



Why Not Ask Students to Explain Themselves? Enhancing Conceptual Testing with Technical Writing

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Note: Based on reviewer comments this paper is submitted to the ASEE 2015 Annual Conference as a “Work-In-Progress” that is intended to be presented at the ChE Division Poster Session.

1. Introduction

Recently a great deal of exciting work has been performed on concept-based instruction in chemical engineering, in particular the efforts associated with the AIChE Concept Warehouse (AIChE-CW)^{1,2}. The AIChE-CW provides chemical engineering educators with instruments for evaluating students’ conceptual understanding of course material. Conceptual learning is not well-served by traditional engineering coursework, which often places great focus on working equations computationally rather than actually understanding the material^{3,4}. Traditional engineering coursework often leaves students in a position where they can construct and solve a series of equations to find a requested answer, but they do not understand “why” or even “what they just did”⁵. This is often evidenced on exams when students do not realize a computed answer is incorrect by multiple orders of magnitude. Indeed, poor conceptual understanding has also been observed in young engineers during their work in industry^{6,7}. With this in mind, instruments which can effectively teach and evaluate engineering students’ conceptual understanding are key tools for modern engineering educators.

In addition to the struggles of engineering students to achieve conceptual understanding, recent engineering graduates’ grasp of written communication and associated skills is often below that expected by their anticipated positions in the modern workplace⁸. Pedagogical research has found that writing assignments effectively facilitate learning by forcing students to explore connections and patterns in the studied material^{9,10}. These benefits of writing assignments are enhanced in fields such as engineering, since students are rarely assigned reflective writing tasks and thus have few opportunities to develop associated abilities^{11,12}. However, conceptual testing instruments in the chemical engineering field generally involve multiple choice questions rather than written responses.

This paper discusses the construction and use of short, written-answer “Concept Quizzes” in the chemical engineering curriculum. These quizzes are intended to evaluate conceptual knowledge while forcing students to communicate answers in written format. The objective of this work is to improve students’ understanding of critical engineering concepts while developing skills in effective written technical communication. A consideration in this study will be the role of diversity in the effectiveness of Concept Quizzes; for instance, English-as-a-second-language (ESL) students may be exceptionally challenged to understand written question prompts as well as explain complex technical phenomena in written English.

Note that this study is planned to be completed through the Summer 2015 semester; at the April 2015 conference proceedings submission deadline, student data was not available for analysis. Additional data collected through the Summer 2015 semester will be presented at the 2015 ASEE Annual Conference.

2. Description of Written Concept Quizzes

Written Concept Quizzes were first introduced by the author into a Transport Phenomena course. The subjects of this course are fluid mechanics and heat transfer, which are topics with numerous equations underpinned by elegant technical concepts. Students often fail to appreciate the concepts serving as the foundation for these topics, which leads to students being woefully unprepared when posed with questions which differ from those explicitly solved in class or homework. In order to combat conceptual misunderstanding, Concept Quizzes requiring a written response were included as part of the grade students received in studied courses. Two examples of these written Concept Quiz instruments are shown in Figures 1 and 2.

As can be seen from Figures 1 and 2, written Concept Quizzes ask straightforward questions which require no calculations. In Figure 2, it can be seen that Parts (a) and (c) can be answered in one word, and may even be able to be guessed correctly with little conceptual understanding; however, the lion's share of the grade on a Concept Quiz involves correctly explaining "why?"

Problem 1 (70%) Suppose you are at a summer family picnic drinking a large glass of iced tea; when you raise your glass from the table to take a drink, a ring of water is left on the table. Your 12-year-old cousin asks you, "why is your glass sweating?" How would you explain this phenomenon to them in simple terms?

Figure 1. Question from Concept Quiz #9 (Spring 2015 Transport Phenomena course).

Problem 1 (100%) Fluid is flowing through a tubular pipe in the laminar flow regime as shown in Figure 1. Four different points in the pipe are labeled. (a, 15%) Is the fluid velocity at Point 1 higher, lower or the same as the fluid velocity at Point 2? (b, 35%) Why? (c, 15%) Is the fluid pressure at Point 1 higher, lower or the same as the fluid pressure at Point 3? (d, 35%) Why?

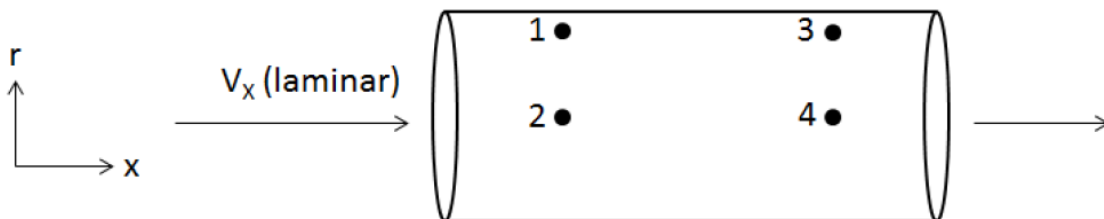


Figure 1. Laminar flow through a pipe with four labeled points.

Figure 2. Question from Concept Quiz #2 (Spring 2015 Transport Phenomena course) [adapted from another source¹⁴].

in written format. There are two key challenges for students when they encounter these explanations:

- 1) Do I have the conceptual understanding required to answer the question?
- 2) Can I communicate this understanding to another person skilled in the art in a brief, cogent written statement?

The goal of combining these two challenges is to allow students to be evaluated on their conceptual understanding while also developing their writing skills. Even students who do not possess requisite conceptual understanding receive the benefits of writing opportunities. The reflection afforded to students by composing a written response also has pedagogical benefits. For instance, the author has observed that some students identify mistakes in their answers to Parts (a) and (c) of the question described in Figure 2 when they begin trying to explain their respective answers in Parts (b) and (d). This self-critique of the student's conceptions (and misconceptions) would seem to represent learning at the highest levels of Bloom's Taxonomy¹³.

3. Methods

Concept Quizzes were incorporated into two courses: an introductory material and energy balances course (CHE 205) and a transport phenomena course focusing on fluid mechanics and heat transfer (CHE 311). Concept Quizzes were given to students as a typical typed question sheet and lasted 10 minutes of class time. When giving a Concept Quiz to students, the instructor also projected the quiz content onto a screen in the classroom, read the questions to the class, and asked students for any questions about the quiz content before the beginning of testing; this was done to ensure thorough understanding of the questions for both domestic and English-as-a-second-language (ESL) students. Student questions during the quiz were also answered by the instructor as necessary.

After Concept Quizzes were graded, the author presented correct responses to the class; in the ensuing (and sometimes lively!) discussion, student questions were addressed and any misconceptions explained by the instructor. Three primary methods were used to evaluate the effect of Concept Quizzes on (1) students' conceptual learning and understanding, and (2) their writing skills:

1. Student responses to Concept Quizzes were categorized regarding conceptual understanding by a coding scheme based on reading of students' individual written explanations. The coding scheme was used to sort student responses based on whether or not the student incorporates expected concepts into their explanation. For instance, in response to the question described in Figure 1, it was expected that the student would incorporate discussion of: (1) source of condensate (non-visible water vapor in air, rather than liquid from inside the glass); (2) mechanism by which water vapor condenses from the air – perhaps describing condensation to the young cousin as “boiling in reverse” (3)

mechanism for water leaving a ring on the table (condensate forms film/droplets which then run down the outside of the glass to the table due to gravity). It was necessary for the concepts involved in the coding scheme to change depending on the content for each problem and the phenomena involved. The major categories for coding student responses for each concept are similar to that used in a related work from physics/statics literature¹⁵:

- Not assessed – the student does not invoke the expected concept at all in their explanation
 - Not properly assessed – the student invokes the expected concept, but in a way that does not demonstrate complete conceptual understanding (such as referencing a concept at an incorrect point in the explanation or in such a way that demonstrates a misconception)
 - Assessed – the student demonstrates understanding of the concept
2. Student responses were further categorized by writing quality in an effort to judge students' overall writing skills. A separate coding scheme was used to sort written student responses according to writing quality:
- Poor – quality of writing is low enough to obscure a student's technical explanation, even if they possess correct understanding
 - Clear but not concise (or associated) – either the student clearly invokes the concepts but rambles through an unnecessarily lengthy explanation, or seems to invoke the concepts but their answer is too short or unclear to confidently assign understanding
 - Clear and concise – written response clearly demonstrates the student's conceptual understanding through a brief, cogent technical explanation

It would be expected that students' coding scores should improve throughout the semester if Concept Quizzes effectively improve their writing.

3. Student scores on exam questions involving concepts previously investigated by Concept Quizzes were compared between different offerings of the same course in the author's chemical engineering department; one set of offerings utilized Concept Quizzes to evaluate and teach student conceptions, while the other set did not. It is noted that a limitation of this study is that different professors taught each set of offerings and offered different exam problems (though with the same underlying conceptual content).

Open-ended student comments from end-of-semester course evaluations were also collected to investigate student views on Concept Quizzes and identify factors not originally considered in the study.

4. Results and Conclusions

This study is planned to be completed through the Summer 2015 semester; at the April 2015 conference proceedings submission deadline, data was not available for analysis. Additional data will be presented at the 2015 ASEE Annual Conference, specifically:

- Coding criteria for all Concept Quiz questions used in the studied courses
- Distributions of coded chemical engineering student answers (and scores) on both Concept Quiz questions and exam questions focusing on similar phenomena
- Statistical analysis via ANOVA and/or hypothesis testing to determine if coded student responses for Concept Quiz questions correlate to exam question performance for similar concepts
- Student responses to open-ended comments regarding their viewpoints on the efficacy of Concept Quizzes and their enjoyment/appreciation of the instrument
- Special consideration will be given to analysis of ESL student performance on written Concept Quizzes – the author is concerned that a drawback of the described written conceptual testing is that students whose native language is not English may be at a disadvantage when attempting to understand written question prompts as well as explain complex technical phenomena in written English. Statistical analysis via hypothesis testing will be used to determine if ESL students perform differently in aggregate from domestic students on conceptual testing. If needed, corrective action will be considered and proposed.

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