Work in Progress: Improving Undergraduate Engineering Education Through Writing: Implementation in the Classroom Alongside a Hands-on Learning Pedagogy

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Abstract

As undergraduate engineering students graduate and advance in their careers, they are faced with multiple tasks that require them to write extensively, whether that be in industry or graduate school. Additionally, the Accreditation Board for Engineering and Technology (ABET) lists the ability to communicate effectively an expected student outcome of accredited baccalaureate programs. Because of insufficient writing requirements in undergraduate engineering curricula, however, many engineers are unprepared for the writing-demand necessary to convey their own ideas or understanding of ideas. More rigorous writing practices would not only improve effective communication skills as undergraduate students pursue their education, it can also help students develop a deeper conceptual foundation of engineering topics. The writing pedagogy of interest follows a scaffolded approach and will be implemented alongside a current hands-on learning pedagogy in a junior-level fluid mechanics class. Two theories build the foundation for this pedagogy: learning through mimicry and learning through instruction. The students begin by taking a pre-test with a descriptive paragraph of the technical phenomena occurring during use of a venturi meter; certain phrases of the paragraph are narrowed to two options, where they have to choose the correct phrase. Students then use the venturi hands-on learning device, followed by a posttest. In the posttest, the sections that were previously narrowed down to two options consist of blanks instead, where students are required to write their own comprehensible phrases. These initial steps will help students learn how to explain engineering concepts, leading them to being able to write full paragraphs describing this technical phenomenon on their own in an exam-setting. The results of this implementation will be compared to previous semesters when the scaffolded writing pedagogy was not used, acting as the control.

Introduction

It is commonly observed that technical writing is not highly valued in the undergraduate engineering community. Regardless of the mode of communication, though, being able to communicate effectively is crucial to articulating ideas. According to the Accreditation Board for Engineering and Technology (ABET), the ability to communicate effectively is an expectation and requirement amongst engineering graduates from accredited programs [1]. More importantly, as undergraduate engineering students advance further into their careers, they are faced with multiple tasks that require them to write extensively, whether that be in industry or graduate school.

Currently, in the standard engineering curriculum, undergraduate engineering students are only required to take a basic writing course, such as Introductory English, and some form of technical writing course, which is typically not engineering-specific [2,3]. Other courses that allow these students to practice writing are engineering lab courses that require lab reports. In these lab classes, professors tend to focus on the quality of the technical material rather than the quality of the writing [4]. This could be due to a number of reasons: professors may not want to put in the time to grade the writing itself, written correctness may not be a heavily weighted portion of the grading criteria, or perhaps the professors themselves aren't comfortable critiquing students' writing. Despite the reason, this is a lost opportunity to improve the writing of undergraduate engineers. Because of this insufficient writing requirement at the undergraduate level, many of these engineers are unprepared for the writing-demands necessary to convey their own ideas or understanding of ideas. This is a significant roadblock in the potential of many engineers because without the ability to rationalize their thoughts through words, there also cannot be a broader or deeper understanding of concepts amongst themselves and their audiences.

Writing is a skill that requires time, repetition, and practice to master; it needs to be taught and applied earlier in the curriculum beginning with the classroom scale. Additionally, if a more rigorous writing program is implemented when students begin their studies, effective writing will be seen as a necessary tool for success, rather than a skill that is haphazardly utilized upon graduation in senior design reports. It is hypothesized that a scaffolded writing pedagogy will improve effective communication skills as undergraduate students pursue their education and, at the same time, help them develop a deeper, more robust conceptual foundation of engineering topics. In the same way that students cultivate a greater understanding of material when they are required to teach the material to someone else, students will have to go through a similar thought process to describe theoretical concepts in words [5]. As for the writing aspect, students can enhance their writing skills and learn how to write about technical phenomena while utilizing engineering lingo through imitation [6]; hence, in this study, a scaffolded writing approach was used, similar to using training wheels on a bicycle.

Related Research

Previous work done by the Improving Undergraduate STEM Education (IUSE) group at Washington State University (WSU) has proven that hands-on learning devices, Low-Cost Desktop Learning Modules (LC-DLMs), positively impacted student conceptual gains of theoretical concepts in the fluid mechanics and heat transfer classroom. Conceptual gains in these studies were measured using pre- and posttests, along with an educational framework called Bloom's Taxonomy. Bloom's Taxonomy was developed in 1956 by Benjamin Bloom et al. to categorize educational goals that correspond to different levels of the cognitive domain [7].

In a specific study performed by Jacqueline Gartner (formerly Burgher) et al., results show that the use of LC-DLMs produced statistically significant effect for questions that tested students at higher Bloom's levels [8]. At lower levels of Remember and Understand, passive learning methods, such as lecture, proved to be sufficient, if not better in some cases. This has led future work in the IUSE group to focus on developing questions for the LC-DLM corresponding pre- and posttests that assess the higher Bloom's levels of thinking.

The highest Bloom's level the IUSE group has been able to target is Evaluate, in which students are required to write a justification for their answers to a question. Because of the lack of care or ability, student responses to these short-answer questions were more-often-than-not less than acceptable. To remedy this gap, these short-answer justification questions can be redesigned to not only test students at higher Bloom's levels but to help them learn how to write using proper grammar, better articulation, and correct formatting.

At the 2016 American Society for Engineering Education (ASEE) Conference and Exposition, Prof. Cary Troy et al. of Purdue University addressed the writing gap in engineering classes and curricula and the potential of using writing to learn [9]. Through theoretical investigation, Troy and his colleagues were able to classify five written-question types: explain what, explain why, explain how, connect knowledge to practice, and pick a side in engineering problems. Additionally, they generated two types of general rubrics, analytical and holistic, needed for grading written assignments. This analysis builds a framework for researchers and instructors who are interested in implementing writing into core engineering classes.

Previous work has proven the need for writing in the engineering classroom and curricula, but it still remains a novel teaching approach in engineering education because of the many factors that go into incorporating writing into a technical classroom. To address these concerns and barriers, development and research plans for a scaffolded writing pedagogy are described below.

Implementation in the Fluid Mechanics Classroom

To follow the studies that have already been performed by the IUSE group at WSU, the writing pedagogy will be tested in the junior-level, the fluid mechanics and heat transfer course (CHE 332) in parallel with the current hands-on learning implementation.

i. Targeting Higher Levels in the Cognitive Domain

To target higher levels in the cognitive domain, it is crucial to start with the students' conceptual foundation. Identifying common misconceptions in the material is a key component of properly designing an experimental learning method; a skewed conceptual foundation will prohibit students from progressing further in their understanding. In previous work, common misconceptions were exposed through interviews with students who had already completed the fluid mechanics and heat transfer class [10,11]. The students were asked to briefly explain what each term in the mechanical energy balance means and draw how pressure and velocity change through a venturi nozzle.

In the interviews conducted by Arshan Nazempour and Jacqueline Burgher, a common misconception amongst students was the idea that fluid is squeezed by the narrowing diameter in a venturi as it goes through the throat, resulting in a pressure increase rather than decrease. In a similar manner, they believe this "squeezed" pressure is released as the pipe diameter increases. Using this information, the writing prompt of interest in this work-in-progress will be designed to focus on the concept of pressure and velocity versus distance in a venturi.

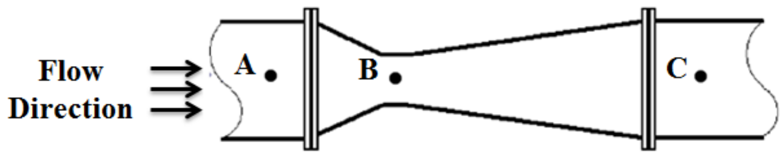
ii. Designing a Writing Pedagogy That Develops Conceptual Understanding

The Bloom's level of interest that will test for deeper understanding is Evaluate. At this level, students must be able to justify, defend, or explain their reasoning for a conceptual belief; all of these action words require writing. As mentioned previously, the writing pedagogy of interest will follow a multi-tiered, scaffolded approach. Over the course of the semester, each tier will be implemented via a quiz, homework exercise, or exam until the students are able to write complete, cohesive paragraphs explaining technical phenomena on their own.

Tier 1 will be implemented after students are first introduced to the material, whether that be through required readings or lecture. A prompt will be used to ask students to circle the correct option out of two in various sections of a mostly filled-in paragraph describing the technical phenomenon. Figure 1 is an example of what students will be given in class.

The beginning tier will be used to test at a lower Bloom's level, such as understanding; the concept is similar to the lower-level multiple choice questions asked in past LC-DLM implementations. Testing at this lower level after required textbook readings, a passive learning method, is acceptable because of the observations previously made that such learning methods are better suited for understanding at lower Bloom's levels. Additionally, having most of the paragraph written in the beginning tier will allow students to observe paragraph structure and the use of technical phrases—circling back to the psychological phenomenon of learning through imitation.

Circle the correct term for each space in the paragraph describing pressure versus distance for incompressible flow through the venturi meter displayed below:

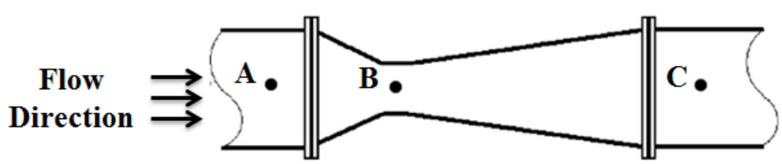


From points A to B, where the cross-sectional area decreases, pressure will increase/decrease due to flow work/kinetic energy being converted into flow work/kinetic energy. The pressure profile as flow proceeds to the right will take on the shape of a straight line/fourth-order polynomial because of the correlation between kinetic energy, velocity, and diameter/pressure. From points B to C, pressure will increase/decrease but will/won't fully recover to its original state due to frictional losses/returning to the same cross-sectional area as that at point A.

Figure 1. *Tier 1 of the scaffolded writing pedagogy, in which the majority of the paragraph is written to help students observe proper format before they progress to further tiers.*

In the next phase of the scaffolded approach, the spaces where a multiple-choice option was given in tier 1 will appear as blanks in tier 2 (Figure 2). These blanks are put in place to have students to write-in their own words or phrases, without seeing an already provided set of options. Because of this change in testing, students will be required to think at a higher Bloom's level, such as apply. The final step of the scaffolded approach is tier 3, the point at which students will be asked to write a full paragraph on their own.

Fill in the blank for each space in the paragraph describing pressure versus distance for incompressible flow through the venturi meter displayed below:



From points A to B, where the cross-sectional area decreases, pressure will ______ due to ______ being converted into ______. The pressure profile as flow proceeds to the right will take on the shape of a ______ because of the correlation between ______. From points B to C, pressure will ______ but ______ fully recover to its original state due to ______.

Figure 2. *In tier 2, paragraph structure is maintained, but the use of blank spaces leads students to formulate logical phrases on their own.*

These initial steps will help students learn how to discuss engineering concepts, leading them to being able to write cohesive justifications on their own. Because of the larger gap between tiers 2 and 3 in comparison to tiers 1 and 2, students will be asked to compose their own paragraph-description of relevant concepts as part of their homework assignments. To address the time concern with grading, the written homework portions will not be graded, but students will be provided with a list of points that should be included in their explanations afterwards.

Tier 3 will then be tested in an exam setting, where students will be asked to write a full paragraph describing the paragraph on their own. The rubric seen in table 1 will be used for grading of each tier; points belonging to each concept may be divided for grading purposes. Over the summer of 2018, the rubric was normed by the IUSE graduate students and co-investigators involved in this project.

Table 1. Grading rubric for scaffolded writing pedagogy

Concept	Point worth (out of 10)
Energy conservation; conversion of flow work to kinetic energy from points A to B.	3
Velocity, pressure, and cross-sectional area relationship (i.e. pressure decreases as velocity increases).	3
Non-linear pressure profile because of the relationship between kinetic energy, velocity, and the diameter.	1
No full recovery in pressure due to frictional losses along the venturi.	3

iii. Integrating Multiple Learning Pedagogies

Because the scaffolded writing pedagogy will be implemented alongside the LC-DLM hands-on learning pedagogy, tiers 1 and 2 will act as the pre- and posttests. To determine the effectiveness of this integrated pedagogy implementation, the results will be compared to previous implementations, where students were given free rein in justifying their answers to previous questions, acting as the control scenario. The diagram below displays the schedule for the implementation.

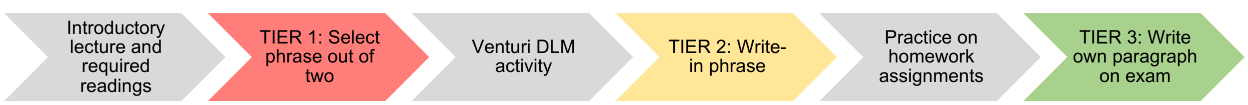


Figure 3. *Schedule of implementation for a single DLM.*

The current novel engineering pedagogy used in WSU's fluid mechanics classroom is the LC-DLM. Because the LC-DLMs have proven to significantly increase conceptual understanding amongst students, especially at higher Bloom's levels, the IUSE group has shifted their focus toward developing questions that target those higher levels. A major concern with questions that test at higher Bloom's levels, specifically short-answer questions, is the amount of time taken in class and required for fine-tuning, generating rubrics, norming, and grading. Because the writing pedagogy of interest is intended to follow a scaffolded approach with short prompts, it will require less time than the justification sections preciously implemented. With the integration of these two methods, student conceptual gains can be further enhanced.

Results and Conclusions

Statistical analysis for this study was performed using the analysis of covariance (ANCOVA) method on SPSS, where the pre-test acts as our covariate. A significance value, p, of 0.01 was obtained with an effect size, partial eta squared, of 0.107. Although the experimental group's average score dropped from pre- to posttest, by the second tier, where students are asked to write their own phrases in given blanks, the experimental group performed significantly better than the control group at a 99% confidence level with a medium to large effect size based on ranges for partial eta squared [12]. The decrease in average score may be due to the time gap between the pre- and posttests; the control group had three days between the two, whereas the experimental group had ten days. The ten days between the two tests was not originally planned, however, upon discussion, it was noted that this the larger time gap may be better for the study because the students are less likely to be answering the questions simply from memory.

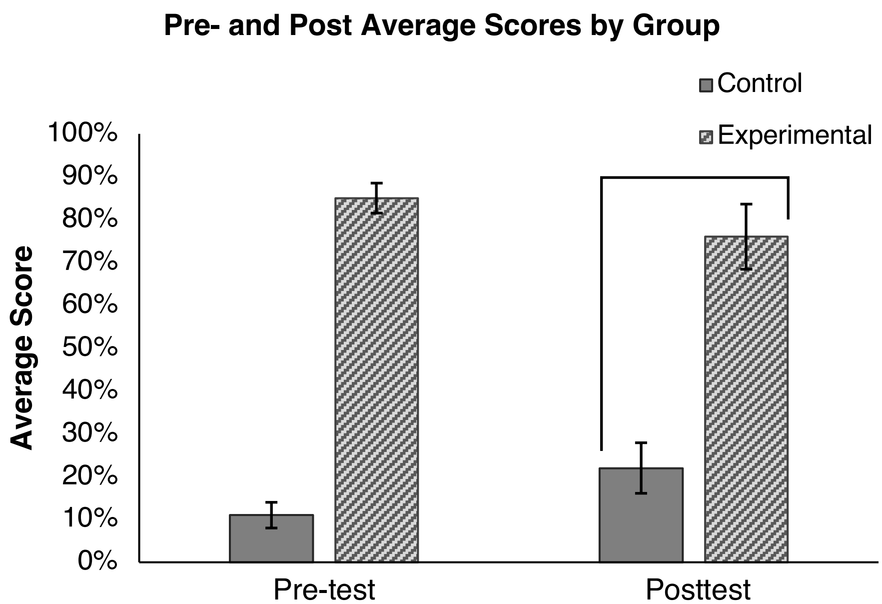


Figure 4. *Pre- and posttest average scores for the control and experimental groups.*

When looking at the concept breakdown, majority of the students lost points when describing the energy transformation between flow work and kinetic energy. This may be due to the concept being less visual, hence why the LC-DLMs would not have aided student understanding; in this case, more emphasis would be required in lecture and homework.

Due to a miscommunication, the final tier of this study will not be implemented until May 2nd, 2019 on the final exam. Having the final tier will allow us to make further conclusions, which will be shared at the 2019 ASEE Conference and Exposition.

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