS TO FACILITATE UNDERGRADUATES' PROBLEM SOLVING PERFORMANCE AND CONFIDENCE

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Educational reform documents in the U.S. promote the incorporation of argumentation in science and engineering as a 21st century learning skill. Our aim was to infuse argumentation in a calculus-based physics course for future scientists and engineers. We conducted a study in a problem solving recitation session of the course. All students were asked to solve the same problem and were provided prompts to structure their solutions. The intervention condition was required to justify their solution procedure prior to solving the problem. Results showed that the intervention condition had a greater proportion of correct solutions, higher confidence in their approach, and were more likely to suggest alternative approaches to solving the problem than students in the control condition.

Keywords: evidence based approaches, physics, problem solving

INTRODUCTION

Argumentation is a key science and engineering practice in the Next Generation Science Standards (NGSS Lead States, 2013) and an important 21st century learning skill (Barak, 2017). Argumentation tasks can improve problem solving, scientific reasoning, and knowledge construction (Driver, Newton, & Osborne, 2000). But, students need scaffolding, such as question prompts to construct arguments to justify their solutions (Ge & Land, 2004). We previously found (Author, 2012) that argument tasks with prompts produce higher argumentation and conceptual quality on physics problems than without prompts. Blending metacognitive/reflective prompts (e.g. confidence rating) with argumentation may also assist students to identify inconsistences in solutions; reflect on, evaluate, and adjust claims (Novak & Treagust, 2018).

Problem solving is a key component in most undergraduate physics courses but students are seldom required to explain their solutions, reflect, or consider alternatives (Dufresne, Gerace, & Leonard, 1997). Novice solvers often use surface features (Chi et al., 1981) and lack an understanding of underlying principles (Leonard et al., 1996). One strategy to address this issue involves four steps (Scott, Stelzer, & Gladding, 2007): a) conceptual analysis – identify the principles and why they are needed to solve the problem, b) strategic analysis – develop a plan for applying these principles, c) quantitative analysis –execute the mathematical solution based on the plan, and d) reflective analysis – reflect on what you learned by solving the problem, how the problem could be altered, and how your solution might change consequently. In addition to this, to become better problem solvers learners must be engaged in tasks that require meaningful justifications and consideration of counterarguments and rebuttals (Jonassen et al., 2009). Although scientific argumentation has been widely studied, there is limited research on argumentation in introductory undergraduate physics problem-solving. To address this issue, we developed prompts to support both problem-solving and argument construction. Our goal was to examine the effects of these prompts on problem solving procedures, confidence and ability to come up with alternative solution strategies. We compared two prompt conditions, with regard to the following research questions:

- Is there a difference between conditions on their appropriateness of problem solutions?
- Is there a difference between conditions on their confidence level of arguments constructed?
- Is there a difference between conditions with regard to both correctness and confidence taken together?
- Is there a difference between conditions on the ability to suggest alternative solution strategies?

METHODS

The study context was a calculus-based course for engineering majors a large, U.S. public university. The course used *Matter and Interactions* (*M&I*) vol. 1 (Chabay & Sherwood, 2015) emphasizing a principle-based approach to solve problems. We developed a task for the 50 minute recitation in the 14th week of the semester after students had received instruction all of the key principles. Each recitation section was assigned to control or intervention conditions. A comparison of performance on prior course exams confirmed no significant differences in conditions. The same TAs taught both conditions. Students worked in groups of four to discuss and solve the task. Each condition received the same problem (Figure 1).

A cylinder of mass M and radius R on an inclined plane has a thin belt wrapped around it. You exert a force of magnitude F on the belt by pulling its end up the plane as shown. Determine the magnitude of the force you must exert on the belt to hold the cylinder at rest. Determine the magnitudes and directions of all of the other forces on the cylinder by objects in its surroundings.

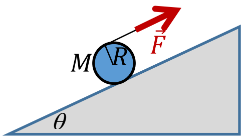

Figure 1. Problem statement for both conditions.

Both conditions (Table 1) used prompts based on a four step strategy (Scott, Stelzer, & Gladding, 2007). The main difference between conditions is that the intervention condition prompted students to clearly articulate their strategy *prior* to mathematical procedures, *reflect on their solution*, and consider *alternative ways* to solve the problem. These argument prompts (Author, 2012) are also consistent with rubrics used by others (Bing & Redish, 2009; Zohar & Nemet, 2002). All these adapt Toulmin's (1958) framework of claim, data, and warrant to facilitate students to blend physical and mathematical reasons for constructing and reflecting on solutions and supporting them with relevant principle-based justifications.

Intervention Condition	**Control Condition**
What principle(s)/concept(s) will you need to solve the problem?	
What assumption(s)/approximation(s) do you need to make to solve the problem?	
How / Why will you apply these principles, assumption/approximation?	(No prompt)
Describe the general strategy you will take to solve the problem.	
Solve the problem. Clearly and neatly work out the mathematical solution	
What is your answer?	
How confident are you about your answer? (circle one) : Very Confident Slightly Confident Slightly Unconfident Very Unconfident	
Reflect on your solution and reasoning. Do the members of your group agree with your strategy? Explain why.	(No prompt)
Can the problem be solved in a different way? If so, explain how. If not, explain why not?	
Describe an alternative problem, seen or previously solved, that has a similar solution strategy.	

Table 1. Prompts used in the intervention and control conditions.

RESULTS

The solutions were coded along three dimensions (i) **Correctness**: Correct solution with supporting justification (coded as 1) vs. incorrect solution or no supporting justification (coded as 0). (ii) **Confidence**: Very or Slightly confident of solution (coded as 1). Slightly or Very Under-confident (coded as 0) (iii) **Alternatives**: Appropriate alternative solution strategies (coded as 1) or inappropriate/no alternative strategies (coded as 0). Two raters coded all responses independently and then discussed codes to reach 100% agreement. The coded data were analyzed using Fisher's exact test to compare the conditions for each dimension and an intersection of (i) and (ii) to compare participants' rates of both correctness and confidence between conditions. Table 2 shows Fisher's test contingency tables with respective p-values. The intervention condition significantly (p-value < 0.05) outperformed the control condition on all measures.

Correctness	Intervention (N = 52)	Control (N = 62)
Correct (1)	41	25
Incorrect (0)	11	37
***p-value* = 0.0001**		

Confidence	Intervention (N = 52)	Control (N = 62)
Confident (1)	41	35
Unconfident (0)	11	27
***p-value* = 0.0163**		

Correct & Confident	Intervention (N = 52)	Control (N = 62)	Alternatives	Intervention (N = 52)	Control (N = 62)
Correct & Confident	36	18	Provided (1)	19	10
Not So	16	44	Not Provided (0)	33	52
p-value = **0.0001**			*p-value* = **0.0163**		

Table 2. Fisher's test contingency tables for (i) correctness (ii) confidence, (iii) alternatives and intersection of (i) and (ii)

CONCLUSIONS

Our goal was to investigate the effect of problem solving and argumentation prompts on correctness, confidence, and ability to suggest alternative solution strategies. Both conditions received prompts to facilitate problem solving. In the intervention condition, prompts required students to clearly articulate their problem-solving strategy prior to moving to mathematical procedures and reflecting on their strategies. We found that the intervention condition was more likely to construct correct solutions, be more confident of their solutions, and suggest alternative strategies. These results suggest that the intervention was effective at improving students' problem solving skills, confidence and metacognitive reflection. These findings have implications for the instructional design to improve students' argumentation and problem solving approaches. Novices often tend to use means ends analysis while solving problems. The use of prompts, such as those used here, may have the potential to wean students away from this approach, making them more likely to solve the problem correctly, become more confident in their solutions, and suggest alternative approaches to solving the problem through the process of argumentation.

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