ASEE's 123rd Annual • Conference & Exposition • New Orleans, LA • June 26-29, 2016

New Orleans JAZZED about Engineering Education

Paper ID #15996

Enhancing Conceptual Testing with Technical Writing

Dr. Matthew Cooper, North Carolina State University

Dr. Matthew Cooper is a Teaching Assistant Professor in the Department of Chemical and Biomolecular Engineering at North Carolina State University where he teaches Material and Energy Balances, Unit Operations, Transport Phenomena and Mathematical / Computational Methods. He is the recipient of the 2014 NCSU Outstanding Teacher Award, 2014 ASEE Southeastern Section Outstanding New Teacher Award, and currently serves as the ASEE Chemical Engineering Division's newsletter editor. Dr. Cooper's research interests include effective teaching, conceptual and inductive learning, integrating writing and speaking into the curriculum and professional ethics.

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

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, and poor conceptual understanding such as this has 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 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 workplace[8]. 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]. Current 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; in particular, the author is concerned 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.

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 were fluid mechanics and heat transfer, which are fields with numerous equations underpinned by elegant technical concepts. Students often failed to appreciate the concepts serving as the foundation for these topics, leading 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.

Figures 1 and 2 show that 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?" 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

> **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?

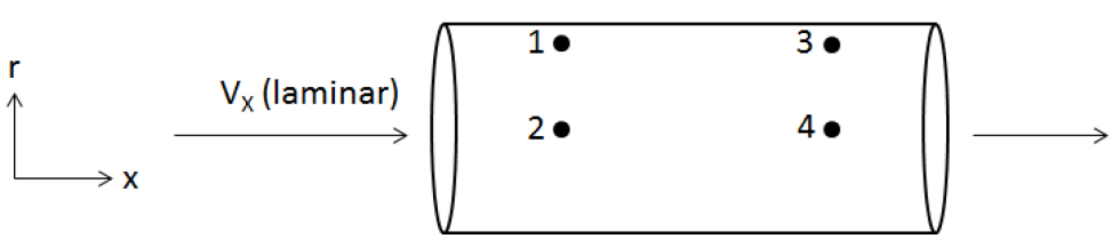

Figure 1. Laminar flow through a pipe with four labeled points.

Figure 2. Question from Concept Quiz #2 (Spring 2015 Transport Phenomena course) [adapted from another source[14]].

possess the requisite conceptual understanding to correctly answer the question 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 Taxonomy[13].

3. Methods

Concept Quizzes were incorporated into Fall 2014 (enrollment: 59) and Fall 2015 (enrollment: 78) transport phenomena courses focusing on fluid mechanics and heat transfer. The topic of each Concept Quiz changed along with changing course content over the procession of the semester. Grading keys for Concept Quizzes were constructed to assess each student's level of understanding of the tested engineering concept; points were not directly deducted for writing quality. The average of each student's 11 Concept Quiz scores across the semester was worth 20% of their final course grade with homework and exams comprising the remaining 80%.

Concept Quizzes were given to students as a typed question sheet and uniformly lasted 10 minutes of class time. When giving a Concept Quiz to students, the instructor 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 process aimed to ensure thorough understanding of the questions for both domestic and ESL students. Student questions during the quiz were also answered by the instructor as necessary.

After collecting students' completed Concept Quizzes, 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. In Fall 2014 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 the physics/statics literature[15]:

   - 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 for writing skills should improve throughout the semester if Concept Quizzes effectively improve their writing.

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

4. Results and Discussion

4.1. Student conceptual understanding and writing performance

Student performance in conceptual understanding and writing efficacy categories on Concept Quiz questions was coded on a 1-3 scale and tracked throughout the semester; mean performances by students on each question are shown in Figure 3. Student writing was found to be strong throughout the semester, indicating that students were generally capable of explaining technical concepts in writing. Contrary to expectations, student writing did not improve throughout the semester, though improvement would be difficult considering the high writing

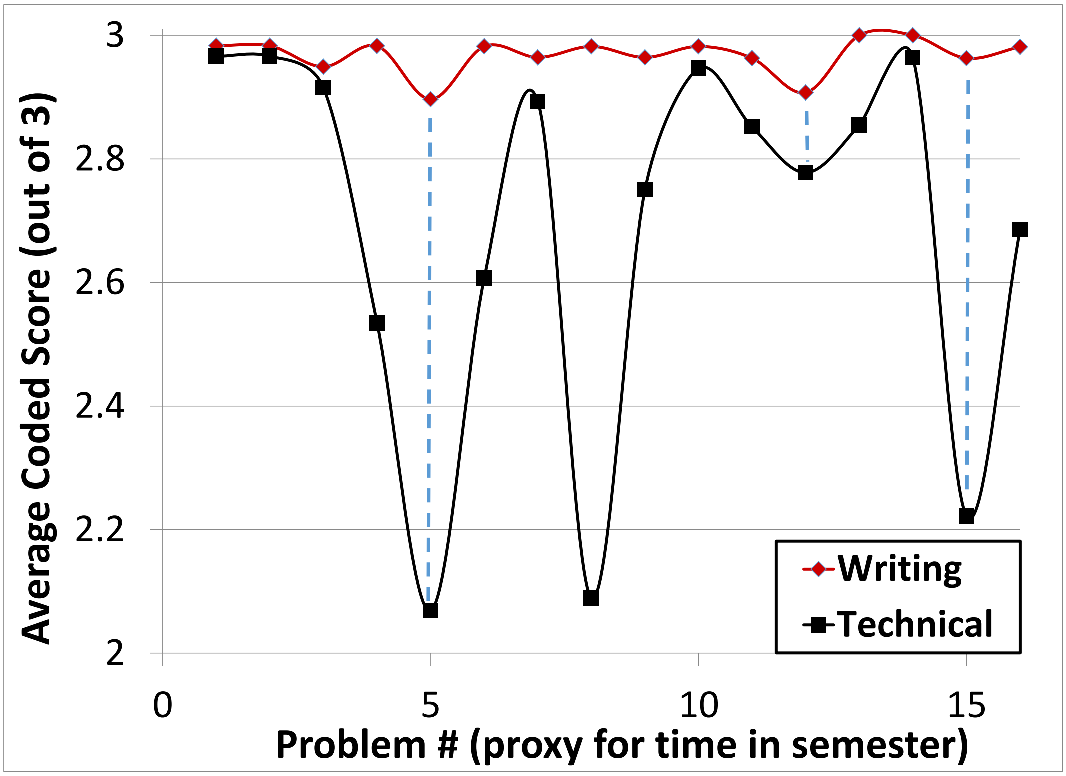

Figure 3. Student performance in the categories of writing quality and technical understanding coded on a scale of 1-3 (where 3 is highest).

scores throughout the study. Interestingly, student writing seemed to be especially strong when students had the firm conceptual understanding needed to answer the question, but lower conceptual understanding scores tended to correlate with diminished writing performance, as indicated by the dotted lines on Figure 3. A possible explanation for this phenomenon is that when students understood the tested concept, they had little trouble explaining themselves in writing; however, when students had misconceptions they struggled to articulate their responses. This finding reinforces that writing assignments guide connections and clarity[10].

4.2. Correlation of conceptual understanding with problem solving

Figure 4 shows the correlation between student conceptual understanding (assumed here to be indicated by a student's average score on Concept Quizzes) and problem solving ability (assumed here to be indicated by a student's exam average) for the Fall 2014 and Fall 2015 semesters. It can be seen that the correlation between the two measures is rather weak, with only 33.8% of the variance in students' problem solving ability attributed to the variance in their conceptual understanding. This finding was unexpected since it seems obvious that students' ability to solve problems would strongly hinge on their conceptual understanding, especially in a concept-driven course like transport phenomena. However, it is also possible this finding

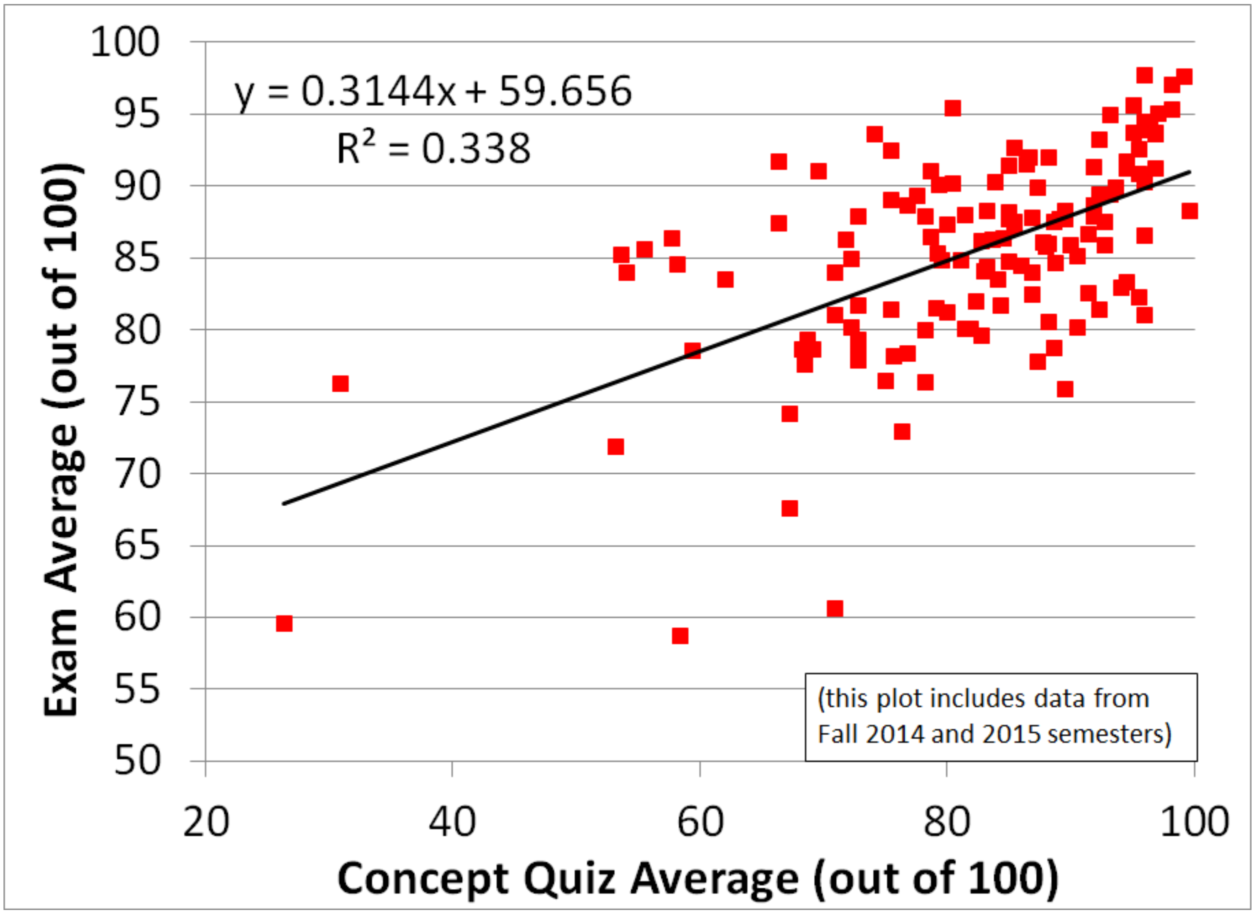

Figure 4. Variance of exam average (indicating problem solving ability) with concept quiz average (indicating conceptual knowledge).

indicates exam questions in the studied classes rewarded other student attributes (such as computational ability) more greatly than conceptual understanding. Other alternative explanations include that student's conceptual knowledge improved after taking Concept Quizzes, allowing them to perform better on exams than Concept Quizzes on the whole (as indicated by the positive slope of approximately 0.3) or that the assumptions of this comparison are incorrect.

4.3. Focus on diversity: are ESL students at a disadvantage?

Inspired by ASEE's recent focus on **diversity**, a special effort was made by the author to investigate whether ESL students were at a disadvantage compared to native-English-speaking students when interpreting written question prompts as well as trying to explain complex technical phenomena in written English. Only 2 out of the 60 students enrolled in the Fall 2014 semester were ESL students, so it must be noted that the sample size of ESL students examined under coding criteria is too small to make inferences with great statistical confidence. That said, a comparison of the performance of ESL students with native English speakers is shown in Figure 5. It is observed that ESL student performance in both technical and writing categories was below the population of native English speakers, indicating that ESL students did indeed struggle with the Concept Quiz format described here. This was somewhat expected since ESL students have the additional challenges of first translating the question prompt and then translating their thoughts into English on top of the technical and writing challenges faced by native English speakers.

In an effort to further compare performance of ESL students against the class as a whole, a plot similar to that shown in Figure 4 was constructed which incorporates data from both the Fall 2014 and Fall 2015 semesters (to increase the sample sizes of the population to 137 and ESL students to 10) while highlighting data points attributed to ESL students; this plot is shown in Figure 6. Interestingly, a stronger correlation between Concept Quiz scores and exam scores was found for ESL students ($R^2 = 0.848$) compared to the population ($R^2 = 0.338$). This indicates that a large factor in the success of ESL students on exams is related to their conceptual knowledge, or perhaps more saliently, a combination of their conceptual knowledge and their ability to effectively and efficiently translate written question prompts (which is a skill needed by ESL students to score well both on Concept Quizzes and exams written in English).

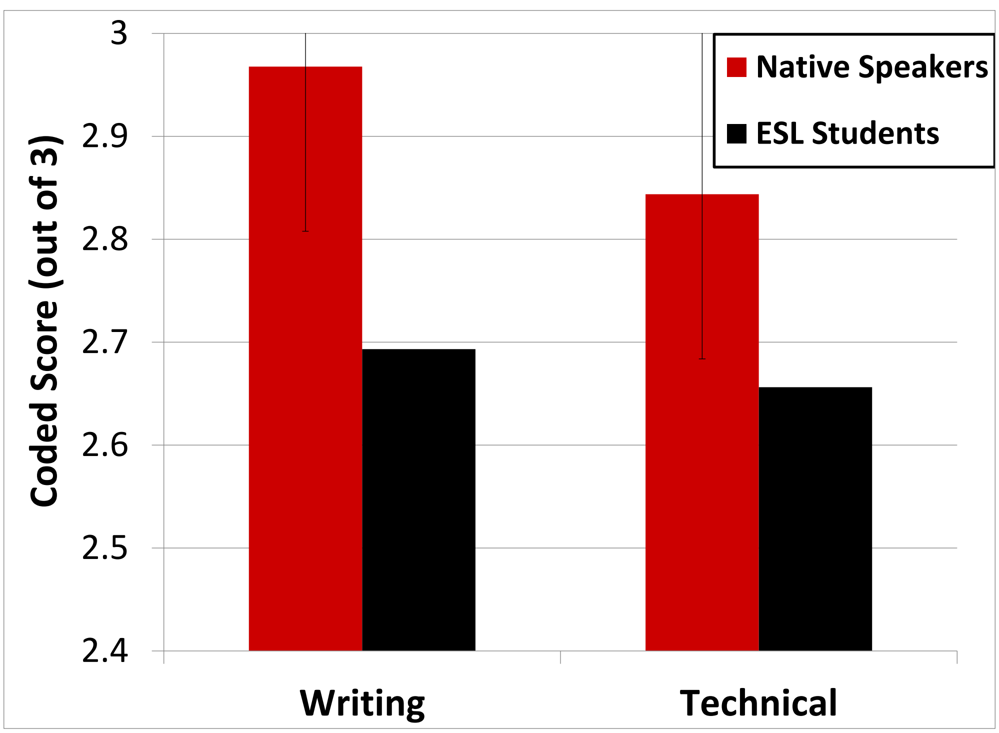

Figure 5. Comparison of average Concept Quiz performance by native-English and ESL students.

Hypothesis testing of the slopes of the two lines describing the different groups shown in Figure 6 finds no significant difference between the two from a statistical perspective ($p = 0.61$), indicating the difference between the slopes for the ESL students and the population is likely noise in the data. While it can be inferred from this finding that gains in conceptual understanding by ESL students result in similar gains in problem-solving ability as for the population, as stated above students who score better on Concept Quizzes may be doing so due to improved English comprehension skills rather than strictly improved conceptual understanding. These findings are further confounded by the persistently small sample size of only 10 ESL students (even with the larger data set combining the Fall 2014 and Fall 2015 semesters) which makes it difficult to confidently determine any meaningful differences from a statistical perspective.

On the positive side, the writing of one ESL student improved significantly throughout the semester. Examples of this student's written explanations at the beginning and at the end of the

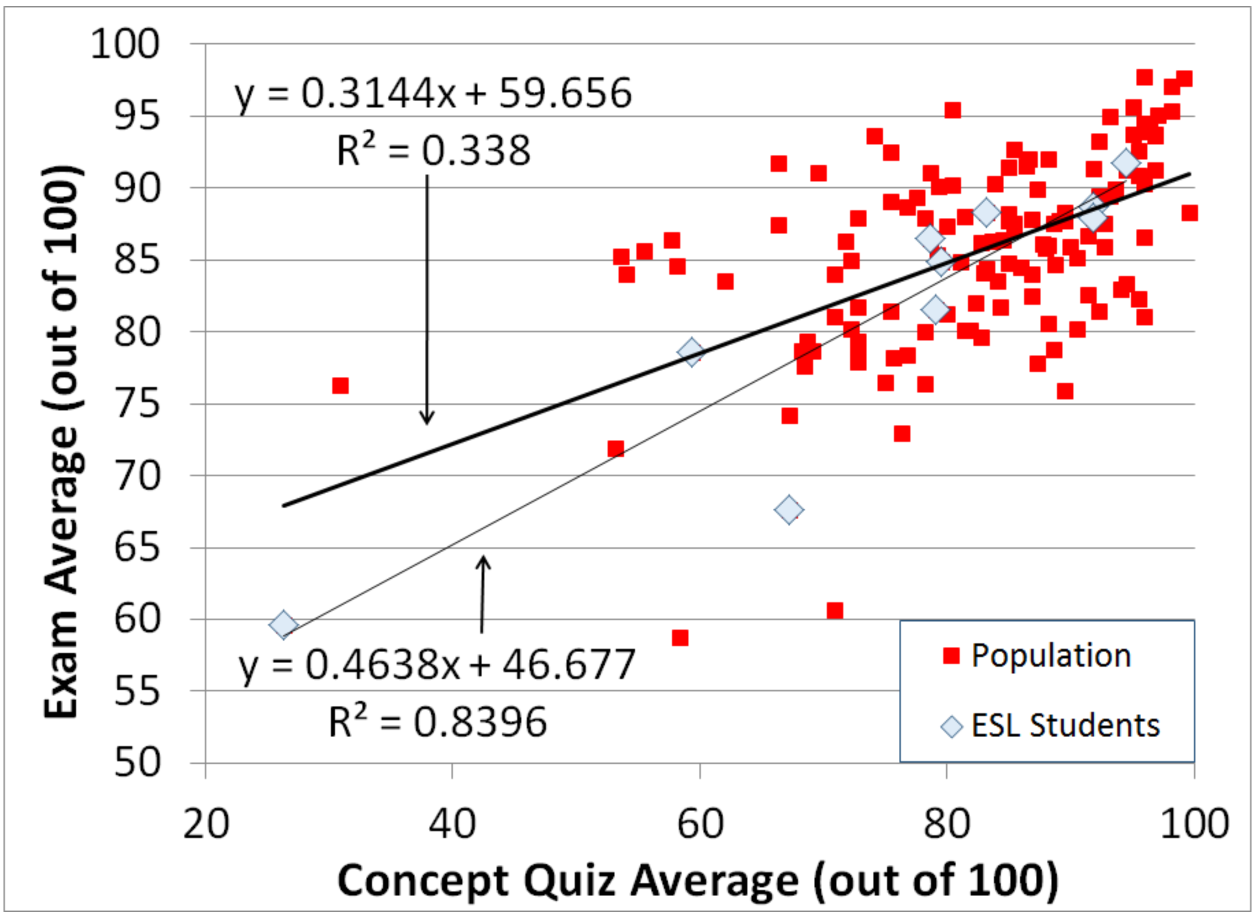

Figure 6. Correlation of exam average with concept quiz average compared between ESL students and population.

semester respectively are given here:

> Written response at the beginning of the semester (regarding why fluid velocity is different at different points of a pipe): *"Because of the friction of the fluid in the pipe wall at Point 1 is higher than Point 2."*
>
> Written response at the end of the semester (regarding what approach should be used in an unsteady-state heat transfer problem): *"General approach should be used because the surface area to volume ratio is small and there is a low thermal conductivity."*

It is possible that this individual student's written clarity improved due to practice and instructor feedback on their explanations of technical concepts on Concept Quizzes. The author posits that without use of Concept Quizzes (or similar short technical writing assignments) in engineering courses, it may be difficult for students (especially ESL students) to improve their written technical explanation skills prior to graduation.

4.4. Student feedback

In order to probe student views on the efficacy of Concept Quizzes, end-of-semester course evaluations for the studied semesters included the question "Did you think Concept Quizzes were effective tools to probe conceptual understanding?" Comments from students indicate they generally had a positive attitude toward Concept Quizzes:

- "Most courses are focused on number crunching. When classes are like that I leave knowing how to solve problems, but not knowing what the heck I just did! I enjoyed how this course focused on knowing what you are doing behind the math."
- "Concept quizzes were a great way to test basic understanding of course material. It also helped me to think of the material more critically, instead of just trying to put numbers on everything and make a calculation. Even when I made a big mistake on a quiz, I was actively thinking about the concept at the time, and reviewing the quiz right after taking it helped me to correct and cement the ideas."
- "Yes, I did! They emphasized the concept, and left a huge mark in our memory bank for the concept in hand. I wish all classes in the ChE department used Concept Quizzes, they are really very effective."
- "It was challenging (in a good way) to explain the concepts we learned in class."

These comments indicate that students appreciated the challenges associated with Concept Quizzes and thought they were effective in reinforcing fundamental concepts. There were also no strongly negative comments, indicating that students don't seem to hate Concept Quizzes as testing instruments – this is always a good thing.

Additional student comments provided food for thought regarding improvements to the instrument, which will be further discussed in Section 4.5.:

- “It was useful that the instructor went over the answers to the concept quizzes immediately after we took them so that he could clear up any misunderstandings.”
- “Please cut the time from 10 minutes down to 5 minutes because that just wastes valuable class time where we could be learning so much more from you. Over the course of the semester that time adds up, and if students don’t know the answer right away then they probably won’t get it, so giving students 5 minutes to answer the question shouldn’t make any difference.”
- “I would appreciate you dropping the lowest concept quiz grade, because I had a couple off days and it was an early class. I would even suggest considering dropping the lowest 2 quizzes.”
- “I believe that too much weight is put on the concept quizzes in this course. A ten minute quiz should not count 2 percent of the overall grade.”

4.5. Lessons learned and tips for faculty trying to utilize Concept Quizzes

- *After collecting completed Concept Quizzes from the class, it is important to project the quiz on the screen, explain the correct answer and elaborate on the concept. This will yield many gasps of relief from students who got the quiz correct, and will also solicit questions from students who got it wrong. Often, by asking questions students will reveal their misconceptions (likely shared by other students in the class) which provides great just-in-time teaching opportunities for the instructor to clarify the concept for students who need it.*
- *Be careful about allotting too much or too little time for Concept Quizzes since the in-class quizzes compete with lecture time. Conversely, providing too little time for students to complete the quiz will create student frustration (which then becomes instructor frustration). When giving Concept Quizzes for the first time, it may be helpful to note when the majority of students appear to be finished answering Concept Quiz questions and adjust the allotted time accordingly in the following semester.*
- *A feature of Concept Quizzes is that sometimes students will receive low grades (even zeros) on individual quizzes due to bearing serious technical misconceptions about quiz content. Student comments indicate frustration with this feature and provide suggestions regarding dropping the lowest quiz score and/or diminishing the impact of Concept Quizzes on the course grade. Both of these suggestions are reasonable and should be considered by faculty using the instrument.*

5. Conclusions

A study of the efficacy of written Concept Quizzes toward improving and evaluating student conceptual knowledge and writing ability was completed. It was found that student writing quality appeared to correlate with students’ level of conceptual knowledge, indicating that technical misconceptions caused students to struggle to articulate their response. It was surprisingly found that only a weak correlation existed between Concept Quiz grades (assumed to indicate conceptual understanding) and exam grades (assumed to indicate problem solving ability). It is possible this finding indicates exam questions in the studied classes rewarded computational ability more greatly than conceptual understanding. A special effort was made to consider the role of student **diversity** in performance on Concept Quizzes. It was found that ESL students had comparably lower scores in writing and technical categories than their native-English-speaking classmates. This is likely due to the additional difficulty faced by ESL students in interpreting written prompts and providing written answers in their second language. A stronger correlation between grades on Concept Quizzes and exams was found for ESL students than for the studied population, indicating that most of the challenge in exam questions for ESL students was attributable to a combination of conceptual understanding and ability to interpret question prompts in written English. It was observed that one ESL student's writing improved considerably over the course of the semester, perhaps due in part to practice explaining technical concepts in writing on Concept Quizzes. Student feedback on the use of Concept Quizzes was largely positive and suggested students appreciate the change in pace from computation-based problems and the challenges of explaining technical concepts in writing. Suggestions for instructors who would like to use Concept Quizzes were provided. The author is happily willing to disseminate all Concept Quiz prompts to any faculty interested in use of the method (they are not explicitly published here to avoid students accessing quiz prompts through ASEE's website); please email the author at –redacted during ASEE review phase–.

Bibliographic Information

1. B. Brooks, D. Gilbuena, J. Falconer, D. Silverstein, R. Miller, M. Koretsky. Preliminary development of the AIChE Concept Warehouse. *Reviewed 2012 ASEE Annual Conference Proceedings*, Paper ID AC 2012-4310 (2012).
2. M. Koretsky, J. Falconer, B. Brooks, D. Gilbuena, D. Silverstein, C. Smith, M. Miletic. The AIChE Concept Warehouse: a web-based tool to promote concept-based instruction. *Advances in Engineering Education* **4** (1), 1-27 (2014).
3. A. Elby. Another reason that physics students learn by rote. *American Journal of Physics*, S52 (1999).
4. R. Felder, R. Brent, Understanding Student Differences, *Journal of Engineering Education*, 57-72 (2005).
5. NCSU ClassEval End-of-Semester Course Evaluations for CHE 311.
6. T. Grose. The missing element. *ASEE Prism Magazine*, 22 (September 2013).
7. R. Rhinehart. Educating students to become engineers. *Chemical Engineering Progress*, 14-15 (June 2014).
8. J. Donnell, B. Aller, M. Alley and A. Kedrowicz, Why industry says that engineering graduates have poor communication skills, *Reviewed 2011 ASEE Annual Conference Proceedings*, Paper ID AC 2011-1503 (2011).
9. P. Elbow, in *Embracing contraries*. Oxford University Press, New York, NY (1986).
10. R. Brent and R. Felder. "Writing assignments – pathways to connections, clarity, creativity." *College Teaching* **40** (2), 43-48 (1992).
11. A. Young and T. Fulwiler, in *Writing across the disciplines*. Boynton/Cook, Upper Montclair, NJ (1986).
12. T. Fulwiler (ed.), *The journal book*. Boynton/Cook, Portsmouth, NH (1987).
13. L. Anderson and D. Krathwohl (eds.), in *A taxonomy for learning, teaching and assessing: a revision of Bloom's Taxonomy of educational objectives: complete edition*, Longman, New York, NY (2001).
14. R. Felder and R. Brent, NCSU College of Engineering New Faculty Orientation Handbook (2012).
15. J. Newcomer and P. Steif. Student thinking about static equilibrium: insights from written explanations to a concept question, *Journal of Engineering Education*, 481-490 (2008).