Challenge Problems: A Method to Improve Critical Thinking Skills

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***Abstract*—The traditional form-factor and delivery method for homework has become less effective as student attitudes towards homework have changed to reflect access to digital modalities. These elements have created an evolving landscape with respect to role of homework. In a sense, our approach to homework has been influenced by the established culture whereby "it has always been done this way." This work introduces a framework to address these changes while increasing context awareness and proficiency with the overall workflow.**

Performance feedback, overall grade impact and access to relevant examples are among the factors motivating student engagement with homework. As the efficacy of homework has decreased, educators are looking for new learning activities to strengthen student preparation. Ideally, the objective of homework should transition from the reinforcement of ideas to the development of critical thinking skills. Our approach is to introduce an activity to supplement traditional textbook problems in an effort extend the bounds of critical thinking and improve student engagement. Students are presented with a set of open-end problems that challenge them to move beyond the boundaries of their textbook problems. These weekly prompts, referred to as "challenge problems" serve to illustrate concepts in an integrated context.

Student response to the "challenge" problem framework has been positive and evaluation of exam data indicate improved performance on exam questions involving combined concepts. Students also express an improved ability to "start" problems in later stages of the class. In aggregate, they exhibit a greater confidence with respect to critical thinking and recognize the importance formulating an appropriate solution strategy at the onset of the process. The challenge problems have been woven into the course lectures and their solutions often serve to scaffold upcoming lecture material. Several example problems are provided. This technique is well suited for instructors looking to increase student engagement and interactivity in the classroom. Students have reflected that the completed challenge problems serve as reference material for follow on courses.

Keywords—homework; open-ended problems; critical thinking

I. INTRODUCTION

Homework is an essential element in engineering education [1,2,3]. While studies indicate the positive impact of homework on the development of student skills, an optimal form factor remains an open issue [4,5]. As the efficacy of traditional homework problems have been influenced by the prevalence of available solutions, educators are looking for new out-of-class learning activities to compliment existing student resources. From the students prospective, key motivators are performance feedback, overall grade impact, confidence building and access to relevant examples [6]. Furthermore, the role of homework is dependent upon the curriculum stage; as students progress from introductory to advanced courses, the objective and focus of homework should transition from the reinforcement of ideas to the fostering of critical thinking [7]. This work outlines a framework to address these requirements and demonstrates application to a junior level mechanical engineering course.

Perhaps the most significant impact to the traditional homework paradigm has been the recent increase in the availability of digital solutions [8]. Student access to online modalities such as discussion forums have influenced their expectations with respect to the availability of engineering solutions. As a consequence, students routinely engage in the habit of "searching" for solutions instead of producing them. While this practice has the positive attribute of providing a resource for self-examination, it presents new challenges with respect to student motivation, academic integrity and fostering intended learning objectives.

While standard textbook problems offer a valuable learning experience, they often do not promote or exercise critical thinking skills at a higher cognitive level. Typically, these problems are well formed and target relevant material related to the most recent topics discussed in class. This type of focused review is essential to build fundamental skills. However, these problems often do not integrate prerequisite concepts or challenge the students to engage higher cognitive approaches. Studies have shown that students benefit from the examination of open-ended problems that integrate a spectrum of concepts [9].

Our approach is to assign a weekly set of traditional problems and provide solutions at the same time. These problem sets have focused prompts and directly reinforce topics recently discussed in class. Work product is not collected and periodic quizzes serve as an assessment related to these skills. To complement this activity, a weekly open-ended problem is assigned as graded material and is returned with detailed instructor feedback. These problems are referred to as "challenge problems" as they typically synthesize elements from prerequisites, current course material and industry relevant conditions. The challenge problem is designed with a certain level of ambiguity and seeks to push the envelope of critical thinking skills. For example, a challenge problem may present a complex mechanical system characterized by multiple failure paths with the prompt "how can this system fail?" Students are encouraged to leverage their entire knowledge base rather than the immediate topics just covered in class. The objective is to present an "approach" to the problem rather than to identity the "correct" answer commonly encountered in traditional problems. To this end, the assessment significantly emphasizes the *workflow* used in the adopted problem solving approach. This method brings problem context to the forefront.

The student response has been positive and evaluation of exam data indicate improved performance on exam questions involving combined concepts. Students also express an improved ability to "start" problems in later stages of the class. In aggregate, they exhibit a greater confidence with respect to critical thinking and recognize the importance formulating an appropriate solution strategy at the onset of the process. The challenge problems have been woven into the course lectures and their solutions often serve to scaffold upcoming lecture material. Student questions invoked through the challenge are often a catalyst for productive classroom discussion as the students share a common vantage point. This technique is well suited for instructors looking to increase student engagement and interaction within the classroom. Limiting the challenge to one comprehensive problem per week allows students the time to prepare a detailed well thought out solution. Students have commented that the completed challenge problems serve as reference material for follow on courses.

II. Approach

A. The "Challenge" Problem

Students often frame their approach to problem solving based the most recent topics presented in class. It can be argued that their thought process has been conditioned by the narrow focus typically exhibited by "end of the chapter" textbook problems. While these problem sets are essential for the reinforcement of concepts and provide basic context, they frequently skew the students' thought process toward their targeted subject matter and thereby do not promote critical thinking as related to a system as a whole. Textbook problems utilize simplified situations to illustrate fundamental concepts and lead the student either by prompt or presentation of an idealized system. To illustrate this process, consider the structural system shown in Figure 1a. The original prompt required students to determine the width of the plate "a" after documenting the ultimate bonding stress between the concrete and the steel. Combined with the absence of the allowable tensile stress of the steel, this presentation leads the student to focus their attention toward the shear bond between the concrete and steel. Based solely on this bond, the student will size the plate without consideration of the additional modes of failure that are also dependent upon the plate width. Reworking the prompt to read, "Identify all modes of failure present in the system shown" engages the student at a higher cognitive level. This prompt typically produces students responses characterizing varied failure conditions illustrated in Figure 1b; (1) the rope fails in tension, (2) the steel plate fails in tension at the minimum cross section, (3) the plate fails at the stress concentration associated with the hole, (4) the steel plate fails in single-line shear just above the hole, (5) the bond between the concrete and the steel fails and (6) the clamp bands forming the rope connection fail.

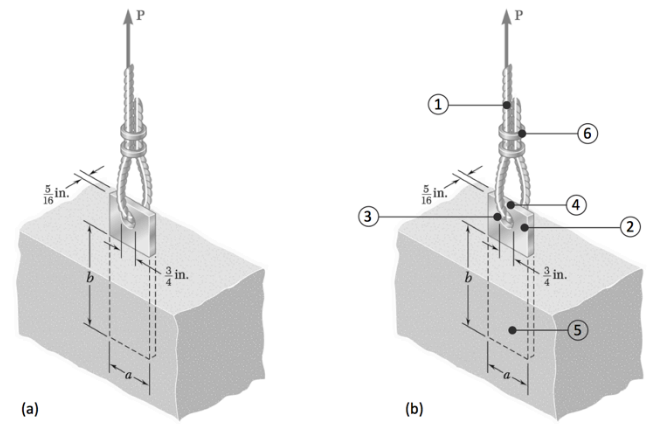


Fig. 1. Structural Failure of Steel Plate Embedded in Concrete Block (a) Idealization Provided with Problem Prompt, (b) Student Identified Failure Modes. Adapted from Reference 1.

The original problem prompt was offered as a text "end of chapter" problem early in the mechanics track as part of a sophomore course. At that point in the curriculum, students have a knowledge base limited to shear and therefore should be expected to identify only the shear mode of failure. Returning to this problem in a junior year course with the modified prompt offers an opportunity "challenge" to the students' approach to problem solving. Once the students have been exposed to the fundamental concepts associated with all potential failure modes, they are in a position to practice their critical thinking at system level. It is at this point we can be begin to ask them to call upon their entire knowledge base to gain a deeper understanding of interacting mechanisms. As all aspects of design are related to a system, students should develop the skill to look at the system above and pose probing questions: What do know about this system; What are the governing mechanisms; What information would I need to evaluate the system; What is the limiting mode of failure? This problem involving a steel plate embedded in concrete formed the basis for the author's initial challenge problem presented to a junior level mechanical design course. Given the practical nature of this system, students can also draw upon their intuition and experience to assess the potential failure paths. This problem has been used with two cohorts (nearly 280 students in total), approximately 15% of the students will identify all six potential failure modes while all of students can identify at least three.

Following the identification of potential failure modes, students working the challenge problem where asked quantify the data necessary to perform an appropriate engineering analysis. Students were encouraged to use references provided with the course syllabus or utilize web-based searches. These data would typical involve material property information and limiting strength conditions as presented in commonly available in engineering reference literature. Students are instructed to develop a detailed analysis for each of the failure modes based on assumptions unique to their approach. They are prompted to compare each mode and determine the limiting case for the system. Students are encouraged to discuss their adopted approach in-class. For example, when given the prompt "what did you learn about the system" a student may respond, "If a ½ diameter medium gauge industrial rope is used, the rope will fail in tension well before the bond strength between the concrete and the steel is exceeded." This approach stimulates productive classroom discussion when reviewed, as there is a wide spectrum of approaches adopted among the cohort.

In developing challenge problem sets, "challenge" does not necessarily imply or require "complexity." While complexity may offer inherent challenge, it may not provide an opportunity to foster critical thinking. The problem should be sufficiently rooted in familiar concepts so as not to overwhelm the student. The problem illustrated above demonstrates that a change in context with respect to a relatively simple system can challenge the student to extend their thinking. Creating new paths of thought while illustrating the links between classical problems and realistic systems should be the primary objective. In general, the following characteristics are suggested for challenge problems.

Open-Ended Format – The challenge problem should have minimum structure and a degree of indeterminacy to provide the latitude for students to formulate solutions based on assumptions that they are required to make. For example, omitting key dimensions or properties will require the student to develop assumptions in the context of the working system.

Integrated Context – The prompt should consider the inter-dependence of mechanisms and concepts. Framing the problem within the context of a familiar engineering system demonstrates the system nature of engineering analysis.

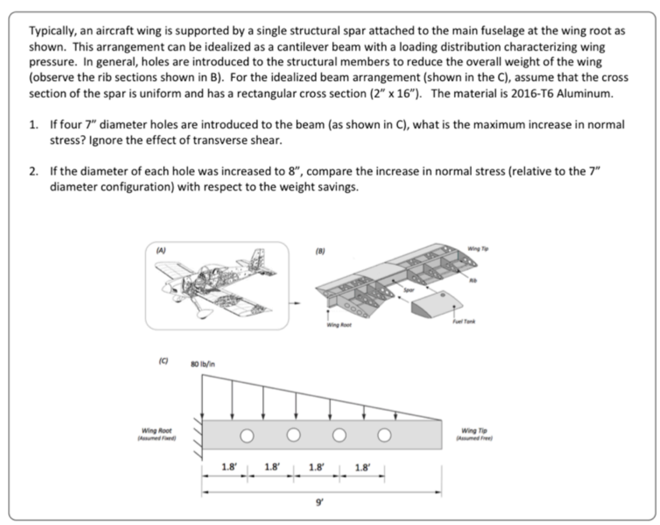
Require the Use of Prerequisite Material – Instructors should reinforce the importance of perquisite material by including prior concepts in the challenge problem. The material could also stem from related tracks of study.

Require the Use of Engineering References – Students should practice searching commonly available sources for engineering data. The instructor should encourage the importance of accurate and appropriate data sources. If professional standards apply, the challenge problem provides an opportunity to demonstrate the standard in context.

Present a "Challenge" – The prompt should include an element that requires the student to go beyond the boundaries of the textbook review problems. Combining concepts, searching for engineering data, developing driving assumptions and professional context are among elements that can create an opportunity to challenge the student.

B. Sample Challenge Problem

Figure 2 illustrates a sample problem using the "challenge" format. This problem combines several fundamental mechanical concepts within the context of an aerospace structural frame. Students recognize the idealization of the wing bending behavior as cantilever beam. While the beam analysis is a straightforward process, the student must recognize and comment on the significance of the assumed loading and boundary conditions as related to the aircarft structural spar assembly. Additionally, the treatment of the stress concentrations developed by the circular cutouts requires the use of reference materials outside of the textbook. Several references are recommended and made available in the school library.


Typically, an aircraft wing is supported by a single structural spar attached to the main fuselage at the wing root as shown. This arrangement can be idealized as a cantilever beam with a loading distribution characterizing wing pressure. In general, holes are introduced to the structural members to reduce the overall weight of the wing (observe the rib sections shown in B). For the idealized beam arrangement (shown in the C), assume that the cross section of the spar is uniform and has a rectangular cross section (2" x 16"). The material is 2016-T6 Aluminum.

1. If four 7" diameter holes are introduced to the beam (as shown in C), what is the maximum increase in normal stress? Ignore the effect of transverse shear.

2. If the diameter of each hole was increased to 8", compare the increase in normal stress (relative to the 7" diameter configuration) with respect to the weight savings.

Fig. 2. Sample Challenge Problem – Structural Analysis of an Airplane Wing Spar. (a) Aircraft System, (b) Actual Wing Structural Assembly, (c) Idealized Wing Spar.

III. Results and Discussion

A. Student Survey

Using a cohort of 148 students, an anonymous survey was performed to collect information on students' interests, perceptions and experiences related to the use of challenge problems. The survey consisted of two parts.

1. Students were asked to state whether they agree or disagree, on a Likert scale, with a series of statements characterizing experiences with challenge problems in the course. The following prompts were presented.

- I actively engage with challenge problems throughout the semester.
- Challenge problems improve my understanding of course material.
- I am more likely to reflect on problem workflow.
- I have an improved approach to problems.

2. Students were asked to rates themselves on a 0-100 scale with respect to success, confidence and motivation across the four problem approach dimensions:

- Identify a problem.
- Formulate a problem.
- Generate a problem solution.
- Ability to evaluate appropriateness of solution in context.

Figure 3 summarizes student perceptions and experiences with the challenge problem concept. The results show a clear indication the majority of the students are actively engaging with the challenge problem concept and report an improved understanding of course materials, workflow awareness and an enhanced solution approach.

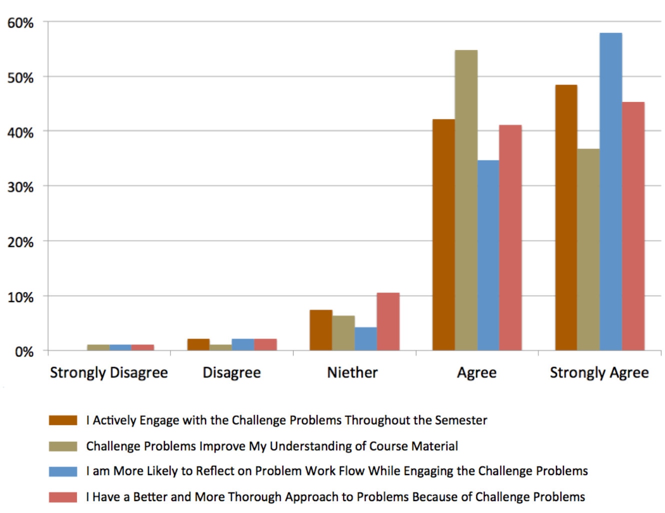


Fig. 3. Student Survey Results – Engagement, Understanding, Workflow Awareness and Approach

Student perceptions with respect to success as related to their experience with challenge problems are summarized in Figure 4. As shown the majority of the students indicate a success rating of at least 70, on a scale of 0-100, with respect to the experience with challenge problem. The ability to "identify a problem" ranked the highest among common characteristics associated with critical problem solving.

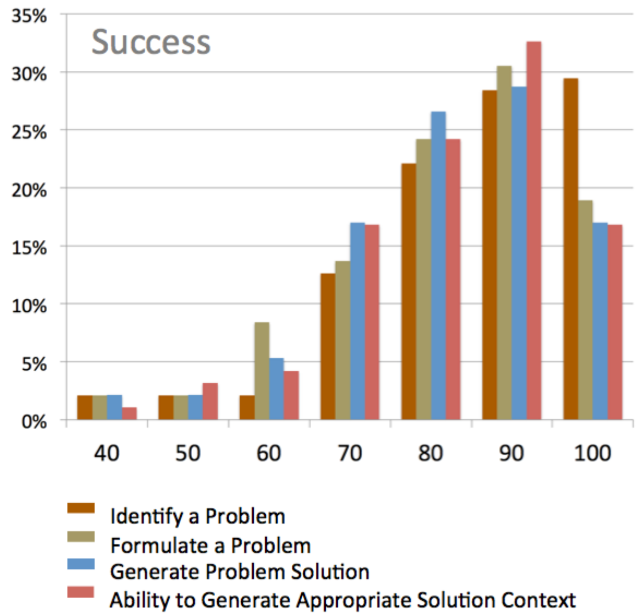


Fig. 4. Student Survey Results – Student Success

Student assessment of confidence level when approaching an open-ended problem after engagement with the course challenge problems is summarized in Figure 5. The pattern is similar to the assessment of success across all four of the problem approach dimensions.

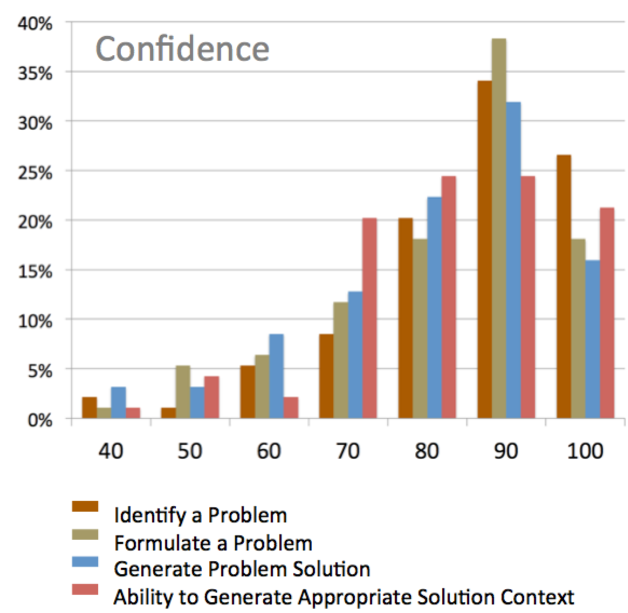


Fig. 5. Student Survey Results – Student Confidence

Student ranking of motivation to engage with the challenge problems is reported in the Figure 6. The results demonstrate a high degree of motivation with respect to student engagement with the challenge problem concept.

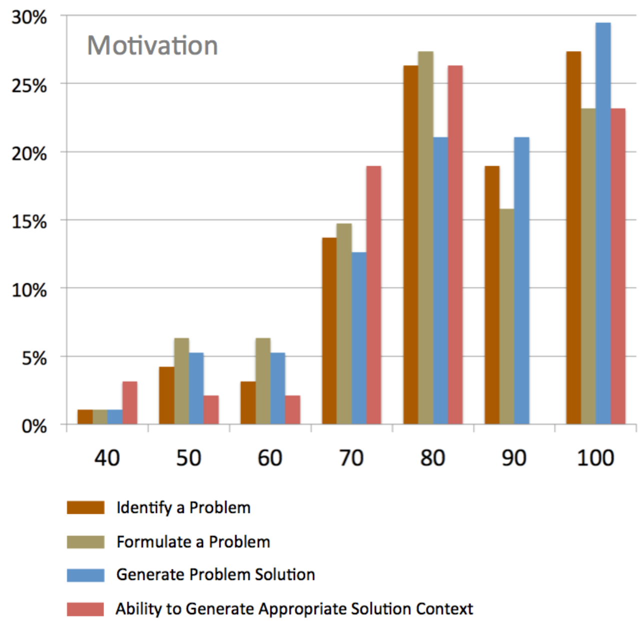


Fig. 6. Student Survey Results – Student Motivation

B. Instructor Reflection

Student questions invoked through the challenge are often a catalyst for productive classroom discussion as the students share a common vantage point. This technique has led to increased student engagement and interactivity in the classroom. The challenge problems become an ideal scaffloding for in-class discussion. Once the problems have been collected the students can be invited to discuss their approach. Experience has shown that a productive student interaction evolves as students share their assessment, assumptions and adopted solution approach. The nature of the challenge problems yield a wide variety of appraches. This becomes an opportunity for the instructor to discuss relative merits, adavantages and drawbacks for each approach. Illustration of the problem workflow has direct context to the student experience as they have worked the challenge problem prior to the discussion and have been confronted with their own limitations or questions.

Limiting the "challenge" to one comprehensive problem per week allows students the time to prepare a detailed well thought out solution. Students should be given time to explore the problem and review reference material.

Students have commented that the completed challenge problems serve as valuable reference material for future course use. Once completed, the student has context-relevant example problem that can be referred to when similar problems are encountered.

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