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Problem Framing Behavior in Statics and Thermodynamics

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Actively working on teaching in a way that uses/develops existing student understanding rather than the traditional method (starting with professor expertise and working backwards) of presenting broad statements important to a field.

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Problem Framing Behavior in Statics and Thermodynamics

Abstract

When engineering students struggle with problems, it usually occurs in the problem framing stage when they are trying to identify the relevant principles and concepts and how they are related to each other (e.g., a free body diagram, vapor dome graph, state diagram). We are interested in identifying when students are experiencing difficulty in this problem framing stage so that we can provide meaningful formative assessment in terms of hints that helps them develop better problem solving skills. To identify when students are experiencing difficulty in problem framing, we collected data on student behavior as they solved problems with different levels of complexity. We used Smart pens to record students' writing/sketching and voice as they used a think-aloud protocol to describe their thought processes. The problem descriptions and information resources were provided within a web-based problem solving environment, ThinkSpace. Our protocol analysis of student cognitive activities during problem solving indicated that there are significant differences in activities between good and poor performing students. This characterization can serve as a basis for identifying students who have having difficulty with problem framing and providing meaningful feedback in order to improve student learning

Introduction

How can we help students improve their problem solving skills so that they are better prepared for their professional careers? We need to focus on developing their problem framing skills. Problem framing is the most critical stage in the problem solving process especially with ill-structured problems that are typical in engineering. It is at this stage that we identify the relevant principles and concepts and how they are related to each other (e.g., a free body diagram, vapor dome graph, state diagram). Diefes-Dux and Salim (2009) as well as Redish and Smith (2008) have studied problem framing from the perspective of constructing a simplified representation of phenomena related to a problem using a model. Not surprisingly, it was found that first year students had difficulties with problem formulation and that more guidance and repetitive practice are warranted (Diefes-Dux and Salim 2009). Correct problem framing is critical at the onset of problem solving because the solution process follows directly from the formulation (Voss and Post 1988). Clement et al. (1981) found that undergraduate students had great difficulty formulating simple math problems (i.e., writing a mathematical expression) that were presented as text descriptions. The students were asked to formulate the problem, but did not have to solve it. In most cases, fewer than 50% of the students could formulate the problem correctly. Similarly in the intelligent tutoring systems literature, Heffernan (2001) identified articulating a mathematical expression as a substantial part of story problem difficulty.

However, methods for measuring problem framing skills are not well-defined, making it difficult to assess student achievement in this area. We are interested in identifying when students are experiencing difficulty in this problem framing stage so that we can provide meaningful formative assessment in terms of hints that helps them develop better problem framing skills. The problem contexts for this study include statics, materials, and thermodynamics. As a first step towards this goal we have studied potential factors that lead to problem complexity which causes difficulties in the problem framing stage. In addition, we have collected and analyzed data on the problem framing stage to develop a metric for differentiating student performance.

Methods

Problem Complexity

As problem complexity increases, students' ability to frame a problem decreases. Therefore, we need a method for assessing problem complexity so that we can create problems in a controlled fashion that achieve the appropriate level of difficulty. Students and instructors were surveyed on problem complexity for problem sets based on the following simple survey instrument based on a Likert scale. This provided a means of calibrating our results in terms of the level of difficulty that students will experience during problem framing.

Please rate how complex (i.e., difficult) you think this problem is.

☐	☐	☐	☐	☐
1	2	3	4	5

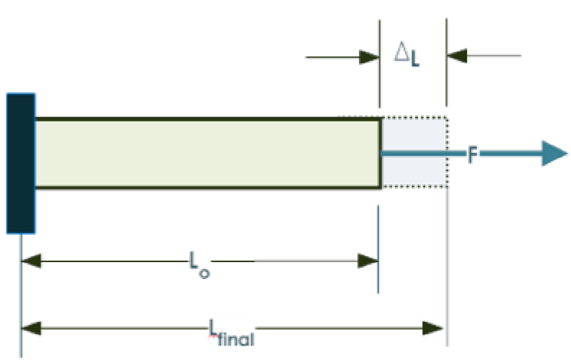
Least complex *Most Complex*

1. *What makes this more or less complex as compared to other problems in this class?*
2. *What might you have trouble with in this problem?*

Students were not asked to solve the problems.

Problem sets were implemented in ThinkSpace, an on-line problem solving environment (http://wiki.its.iastate.edu/display/CBL/Welcome+to+the+ThinkSpace+Wiki) for an introductory mechanical engineering course that focuses on statics and a traditional sophomore level thermodynamics course. Here we show two examples of the problems used in a freshmen level introductory course in mechanical engineering. Problem 1 was designed to be a simple problem and problem 2 was designed to be more ill-structured.

Problem 1 Engineering Strain



Engineering strain, ε, is ratio of the change in an object's length to the object's initial length and is given by,

$$\varepsilon = \frac{\Delta L}{L_0}$$

where,

$$\Delta L = L_{final} - L_0.$$

L_0 is the original length of the object and L_{final} is the object's final length. For an object that started with a length of 3 cm and was determined to have a final length of 1.25", what would be the value of the engineering strain?

Problem 2 Horsepower

A 2405 lb Yaris has run out of gas 1/4 mile from the nearest gas station. By pushing the car, it accelerates from a velocity of 0 m/s to 1 m/s in 1 minute. After the first minute, the car moves at a constant velocity. You can assume that the rolling resistance of the tires is negligible and that the road is flat.

Answer the following questions:

a) How much power, in horsepower, is required to accelerate the car?
b) How much energy is required to push the Yaris the 1/4 mile to the service station?
c) How long will it take to push the vehicle to the service station?

Think-Aloud Protocol

Expanding on the work of Leonard et al. (1996) who categorized problem framing activities into (1) major principles and concepts that are relevant to the problem, (2) justification for including those principles and concepts, and (3) a procedure that can be applied to find the solution, we defined the following categories based on initial data obtained from the Smart pens when students solved statics and thermodynamics problems. Our protocol for problem framing was defined as shown in Table 1. The shaded gray region contains different forms of the same activity in which the student tries to relate multiple phenomena in the problem.

Table 1 Problem Framing Protocol

Category	**Subcategory**
Information	**Reading** the problem description
	Finding information
	Picking information
	Deselecting information
Reasoning	**Connecting** multiple phenomena

	Drawing a diagram/figure
	Writing an **equation**
	Identifying **relevant** phenomena
	Stating an **assumption**
	Describing a relevant **principle**
	Justifying phenomena, assumption, principle…
Metacognitive Activity	**Developing** a plan/approach to solving the problem
	Monitoring their current status
	Evaluating their approach
	Justifying their plan or evaluation
Other	Any other activity (e.g., calculating)

Pencasts and screen captures

Using the problem sets implemented in ThinkSpace, we simultaneously collected pencasts using Smart pens and screen captures using Camtasia. Student data were collected by scheduling individual sessions with each student so that the students would not be inhibited by other students. We found that when multiple students were working in the same room there was little "think-aloud" activity. The graduate assistant responsible for the session read a set of instructions for each student on the concept of "thinking-aloud". In addition, students were shown a video example of another student "thinking-aloud". The data were converted to Quicktime movies compatible with ANVIL (Kipp 2010), a video annotation program. The pencasts and screen captures were coded using ANVIL and the problem framing protocol. The coding category, sub-category, start time, and end time are stored in an XML file that can be used in subsequent analyses.

Results

Problem complexity

The results of the problem complexity survey for the example problems 1 and 2 are given in Table 21. We surveyed two instructors not associated with this study to provide some calibration of student responses. Although there are only two responses, they appear to be consistent with student assessments of problem complexity. These results indicate that these two problems have different levels of complexity.

Table 2 Problem complexity scores

		Average complexity score	
Response Type	**No. of Responses**	**Problem 1**	**Problem 2**
Student	55	1.3	2.7
Instructor	2	1.0	3.0

To characterize the possible factors that contribute to this complexity, we developed a set of factors based on previous research and rated all the problems in the problem sets (8 total) as shown in Table 3. Using the complexity scores for all the problems, we calculated the correlation coefficient (Weisstein 2012) between each of the factors and the complexity score. We selected a threshold of 0.5 or -0.5 for the correlation coefficient as an indicator that a factor contributed to problem complexity. Given the small number of samples (in terms of number of problems), we were not able to quantify any interaction effects between factors.

Table 3 Problem complexity factors

Designation	**Factor**
A	Number of principles from this course
B	Number of principles from other courses
C	Number of concepts from this course
D	Number of concepts from other courses
E	Length of problem description (High, Medium, or Low)
F	Number of related elements but not necessary (i.e., irrelevant)
G	Need to decide on the problem goal (0 – No; 1-Yes)
H	Likely to be an unfamiliar context (0-Not Likely; 1 - Likely)
I	Need to re-represent problem (e.g. graphically) to organize the information (0 – No; 1-Yes)
J	Sub-parts to problem are needed but not provided (0, 1)
K	Need to simplify problem (e.g., make simple harmonic approximation) to make progress (0 – No; 1-Yes)

The results indicate that five factors met the threshold requirement as shown in Table 4. Given the high correlation of factors H and E, either of these factors could potentially be used as a metric for problem complexity. Factor H (*unfamiliarity with the context*) would be more difficult to assess a priori by an instructor than factor E (*description length*). These high correlations also suggest that instructors should be crafting problems with multiple contexts and long problem descriptions, because students need to develop cognitive skills that enable them to be more effective problem solvers when they encounter these types of problems. ThinkSpace was originally designed to address this very issue. Surprisingly, factor J, *sub-parts are needed*, was not highly correlated, which seems counterintuitive. We expected that this factor would contribute to problem complexity because it is not well-defined for the students. One explanation could be that students did not see the need for sub-parts and therefore, did not factor that into their assessment of problem complexity. It is recommended that additional survey data be collected to more fully evaluate potential contribution of the factors to problem complexity.

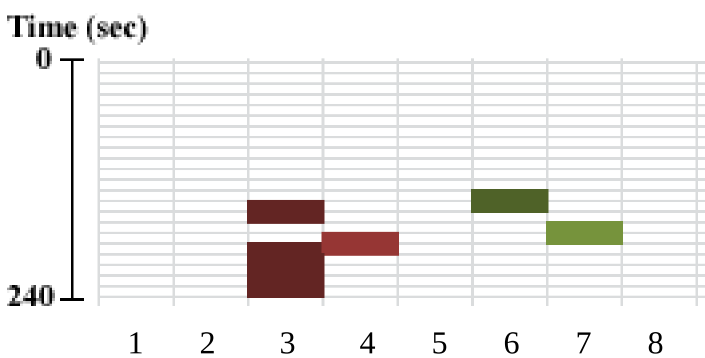
Table 4 Contributing factors

Factor	**Description**	**Correlation coefficient**
H	Likely to be an unfamiliar context (0-Not Likely; 1 - Likely)	**0.81**
E	Length of problem description (High, Medium, or Low)	**0.74**

K	Need to simplify problem (e.g., make simple harmonic approximation) to make progress (0 – No; 1-Yes)	**0.7**
I	Need to re-represent problem (e.g. graphically) to organize the information (0 – No; 1-Yes)	**0.59**
C	Number of concepts from this course	**0.52**
A	Number of principles from this course	0.38
J	Sub-parts to problem are needed but not provided (0, 1)	0.31
D	Number of concepts from other courses	0.01
B	Number of principles from other courses	-0.08

Problem Framing Behavior

For problem 1 the problem framing behavior was consistent across all the students which is not surprising given the low level of problem complexity. Figure 1 shows the typical pattern for the students.



Key
1 Information - Reading
2 Information - Finding
3 Reasoning - Connecting
4 Reasoning – Relevant phenomena
5 Reasoning - Principle
6 Metacognitive - Planning
7 Metacognitive - Monitoring
8 Metacognitive - Evaluation

Figure 1 Problem Framing Behavior for Problem 1

Not surprisingly, students did not search for any information related to the problem because all the information was provided in the description. Metacognitive activities were minimal and were observed early in the problem framing stage as would be expected. They were closely followed by the necessary reasoning activities to set up the problem such that it led to the correct solution. Also note that the time to frame the problem was relatively short (i.e., 6 minutes). This behavior was consistent across all the students.

Problem 2 however, was quite different as very few of the students were able to frame the problem well. In Figure 2 we contrast a good student performance with a typical poor performing student. As compared to problem 1, a much more diverse set of activities occurred and there are noticeable differences between the poor performing students and better performing students. Not surprisingly, there is a significant difference in the total time as the activities for the good performer are much more compact. What is interesting to note is that the metacognitive activities for both types of students have been shifted towards the end of the sequence. This suggests that we need to provide more formal instruction in problem framing so that students learn how to perform metacognitive activities early on in the process.

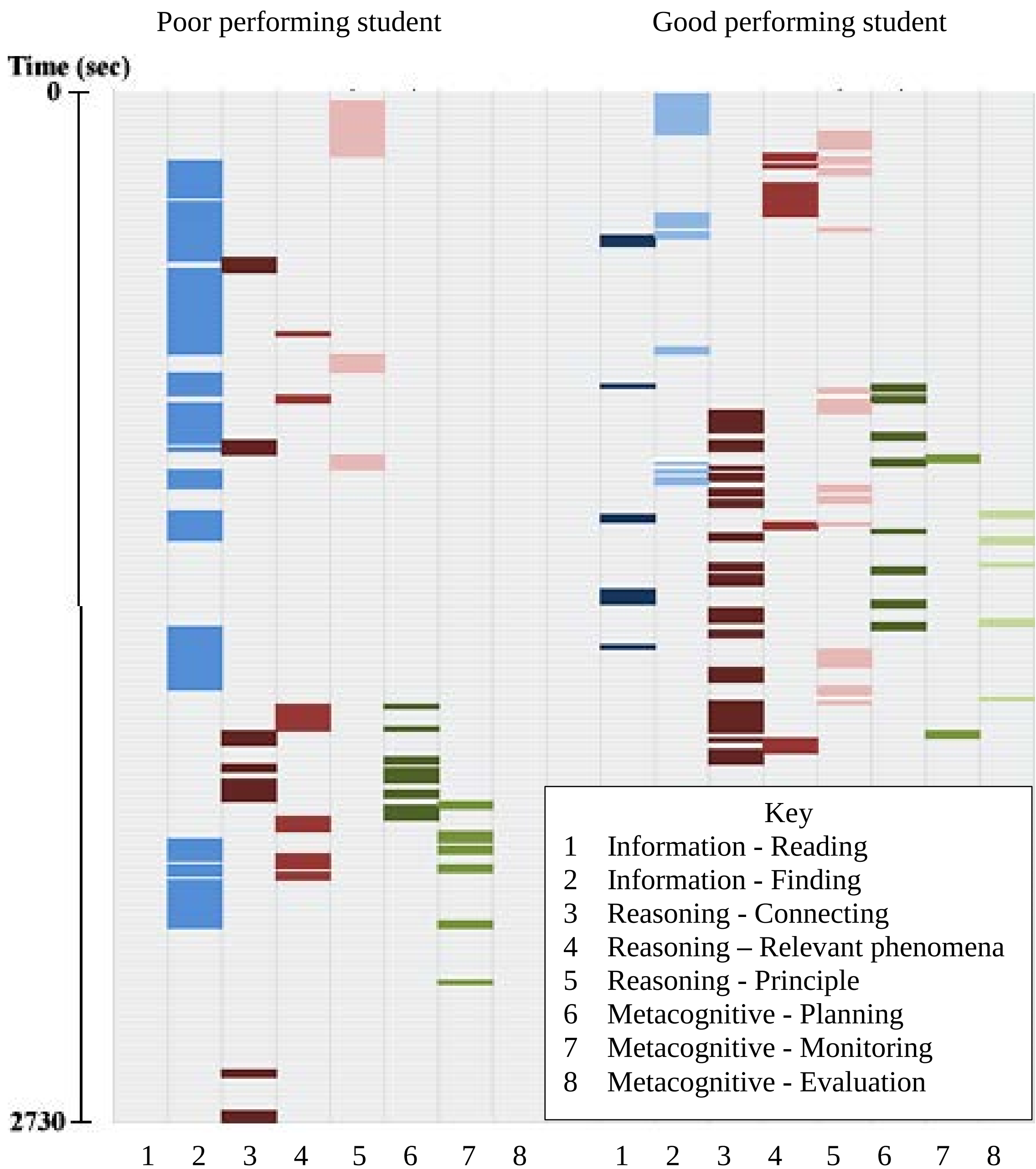


Figure 2 Problem Framing Behaviors for Problem 2

Another stark contrast between the two behaviors is the relative amount and frequency of information seeking behavior for the poor performer versus relatively low usage of information by the better performer. This may be a good metric for identifying the poor performer and providing them with feedback (e.g., a short quiz on key concepts) that would be more beneficial to their learning process than trying to complete the problem. The good performing student exhibits a significant percentage of the time with frequent reasoning activities as they try to address the problem. Most of those activities are focused on relating the different phenomena related to the problem.

Conclusions

Students need to learn how to formulate problems in a coherent manner if they are going to be successful problem solvers in professional practice. Otherwise, they will end up chasing a lot of rabbits down their rabbit holes which leads to excessive engineering costs and schedule delays. In order to measure student performance during problem framing, we developed a new methodology for collecting data on student behavior as they solved problems with different levels of complexity. Smart pens were used to electronically record students' writing and sketching, as well as their voice as they described their thought processes during problem framing. In addition, we recorded information gathering activities as students opened supplemental documents or searched the Internet for related information. Using protocol analysis, we developed a new protocol for problem framing and analyzed student cognitive activities related to reasoning, metacognition, and information seeking so that we could classify the different types of behaviors. Survey results on problem complexity indicated that five of our factors correlated with perceived complexity, namely, if the problem appears in an unfamiliar context, the amount of information in the description, when a problem needs to be simplified, if we need to create another representation of the problem, and the number of concepts from the course that are included in the problem. These factors can provide guidance in constructing a set of problems of increasing complexity.

From our protocol analysis, we found that the cognitive activities were similar and relatively few in number when students solved low complexity problems. Typically, a sequence of metacognitive activities was followed by a sequence of reasoning activities with little or no information gathering activities during problem framing. With more complex problems the behaviors were strikingly different as the poor performing students appeared to be "stuck" and resorted to primarily information gathering activities that were fruitless. The goal of this characterization is not to provide more evidence that the "better students are better students," but to serve as a basis for providing real-time formative assessment in an online environment. Future work will involve collecting data on these formative assessments to evaluate their impact (if any) on student learning. It is interesting to note that even the better performing students had difficulty with the more complex problems and resorted to some of the behavior observed with the poor performing students. Of particular concern was the lack of metacognitive activities early in the problem framing stage for all students which could be due to a variety of reasons including the "fog" of the problem or perhaps the lack of formal instruction in metacognition and/or problem framing.

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