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Something to Write Home(work) About: An Analysis of Writing Exercises in Fluid Mechanics Textbooks

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Abstract

Writing has been identified as a critical skill and element of the engineering profession, yet it is rarely included in sophomore and junior level courses. Reflecting on our own prior efforts to develop writing assignments for such courses, we became curious about the extent to which the most popular engineering textbooks include writing prompts and related writing activities. This question seemed particularly important given that textbooks often play critical roles in engineering curricula and courses. Textbooks often influence how courses are structured, and reading assignments and homework problems are frequently assigned directly from textbooks. In this project, we systematically searched for and analyzed writing-based problems in six popular fluid mechanics textbooks, with a focus on chapters with similar technical content. We focused our efforts on identifying learning activities that could potentially allow students to practice writing, to learn through writing, and to use writing to relate course content to broader applications and contexts. We discuss our findings by classifying the types of writing prompts found, and we give recommendations for how professors could easily include writing in their courses with some of the textbooks that are already most commonly used. The result of this analysis will be an understanding of how well popular fluid mechanics textbook assignments guide students in writing, and how well the textbooks equip instructors to make use of those assignments. Some possible directions for further research are also proposed.

Keywords: textbook analysis, fluid mechanics, homework problems, content analysis, textbooks, writing prompts

Introduction

As assessments of learning outcomes are increasingly emphasized through accreditation requirements (e.g., via ABET) and other quality assurance initiatives, written communication is one area that engineering instructors often find challenging to incorporate and assess.[1] This is particularly true in large core courses at the sophomore and junior levels. Yet it has also been found that technical writing is best taught during the learning of technical material.[2]

This study is part of a larger ongoing project to understand and expand the incorporation of writing in large-lecture engineering courses, including investigation of faculty perspectives and textbook assignments and assessments.[3] The investigation of fluid mechanics textbooks, as presented in this paper, serves as an example and demonstration of a junior-level engineering class. Furthermore, fluid mechanics is a required course for multiple disciplines and many of the disciplines use similar textbooks for their course. This snapshot of writing-across-engineering will then inform efforts to create a range of writing activities and assessment methods that are mapped to ABET learning outcomes (e.g., criterion 3.g. "an ability to communicate effectively" or criterion 3.h. “the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context”) and can be incorporated in large engineering classes. Our efforts will focus on widely taught courses and topics like thermodynamics, materials, circuits, statics, and dynamics. The analysis and implications presented here of the fluid mechanics textbooks can likely be extended to other courses and topics.

Writing in the engineering curriculum is often only included through incidental writing exercises or as formal writing exercises, and rarely included in sophomore and junior level courses.[4,5] This gap is problematic from a learning-to-write standpoint, as well as a missed opportunity for instructors to leverage writing in the learning of technical content (writing to learn). In general, courses in the sophomore and junior level are lecture-based and the homework is almost exclusively focused on solving numerical problems, often directly from a textbook. In an effort to ease the inclusion of writing in a curriculum, we believe that if textbooks included writing exercises, faculty and teaching staff might more readily include and assign their students writing exercises in these large classes where writing is generally absent. Although there exist books devoted to writing in engineering, we are exploring the writing options from a textbook that students would have already purchased for the course. Furthermore, even if writing exercises are included in an engineering textbook, we have found that modes of assessment and feedback are possibly keeping faculty and teaching staff from using these writing exercises in their classroom. Without scoring rubrics, sample answers, and assessment guidelines, faculty are likely discouraged from including these writing exercises as they lack resources to give good feedback and assign grades.

In order to establish a better sense of how leading engineering textbooks incorporate writing, this work seeks to examine six fluid mechanics textbooks that are regularly used at top-ranked engineering schools. Our analysis aims to identify and quantify the end-of-chapter writing exercises that could potentially be assigned to students, including the number and types of writing prompts included. Furthermore, we report on our initial efforts to seek out rubrics or assessment guides for such prompts, which may enable faculty to include writing in their classes.

Ultimately, the goal of our larger project is to provide a reference that includes writing prompts, example rubrics, and writing samples as resources to faculty and teaching staff that will make the inclusion of writing in sophomore and junior level engineering courses more exciting and accessible. We will use this data to identify areas in which more writing assignments and assessment training would be useful for the teaching of engineering. This paper will likely be of particular interest to faculty and staff interested in using writing to support a variety of technical, professional, and global learning outcomes in core engineering courses.

Literature Review

Despite a growing body of scholarly work on engineering communication, writing, and related topics,[6] we are not aware of any prior literature reporting how writing has been incorporated in technical textbooks in engineering or other STEM fields. However, one study by Wolfe[7] did highlight significant gaps and shortcomings in how twelve popular technical communication textbooks treated writing styles and genres that are most typically encountered in science and engineering. A handful of papers have also performed systematic analyses of textbooks focused on other themes. For instance, Purzer and Chen[8] carried out an in-depth study of fourteen first-year engineering textbooks to examine how they addressed decision-making and related themes. Additionally, Sangam and Jesiek[9,10] analyzed how six introductory textbooks treated DC circuit theory based on a conceptual understanding framework. Casting a wider net reveals other notable examples, including systematic analyses of introductory computer science,[11] programming,[12] and web engineering[13] textbooks. Still other papers have suggested useful categorization schemes for STEM-related writing-to-learn exercises, e.g., Braun's[14] discussion of personal, expository, critical, and creative writing prompts in undergraduate mathematics courses. We intend for our study to contribute to the extant literature on writing-to-learn strategies and systematic textbook analysis in engineering and other STEM fields.

Methods and Rationale

Textbook Selection

In order to gain an understanding of the presence or absence of writing assignments in large enrollment fluid mechanics courses, we began with a list of the top ten engineering programs in the U.S.[15] Through an online search, we were able to find syllabi or textbook requirements for introduction to fluid mechanics courses in these schools' civil and mechanical engineering programs. While we were not always able to locate the current requirement for each school, all officially required texts listed online had been posted within the last 4 years. Among these top programs, one book was the overwhelming leader: Munson et al.[16] (8 adoptions). In addition to Munson et al., we used other textbooks adopted or listed as key references by at least 2 different programs: Elger et al.[17](3), White[18] (2), Cengel & Cimbala[19] (2), and Smits[20] (2), and Pritchard & Mitchell[21] (2). Table 1 provides the details of the six texts selected for our analysis.
While this sample of textbooks is not comprehensive, it can reasonably be construed as representative. These books represent the most common textbook resources available for students and instructors at the most highly ranked engineering programs in the U.S. Understanding the kinds of writing prompts provided in this sample of textbooks helps shed light on the state of the discipline regarding writing in core engineering textbooks and courses.

Of course, the existence of homework assignments involving writing does not necessarily mean that these homework assignments are actually being used by engineering instructors. We treat these problems and types as merely a baseline demonstrating the *availability* of writing prompts for engineering professors teaching in large enrollment sophomore and junior level classes. If writing-based problems are few or missing altogether, then it seems unlikely that instructors will supplement the homework problems in the textbook with their own problems that rely on writing.

Quantification and Categorization of Writing Questions and Prompts

To quantify the number and types of writing questions included in the six textbooks, we selected a single, similar, representative chapter from each textbook to survey. For all texts, this was the chapter that dealt with the Bernoulli Equation, one of the key concepts learned in any introductory fluid mechanics course. For all texts we verified that this chapter's end-of-chapter questions and writing content were indeed qualitatively and quantitatively similar to other chapters in the books. We defined questions to "involve writing" if the question or its parts – as phrased – could not be answered with either numbers alone or single word responses (e.g., "yes" or "no", "higher" or "lower", "Point B", etc.).

Table 1. Fluid Mechanics Textbooks and Chapters Selected and Analyzed

Textbook Title	Author(s)	Year, Edition	Chapter Analyzed	Pages Analyzed
Fluid Mechanics: Fundamentals and Applications	Cengel, Y.A., & Cimbala, J. M.	2014, 3rd Ed.	5. Bernoulli and Energy Equations	230-242
Fundamentals of Fluid Mechanics	Munson, B.R., Okiishi, T. H., Huebsch, W.W. & Rothmayer, A.P.	2013, 7th Ed.	3. Elementary Fluid Dynamics – The Bernoulli Equation	141-156
Engineering Fluid Mechanics	Elger, D.F., Williams, B.C., Crowe, C.T., & Roberson, J.A.	2013, 10th Ed.	4. Bernoulli Equation and Pressure Variation	157-168
Fluid Mechanics	White, F.M.	2011, 7th Ed.	3. Integral Relations for a Control Volume	195-227
A Physical Introduction to Fluid Mechanics	Smits, A.J.	2000	4. Introduction to Fluid Motion II	142-152
Fox and McDonald's Introduction to Fluid Mechanics	Pritchard, P.J., and Mitchell, J.W.	2015, 9th Ed.	6. Incompressible Inviscid Flow	236-243

Three of our co-authors individually analyzed one or more textbook chapters. This analysis informed the creation of a categorization scheme to allow categorization of all end-of-chapter writing questions found in the textbooks. After a first round of sorting the prompts into these categories, a number of ambiguous and uncertain cases were discussed in a larger group meeting with all of the study co-authors. The categories were revised based on this discussion, and then used by the original coders to review, finalize, and compile all of their categorization decisions. The final categorization scheme is composed of the following types of writing questions we identified, with textbook authors and specific problems identified parenthetically:

1. *Explain-a-problem:* For this type of writing prompt, students are asked to write more formal descriptions of their numeric solutions to standard homework problems involving calculations, and beyond listing calculations and assumptions. This type of writing prompt has been used in large engineering courses to some degree, with the benefit that it can be easily added to any standard end-of-chapter calculator problem.[22,23] In the end-of-chapter problems, this writing prompt was most commonly specified by simply appending the words "explain" or "explain your answer" to the end of the question. These problems sometimes involved more specific requests for explanation, such as "Why doesn't the answer depend on the properties of the jet?" (White 3.46) and "Why might this result be different from that obtained in part (a)?" (Smits 4.23). It should be noted that any homework problem can easily be modified to an "Explain-a-problem" problem, with the simple addition of the "Explain" directive at the end of the numeric question.

2. *Real-world example:* Several texts had writing-based questions that ask students to present, describe, and/or discuss a real-world example or application of a concept covered in the chapter (without relating it back to the concepts). The Munson et al. text used this prompt extensively, asking students to "print a photograph or image" or "describe a few examples (include photographs/images) of turbines…" Other examples of this prompt include questions asking students to write brief reports on fluid mechanics topics or devices related to the chapter content, e.g., "Research available techniques for airflow measurement…" (Cengel & Cimbala, 5-144).

3. *Conceptual questions:* We found many writing prompts that asked students to define, explain, and/or identify learning concepts from the chapter in question. These prompts ranged widely in their complexity, ranging from asking students to simply re-state definitions (e.g., "What is the definition of a steady flow?") to fairly complex questions involving critical thinking and determinations/applications of unstated concepts (e.g., "Can water or oil with a specific gravity of 0.8 go over a higher wall? Why?" Cengel & Cimbala 5-36C). We further classified these conceptual questions into the following three sub-categories:

   3a. Definition: These writing prompts ask students to simply state, re-state, or paraphrase concepts, assumptions, or terms from the chapter. These questions seem to assume that students would simply look up these terms in the chapter and re-state them in their own words, and as such these question involved minimal generative writing and almost no critical thinking. Examples of this type of prompt include: "Define mass and volume flow rates.

How are they related to each other?" (Cengel & Cimbala 5-2C) and "Under what conditions does Bernoulli's equation hold?" (Smits 4.1).

3b. Explanation of a concept: For this type of prompt, the text asked students to explicitly explain or apply a <u>stated</u> concept and/or discuss its assumptions and limitations, typically in the context of a given situation, diagram, or real-world example. The concept is named explicitly in the problem statement, and the student must figure out and explain how to apply the concept in the context of the given situation. An example of this writing prompt, which included description of flight speeds for various aircraft: "…Is it reasonable to use the incompressible Bernoulli equation to study the aerodynamics associated with their flight? Explain." (Munson et al. 3.126) Another example of this type of writing prompt is: "Why do you think the stagnation pressure is sometimes called the 'total pressure?'" (Smits 4.3)

3c. Identification of a concept: These writing prompts require students to assess a given situation, image, or solution, and to identify and describe the concept(s) relevant to the situation. This prompt differs from the "Explanation of a concept" writing prompt because the concept involved is not given to students, who must then figure out the concepts involved on their own. As an example of this type of writing prompt, the White text described how the Alvin submarine left weights at the bottom of the ocean following its descent, and asked students to "…explain, in terms relevant to this chapter, how these steel weights are used." (White W2.9) Another example from the Cengel and Cimbala text described a hose draining water from the bottom of a tank and asked students to "Explain what may cause the water from the hose to rise above the tank level" (Cengel & Cimbala 5-74C).

Results

Number and Types of Writing Prompts

As summarized in Table 2 below, the texts showed varied levels of writing prompts included in the end-of-chapter problems. On average, 16.7% of the problems included writing prompts, with a range from 6.8% (White) to 29.7% (Cengel & Cimbala). While the Cengel and Cimbala text had the most writing problems by number and percentage, it is worth noting that a large percentage of these questions are of the type 3.a, "Conceptual: Definitions," where students are simply asked to re-state definitions or assumptions that are given in the text. If these types of prompts are removed from the tally, the percentage of writing questions in this textbook chapter is a more modest 23%. The text that included the least number of writing prompts was the White text. Ironically, the White text chapters actually had dedicated sections for "Word Problems," but these were a small number of problems relative to the large number of end-of-chapter problems (the White text had the greatest number, 207, of total end-of-chapter problems, by far).

Table 2. Number and Types of Writing Prompts for Select Fluid Mechanics Chapters

Textbook		Cengel & Cimbala[19]	Elger et al.[17]	Munson et al.[16]	White[18]	Smits[20]	Pritchard & Mitchell[21]	Relative % for each prompt[a]
Number of Each Type of Writing Prompt	Explain a HW Problem (1.)	7	1	3	6	1	7	23.6%
	Read World Example (2.)	2	1	8	1	0	0	11.3%
	Conceptual: Definition (3. a.)	13	2	0	0	1	0	15.1%
	Conceptual: Explanation of a concept (3. b.)	13	7	3	3	6	0	30.2%
	Conceptual: Identification of a concept (3. c.)	9	3	4	4	1	2	21.7%
Total Writing Prompts in Chapter/Total End-of-Chapter Problems		44/148	14/112	18/135	14/207	9/42	9/90	
Percentage of problems with writing prompts (%)		29.7%	12.5%	13.3%	6.8%	21.4%	10.0%	

[a]Total writing prompts: 44+14+18+12+9+9=106. Relative % given as sum of found prompts divided by 106.

Textbook Summaries and Analysis

As part of our analysis, the research team also examined each textbook for features that might be synergistic with supporting writing. Below, each textbook's overall organization is described and descriptions given by the author(s) are provided if applicable.

Cengel and Cimbala: The preface of this textbook offered some insight into how the end-of-chapter problems were organized and how the authors intended for them to be used. In the section titled "A Wealth of Realistic End-of-Chapter Problems," the authors describe that "within each group of problems are *Concept Questions*, indicated by 'C,' to check the students' level of understanding of basic concepts." Furthermore, there are problems designated as *Design and Essay* problems, which "are intended to encourage students to make engineering judgments, to conduct independent exploration or topics of interest, and to communicate their findings in a professional manner." The section ends with "answers to selected problems . . . listed immediately following the problem for convenience to students" (p. xx in the preface). It is further worth noting that some of the problems in this textbook closely resembled engineering practice activities, such as contacting manufacturers for information about the specifications of their products. For example, Problem 5-145 is as follows:

> Computer-aided designs, the use of better materials, and better manufacturing techniques have resulted in a tremendous increase in the efficiency of pumps, turbines, and electric motors. Contact one or more pump, turbine, and motor manufacturers and obtain information about the efficiency of their products. In general, how does efficiency vary with rated power of these devices? (p. 242)

Such a problem can easily demonstrate to students a typical activity they might need to do as part of a position in industry, including the ability to perform and discuss a comparison of devices.

Elger et al.: This textbook included many different types of writing scattered throughout the end-of-chapter homework problems, with no dedicated sub-sections. However, it offered little to no support for students regarding appropriate types of responses for different kinds of questions. At the beginning of the textbook, detailed information about the proper method for writing engineering homework solutions was outlined, including all example problems within each chapter being written with all these necessary components of a "complete" engineering solution (ex: problem statement, assumptions, given, find, solution). However, in contrast, no information was provided regarding correct structure, composition, or length of solutions to written problems. This was generally true of all texts, as discussed in the next section.

Munson et al.: This text included writing-related elements of several kinds. For instance, each chapter featured several "Lifelong Learning Problems," where a "state-of-the-art" fluid mechanics situation or device was introduced, and students were asked to write a research report on the topic. Also, every chapter of the text had several questions asking students to obtain an image or photograph of a situation related to the concepts in the text, and to write briefly about the image. Such prompts were unique to this textbook, and may be an effective way to convince students of the relevance of the material they are learning.

White: The White text had a dedicated section of "Word Problems" (generally less than 15 questions per chapter), which were definitely writing-intensive conceptual questions. However, because of the large number of end-of-chapter problems – White's text had by far the most end-of-chapter questions – the overall percentage of writing questions is low for this text. Many of the "Word Problems" were engaging questions, posing a scenario and asking students to explain it in terms of either stated or unstated concepts (e.g. "Explain in words why a spinning ball moves in a curved trajectory…", W7.12).

Smits: The Smits text is a shorter textbook (527 pages) that covers the basic concepts of fluid mechanics at an introductory level, and it works to provide students with physical explanations and linkages to the myriad mathematics associated with (even) introductory fluid mechanics. The Smits text has a correspondingly lower number of homework problems at the end of each chapter (typically about 30, as opposed to more than 100 for the other texts). However, the first problems for each chapter were generally writing questions, often asking students to interpret equations from a more physics-based perspective (e.g., "Why do you think (the stagnation pressure) is sometimes called the total pressure?"). Additionally, for later questions that did involve calculations with a writing component, the questions – which we generally categorized as conceptual questions with stated concepts (3.b) – were of a higher level than the other texts, going beyond the simple "Explain…" prompt and asking students to discuss interesting contradictions or elements of their solutions.

Pritchard and Mitchell: This text had a relatively low number of writing prompts in end-of-chapter problems, most of which we classified as "Explain a HW Problem" (Type 1). However, these writing questions tended to be challenging, targeted questions that had students explain specific elements of their calculation and solutions or extensions of their calculations. For example, students are asked to discuss "what the relation among the three points…. suggest about the flow field" (P&M 6.27) and whether "the actual flow (will) be more or less than (the) predicted flow" (P&M 6.53). The questions appeared to be designed to have students think about their solutions beyond the simple procedure used in the solution. While not counted as writing by our survey, a significant number of end-of-chapter problems in the Pritchard and Mitchell text asked students to graph elements of their solutions, presumably to better understand the implications of the various formulae used in these problems.

Solution Manuals: Writing Problems

Taken together, the textbooks and chapters discussed above provide considerable inspiration for those wishing to incorporate more writing in fluid mechanics courses. Nonetheless, there remains the question of what resources are available for instructors who are considering use of these types of questions and prompts. In essence, while it may be relatively straightforward for an instructor to construct or modify a homework question to involve writing following the examples in the textbooks, the tasks of assessing these written responses and coaching students on their responses are not straightforward, and generally require additional resources in the form of sample written solutions and grading rubrics. To determine what companion materials are provided to instructors and students for written problems, we also examined the solution manuals of the two top-rated texts (Munson et al. and Cengel & Cimbala). These two texts were found to provide varying degrees of support for the questions involving writing, but neither text provided any guidance related to the implementation or grading of these questions.

In the Munson et al. solution manual, solutions to writing questions included little or no writing. Questions prompting students to "explain" their solutions were most often solved in the solution manual using a series of equations punctuated with a final statement addressing the question with a number of equations and statements (e.g., A=B, C=D, and E=F; "Thus, the flow can be considered incompressible," Munson 3.127 solution). This level of explanation was similar to what was found in answers to problems that we classified as not involving writing, i.e., the standard "calculator" problems. Further, many writing questions that involved writing alone (e.g., finding an example and writing about it) were omitted from the solution manual altogether. For solutions in the solution manual where some written explanation *was* provided to the reader, the text often primarily served to mathematically guide the reader through a series of calculations addressing the question, in lieu of an explanation of the concepts and their application, or descriptions of why certain equations should be used.

The Cengel and Cimbala text had more in the way of written, explanatory solutions. Nearly every problem had a "discussion" portion of the solution that provided at least one sentence commenting on the results. In particular, all the questions the textbook labeled as conceptual (designated with a "C" following the problem number) were explained in prose and often included an explanation of the appropriate thought process.

For example, Problem 5-4C states: "When is the flow through a control volume steady?" This problem, which we designated as conceptual-definition (3.a.), was explained in detail in the solutions manual, breaking it up into analysis and discussion pieces. This information and explanation in the solutions manual would provide considerable information for an instructor to make a judgment on a student's understanding and assign a grade.

> Analysis: Flow through a control volume is *steady* when it involves **no change with time at any specified position.**
> Description: This applies to any variable we might consider – pressure, velocity, density, temperature, etc.

However, problems in the "Design and Essay" designation were not explained in the solutions manual beyond stating: "Students' essays and designs should be unique and will differ from each other."

It is important to note that although the Cengel and Cimbala solutions manual provided helpful explanations of the conceptual problems, these descriptions and sample writing responses are not intended to be available to students. They are model writing responses that are systematic and would be useful to professors; however, there is no description for students about how a writing response should be structured or any guidance on how it might be assessed. Ideally, a student would be provided a rubric and requirements for their writing assignments, and an instructor would grade and assess those writing responses according to that rubric. In this case, an instructor would have no guidance on how to award partial credit, how to weight writing skill as opposed to quality of reasoning or calculated answers, or how the model answer might serve as a rubric that could actually be applied to student answers.

Discussion and Recommendations

The successful inclusion of writing in homework problems would seem to involve (1) the creation of the problems, for which the textbooks provide some inspiration; (2) the implementation of these problems, for which we find the textbooks provide very little guidance.

Writing prompts

As a whole, the fluid mechanics textbooks examined provide good examples and ideas for different ways to incorporate more writing into student homework problems. If applied, they can serve to promote technical learning and allow students additional opportunities to practice writing, even in courses where writing is traditionally absent. The writing prompts that we have found range widely in their complexity, from the simple writing of definitions to complex questions involving the application of newly-learned concepts to real-world situations. Instructors can additionally leverage these writing questions for other purposes, including the attainment of non-technical ABET outcomes, the development of critical thinking skills in students, and helping students to see the relevance of the technical material they are learning.

The simplest type of writing prompt to construct is the “Explain-a-problem” prompt, which is also the most versatile, since virtually any traditional end-of-chapter textbook “calculator” problem can be modified to have students explain their solutions in writing. These explanations can vary widely in their complexity.[22,23]. The textbooks we surveyed most typically employed this prompt with the simple addition of the instruction “Explain” at the end of a problem, and it was not clear why the various texts chose the selected problems as worthy of additional explanation (and, recall that most of these problems were not “explained” in the solution manual anyway!).

In our previous work incorporating writing into large lecture courses,[3] we found some success in assigning what we called “Take a Side” writing prompts, where students were asked to state and defend a position on a relatively contentious engineering project or idea (e.g., the Keystone XL Pipeline project). The “success” for this prompt was that students were very engaged with the exercise, and it seemed effective in convincing students of the relevance of what they were learning (e.g., pipe flow). This type of prompt was not found in any of the texts examined, but could easily be included with additional, stand-alone writing questions (with or without calculations to support the students' positions).

Support resources for writing problems

It is unfortunately only marginally helpful for textbooks to (for example) remind instructors that they can ask students to explain their answers in writing. What dictates whether instructors actually do ask their students to explain their solutions, or answer a writing question, is likely not the textbook's suggestion, but rather the availability of resources to support the assessment and feedback associated with those collected written student explanations.[3] To that end, our study finds that while textbooks do provide instructors with examples of homework questions involving writing, they provide little in the way of support resources.

What support resources would be helpful for the textbook writing problems? Resources are needed for both the instructors and the students. As a start, sample solutions to the writing questions are needed, in the same way that solutions to numeric problems are provided, both in the solutions manual and in the companion student study guides. Students need exemplars to illustrate the expected qualities of high-quality written responses, and to provide an example of the expected format, given how varied one's "explanations" of a problem can be. Additionally, instructors themselves likely need examples of written solutions, since with writing solutions even the instructors themselves may not have a good sense of what they are looking for in the way of grammar, style, length, and tone for the students' written responses.

Moreover, instructors may want access to a range of differently-formatted written solutions to the same question, in order to see the possibilities of the assignment. For example, if an instructor simply wishes to leverage writing to enhance learning of technical skills, an informal, loosely-written response that is technically correct may be appropriate. In the opposite extreme, if the instructor wishes to engage the writing question in order to additionally teach proper writing techniques, then a more formal example would be helpful, especially to provide as an example for the students. An even richer resource might be for the textbook to provide exemplars demonstrating high, average, and low achievement (using the exemplars almost in the manner of a rubric).

Of equal importance to providing example writings, we believe that additional, explicit instructions are necessary to clarify the nature of expected student responses (the example solutions essentially imply these instructions, but explicit instructions are obviously more direct). These instructions would specify the required length (e.g., "In one sentence, …"; "In one paragraph, …", "Write a one page report," …), audience (e.g., instructor, fellow student, general public, …), and any additional format requirements (e.g., "Without using equations, ….", "In your own words, …", "include the words 'steady' and 'uniform' in your response").

Once the student papers are collected, instructors and graders need a means to assess the written responses and provide feedback to students. This is one of the most daunting tasks for engineering faculty, since while they are generally strong writers by virtue of being academics, they are not well-trained or experienced in providing guidance to other writers, especially writers at the undergraduate level.[3] In our own previous efforts to include writing in a large fluid mechanics course, we unwittingly ended up hyper-focusing on grammatical mistakes in our assessment of short paragraph assignments, which both undermined our ability to leverage the exercise to enhance student learning of technical material, and led to student resentment of the exercises.[3]

Simple rubrics would be helpful additions to instructors' manuals. A simple rubric might break down a problem into percentages, with, for instance, a certain percentage for accuracy of calculation, a certain percentage for identifying the correct concept, a certain percentage for correctness of reasoning, a certain percentage for clarity of writing, and a certain percentage for writing mechanics. The instructors' manual might include answers or details in parts of the rubric, but even student solutions should include the recommended percentage breakdown so that they understand how the writing part of the problem will be assessed.

Conclusions and Next Steps

Based on the preceding analysis and discussion, we conclude that:

1) When leading fluid mechanics textbooks include writing in their end-of-chapter problems, these prompts and activities generally fall into five major categories or types. The various types of prompts vary in their complexity, and can be leveraged in assignments to target different outcomes.
2) The most common types of writing prompts and activities in leading fluid mechanics textbooks supplement traditional numerical problems and/or promote conceptual learning. More realistic professional writing tasks are less common, and we find no evidence of textbooks providing students with writing guidelines, resources, tips, etc.
3) Solutions manuals provide relatively little supporting material for instructors, e.g., scoring rubrics, examples of acceptable answers, guidelines for length and format, etc. We hypothesize that the inclusion of these materials would lead to greater inclusion of the found writing elements in end-of-chapter problems.

In our future work, we intend to expand our efforts beyond the textbooks and chapters reviewed here. This will allow us to revise and finalize our classification scheme for writing prompts, which we see as a major contribution of this larger study. Further, we would like to investigate possible differences in the number and quantity of writing prompts appearing in a variety of engineering science fields and subfields. We aim to expand this research effort to include similar textbook review of various subfields of engineering topics, such as statics, dynamics, electrical engineering, materials engineering, aerodynamics, and others.

Ultimately, we would like to develop the findings of this work into a useful set of online resources that would be made available to engineering faculty to help them incorporate writing into their engineering courses. Such a resource would include strategies for transforming existing prompts into writing prompts, providing writing rubrics to students and faculty alike, assessment and feedback strategies, and sample student work.

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