Documenting the Redesign and Scaling-up of an Ill-Structured Problem

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Engineering education strives to prepare students to solve complex problems within rapidly changing, multi-disciplinary environments [1]. One approach to address this need is to provide students with the opportunity to experience design problems, open-ended problems, and ill-structured problems throughout their undergraduate studies [2]. Unlike well-structured problems and exercises, these problems require students to collect information, evaluate sources, and provide a justification for their work. These processes are required because ill-structured problems are typically noted as having the following characteristics: possess multiple solutions, do not present all problem elements, and require learners to make judgements about the problem by expressing personal opinions or beliefs about the problem interpretation [3]. Through the experience of solving ill-structured problems students have the opportunity to develop skills and strategies that can be transferred to larger design experiences. One challenge with incorporating ill-structure problems in engineering education is providing students with the support they need to develop the skills and strategies to solve these problems, which can be a challenge for students and instructors [5]. To successfully solve an ill-structured problem, students must collect information, evaluate sources, and provide a justification for their work, which is not required to solve well-structured problems. Without appropriate support, students may experience uncertainty about how to start an ill-structured problem, what resources are appropriate, and how they will be assessed by their instructor. Similarly, faculty may face challenges supporting students through the process of completing an ill-structured problem and may not know how to appropriately assess students' work.

Multiple studies in engineering education have sought to investigate the processes students use to solve ill-structured problems [4]–[6]. The outcomes of these studies provide suggestions for how faculty can support their students. We considered the results of these studies when we developed the assignment for our pilot study and in the redesign of the assignment. In addition to studies that have investigated the processes students use to solve ill-structured problems, there has also been work to develop rubrics that align with problem solving processes. One example of such a rubric was developed by Grigg et al. [7]. This rubric was developed based on the steps that students used to successfully solve first-year engineering problems. It also provides detailed feedback about the documentation of each step of the problem solving process and identifies where in this process students made errors [8], [9]. Because of the structure of the rubric and focus on the problem solving process, it can be used to support students as they develop their problem solving skills in engineering [10].

The goal of this work was to redesign and scale-up an ill-structured problem within a first-year engineering course that primarily assigns well-defined and close-ended problems, based on the results of our 2017 pilot study [11]. In the pilot study, the problem was assigned as extra credit and students were invited to complete an open-ended survey. Through our analysis of students open-ended responses we identified that students 1) students did not find it difficult to identify a phenomenon to analyze; 2) students reported struggling to assess the reasonableness of their numeric answer; and 3) students primarily used online resources to gather information but did not justify the use of their sources.

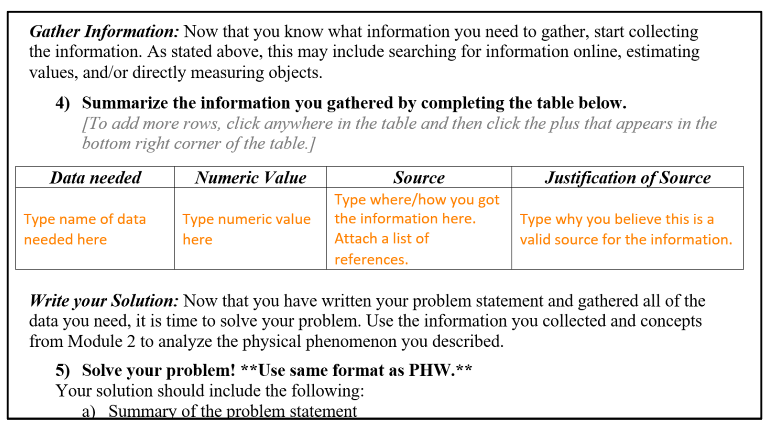
Redesign of Assignment to Scale-up

This work is situated within a first-year physics course for engineering students. The course uses lectures as the primarily means of instruction with well-structure homework problems following. The students also meet for lab two days a week where they do problem sets, conduct labs related to the lectures, and complete one design project over the course of the semester. For the ill-structured problem assignment, students could pick any physical phenomena to analyze using the principles from the course. They were asked to describe the phenomenon, write a problem statement, collect required information/data, calculate a numeric answer, and justify their solution.

Informed by our pilot study, Grigg et al.'s [7] problem solving rubric, and our own experiences, we redesigned the ill-structured problem assignment used in spring 2017 and assigned it to 130 first-year engineering students as a replacement for a 20-point exam question. The assignment required students to identify and analyze a physical phenomenon using physics principles from the course. The module that this was assigned during focused on Newtown's Laws, forces, circular motion, drag, terminal velocity, Newton's Universal Law of Gravitation, and weightlessness. Students were given two weeks to complete the assignment and encouraged to consult with their instructors and teaching assignments. We provided two example problems that were developed by our teaching assistants so that the students would have a better idea of what we were expecting from them. Our redesign focused on the following goals: 1) providing students with scaffolding to complete the assignment, 2) challenge students to think about the reliability of the sources they used, and 3) develop an assessment mechanism to allow for quick turn around and detailed feedback.

Informed by the results of the survey in our pilot study [11], we developed a robust assignment packet that walked students through the steps of solving an ill-structured problem. The packet included prompts that asked students to think about key parts of the process, assess their sources of information, and evaluate their numeric answer. The assignment packet was available to students electronically and was developed as a form in Word so that students could only type in certain fields. There fields were clearly marked with orange text that prompted students to click in the space and begin typing.

The beginning of the assignment packet described the primary goals for the assignment: 1) identify and analyze a phenomenon in the world using concepts from the current module and 2) gather data and make estimates to solve an ill-structured problem (a problem that does not have a single solution and requires some degree of estimation and investigation to solve). We believed that it was important to include the goals for the assignment since it was the first ill-structured problem assigned to them, and we wanted to make sure they did not assume the problem was like the other problems in the course. The rest of the packet, walked students through the major steps needed to design and then solve their problem. These steps included, identification of a phenomenon, writing a problem statement, identifying information needed to solve the problem, gathering information and thinking about the reliability of the source, and writing the solution to the problem. Each step described what students were expected to identify/gather and report, providing them with editable fields to input required information (Figure 1).


Gather Information: Now that you know what information you need to gather, start collecting the information. As stated above, this may include searching for information online, estimating values, and/or directly measuring objects.

4) Summarize the information you gathered by completing the table below.
[To add more rows, click anywhere in the table and then click the plus that appears in the bottom right corner of the table.]

Data needed	*Numeric Value*	*Source*	*Justification of Source*
Type name of data needed here	Type numeric value here	Type where/how you got the information here. Attach a list of references.	Type why you believe this is a valid source for the information.

Write your Solution: Now that you have written your problem statement and gathered all of the data you need, it is time to solve your problem. Use the information you collected and concepts from Module 2 to analyze the physical phenomenon you described.

5) Solve your problem! **Use same format as PHW.**
Your solution should include the following:
a) Summary of the problem statement

Figure 1: Screen shot of two of the steps outlined for students in the assignment packet.

Our pilot study revealed that students primarily used online resources to collect the information they needed to write and solve their own problem; however, the students did not provide a lot of detail about how they determined if the sources they used were reliable. We wanted to encourage students to think about the quality of the sources they used, so we included a prompt in the assignment packet under the “gather information section” that required students to write why they believed the source is reliable for the information they collected (Figure 1). When the assignment was presented to in class, we briefly talked about the reliability of online sources and how they can find sources that are reliable.

A major concern in scaling-up this assignment was providing robust feedback to the students in a reasonable amount of time. As such, we looked to the problem-solving literature and identified a problem-solving rubric that focuses on the following steps: 1) identify problem and system constraints, 2) represent the problem, 3) organize knowledge, 4) allocate resources (execution), and 5) evaluate the solution. [7]–[10]. Informed by this work and our goals for our students, we designed a rubric with three major sections: problem set-up, problem solution, and formatting (Figure 2). The problem set-up section provided a mechanism to assess the development of the problem statement, which included identification of a phenomenon, gathering information, and writing a problem statement. The problem solution section assesses the students’ work to solve the problem. This section was broken down into sub-sections that aligned with the steps in the problem solving process identified in Benson et al. [8].

Problem Solving Steps	Documentation			Correctness	Step Score
	Absent	Incomplete	Complete	Errors detract from the step score (-1 pts)	Documentation minus errors
----- *Problem Set-up* -----					
☐ Identify phenomenon from Mod. 2 ☐ Write problem statement ☐ Include picture/diagram to go along with problem statement ☐ Identify ALL information needed to solve problem ☐ Collect ALL needed information	0	4	6	☐ Responses not clearly communicated ☐ Responses lack detail ☐ Problem statement is not complete ☐ Missing information needed to solve problem ☐ Justification of sources are vague ☐ Justification of sources is circular ☐ Numeric values are unreasonable ☐ Missing information about data needed	
----- *Given/Required* ------					
Define the Problem ☐ Summarize problem ☐ Identify desired value & units ☐ Identify constraint(s)	0	--	1	---	
Represent the Problem ☐ Identify known values ☐ Identify a coordinate system ☐ Draw ALL needed FBDs ☐ Draw ALL needed KDs ☐ Label diagrams	0	2	3	☐ Sketch labelled with incorrect values ☐ Missing dimensions ☐ Misidentified known values ☐ Inappropriate or inadequate CS ☐ Missing forces on FBD ☐ Missing components on KD	
----- *Solution* -----					
Complete Required Calculations ☐ Identify ALL relevant base equation(s) ☐ Plug known values into base equation(s) ☐ Document math for all steps	0	4	5	☐ Used wrong/flawed equation ☐ Incorrectly manipulated equations ☐ Missing value in equation ☐ Used incorrect angle ☐ Miscalculation (work correct/value not) ☐ Didn’t carry units throughout problem ☐ Didn’t complete all parts of the prob. ☐ Intermediate rounding ☐ Inconsistent units in calculation ☐ Plugged incorrect value into equation ☐ Plugged in value with incorrect sign	
----- *Answer* -----					
Evaluate and Justify Answer ☐ Check calculations ☐ Check reasonableness ☐ Check units ☐ Write a valid justification for your answers (not just math!) ☐ Justification included for each part of the problem	0	2	3	☐ Unreasonable precision (# of digits) ☐ Physically unreasonable (impossible) ☐ Missing/Incorrect units on solution ☐ Answer is not boxed ☐ Inadequate/flawed reasoning ☐ Circular logic	
----- *Overall-* -----					
Formatting – follow guidelines ☐ Well communicated and organized ☐ Used approved paper ☐ References attached	0	1	2	☐ Missing an identifier (Name, class #, section #, date, problem #, page number) ☐ Neatly written ☐ Rubric not attached ☐ Wrote on wrong side of paper ☐ Pages are not stapled	
				Actual Score	____/20

Figure 2: Screen shot of the rubric used to assess the assignment.

Conclusions and Future Work

Many of our concerns with scaling up this assignment were related to assessing 130 students’ work. We wanted to make sure we would be able to provide detailed feedback so that student could continue developing skills to solve ill-structured problems, but we also wanted to make sure the feedback was provided in a timely manner. Using a structured problem-solving rubric (Figure 2), provided a means to meet both of these goals. It took the instructor about 8 hours to grade the assignment, averaging four minutes per student. While this rubric is specific to our assignment, the overall structure could be translated to other ill-structured problems, where students are given points for gathering the information they need and outlining the set-up for the problem. Recently, Grigg and Stephan [12] presented an updated version to the problem-solving rubric that informed the development of our rubric. Her new rubric still includes the same problem solving steps, but simplifies the assessment. Future work will look at revising our rubric to align with the work presented by Grigg and Stephan [12]. The assignment packet provided the students with a robust structure to support them as they developed their solution. On average, the students scored very well on this problem and met the instructor’s expectations. Future work will specifically investigate the students’ experiences in solving this type of ill-structured problem to learn more about the challenges they face and processes they used. This will inform future versions of the assignment and add to the general knowledge in the problem solving community.

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