Work in Progress: Improving Critical Thinking and Technical Understanding as Measured in Technical Writing by Means of I-depth Oral Discussion in a Large Laboratory Class

Dr. Mechteld Veltman Hillsley, Pennsylvania State University, University Park

Dr. Hillsley is an Associate Teaching Professor in the Department of Chemical Engineering at Pennsylvania State University. She received a BS in Chemical Engineering from Virginia Tech in 1988 and an MS and PhD from Penn State in 1990 and 1994, respectively. Dr. Hillsley spent approximately 10 years doing research at Penn State on fluid shear stress effects on mammalian cells before switching to teaching. Dr. Hillsley's primary focus for the past 10 years has been teaching the Unit Operations Lab. Dr. Hillsley is married and has four children.

Dr. Xueyi Zhang, Pennsylvania State University

Zhang is the John J. and Jean M. Brennan Clean Energy Early Career Assistant Professor of Chemical Engineering at the Pennsylvania State University. Zhang's teaching interests include mass transfer, unit operations, and chemical engineering lab. Zhang's research interests are porous materials synthesis, membrane for separation, and catalysis. Before joining the Pennsylvania State University in 2015, Zhang obtained his Ph.D. from the University of Minnesota in 2013 (with Michael Tsapatsis). Following his Ph.D., Zhang worked in Enrique Iglesia's group at the University of California, Berkeley as a postdoctoral researcher from 2013-2015.

Work in Progress: Improving critical thinking and technical understanding as measured in technical writing by means of in-depth oral discussion in a large laboratory class.

Engineers are expected to be good at critical thinking, yet it is something that is difficult to teach and difficult to measure. It is especially challenging to do so in a large class. Two common methods of improving critical thinking are through reflective writing and problem-based learning. Another common element that is often shown to help is discussion, either between team members, or facilitated by the instructor. A pilot study by Zhao[1] suggests that an oral exam in a large class helps student understanding as well as instructor awareness of student weaknesses. In this study we also aim to use an oral report and discussion time to improve the level of critical thinking in our senior level chemical engineering unit operations lab course.

In our Chemical Engineering Unit Operations Lab at Penn State University, the course is problem-based by nature. We also emphasize technical writing to assess understanding of the material. However, written feedback on writing is often ignored or editing is applied simply to the location of the feedback, instead of reworking the entire document. To be effective, feedback should be immediate[2,3]. We set out to increase the usefulness of instructor feedback by adding an oral report with discussion before the written report. The discussion portion is important. This is a time to go in depth with the students starting from their level in the hierarchy of development of critical thinking with the aim to move them up one level by the time they write the written report. We noticed a shift in mean grade distribution of the first written report by approximately 2.5 points, as measured by 1 tailed student t-test of equal variance ($p<0.03$), when the oral discussion period was added to the course.

In this Scholarship of Teaching and Learning work, instructor time is shifted from grading rewrites to grading oral reports. The oral reports afford time for in-depth discussions with students and give students constructive criticism on their analysis. As a result, students wrote more cohesive reports that link data to theory with more thought and better analysis. Instructors report that it was more time-efficient to read and grade reports after this intervention when they were better written. The additional minutes spent in discussion appeared to be reduced in the written grading load. This shift of instructor time appears beneficial to student understanding and student critical thinking development as well. This work will examine the shift in overall report grade in more detail by focusing on key discussion points in individual reports using a data analysis rubric based on critical thinking skills.

Background and Methods:

The study analyzed consecutive semesters of our chemical engineering unit operations course at Penn State in 2017. Spring semester (before intervention) consisted of 2 sections with a total of 72 student. Fall semester (after intervention) consisted of 3 sections with a total of 143 students. Spring semester students had an average gpa of 3.33 ± 0.364 (1 sd) before starting the class and fall semester students had an average gpa of 3.44 ± 0.385 (1 sd). The course is a required senior level course and a designated writing intensive course, meaning that writing is taught/developed and instructors grade all written reports.

In this course, students run unit operation type experiments, analyze data and compare it to theory. They then present their data as an oral report and/or a short written report. The same instructors co-taught the course in Spring and Fall of 2017. In Spring 2017, students completed 5 experiments and either wrote a written report or presented an oral presentation on each, for a total of 3 written reports and 2 oral reports. All students wrote a written report for the first experiment, followed by a rewrite. In Fall 2017 the number of experiments was reduced to 4 experiments, but this time students completed both an oral and a written report for the first 2 experiments. The oral was presented to the instructor 1 week after the experiment and the written was completed 4 days after the oral report. Thus, the oral feedback was available for preparation of the written report. The 3rd experiment was a written report with an optional (ungraded) oral report beforehand, and the final report was oral. The first written report had the option for a re-write, similar to the previous semester, but it was not required. The number of required deliverables remained the same, but the number of experiments was reduced from 5 to 4.

The intervention studied is the oral report and discussion added before the written report. These report and discussion periods consist of a 15-20 minute formal oral report, followed by 15-30 minutes of questions and answers, depending on the number of errors and omissions in the report, followed by some time for students to ask follow up questions. Total time spend with each team was typically 50-60 minutes.

Students worked in teams of 3-4 students with most teams consisting of 4 students. Labs and reports were prepared as a team. Student teams start a typical experiment by completing extensive pre-lab calculations which prepare them for data taking and review the theory covered in the experiment. They then meet with the TA to go over these calculations/questions to make sure they understand them and prepare for the experiment. Teams run the experiment the following week and process all data. The data processing is checked by the TA and should be correct at this point. The oral and/or written reports are then prepared.

Teams rotate through the different experiments, meaning that teams have different 1st experiments, 2nd experiments, and so forth. The same 2 instructors taught both semesters as a team. They had taught this course together previously and their grading was calibrated and similar throughout. The study evaluates the written discussion content from the two semesters, before and after addition of the oral report/discussion.

Course data was evaluated without student identifiers. Student report grades for the first written report of the semester were averaged and reported in aggregate. No attempt was made to separate grades by experiment type. The grading rubric for the written report included objectives, discussion, figures, and conclusion, as well as 20% for Excel data processing (submitted, correct, and well organized). The grading rubric for the two semesters remained the same.

In evaluating individual written material samples from the course for the current study, course material was downloaded, de-identified and assigned a random number. Before and after intervention reports were mixed, sorted only by experiment type. The authors used the rubric in table 1 to evaluate individual discussion questions. If the question was attempted a minimum score of 1 was given. A score of 2 required a good attempt at analysis, but the analysis might be incomplete or contain minor errors. A score of 3 indicates a good and cohesive discussion, answering the discussion question and fitting it in with other data collected. The rubric values were then entered in a spreadsheet and the random numbers re-associated to the correct semester. Written evaluation was done on specific experiments, thus the sample size for this work is much smaller than for the average grade analysis. The number of written distillation reports submitted for the 1st report for spring 2017 and fall 2017 were 4 and 9, respectively. This is the number turned in at one time. Two successive submissions are additive for the number of reports (e.g. 9 teams

Table 1 Key report question grading rubric

Scoring	Points
Not done	0
Wrong/major errors/only data shown without analysis	1
Attempted but small errors or faulty conclusions	2
Good and cohesive discussion	3

turn in distillation for the 1st report and 9 additional teams turn in distillation reports for the 2nd report). Preliminary work was done on two discussion questions for the distillation report. Care was chosen to only evaluate questions for which the wording had not changed. Some other questions had small changes in clarifying text. These were avoided because multiple factors were changed. Statistics was performed on the measured variables. An f-test was performed to determine equal or un-equal variance and then the appropriate one-tailed t-test was performed on the data.

Results and Discussion:

We examined the before- and after- intervention grades of students for the first written reports of the semester. As students rotate through the experiments, this is an average of all the reports submitted, encompassing 4-5 separate experiments. There was a shift in mean grade distribution by approximately 2.6 points, as measured by 1 tailed student t-test of equal variance ($p<0.029$), when the oral discussion period was added to the course. The average before-intervention was 82.4 +/- 9.8 (1 sd) and after-intervention it was 85.0 +/- 8.8 (1 sd). **Figure 1** shows the shift in overall grade distribution from before and after the intervention. There is a clear upward shift in grades. It appears that the lowest performers (grades below 80%) did not change much. However, there is a large shift in the number of students from the 80-85 % range to the 85-90 % range. It may be that the lower-performing students did not have much interest in learning and just wanted to get through the course, thus the intervention had little effect on these students. However, the lower-mid range students improved considerably. Presumably this was a direct result of the intervention.

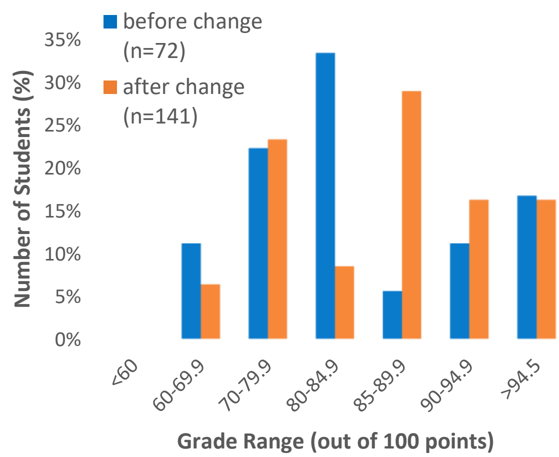

Figure 1. Percent of students in each grade bracket for the 1st written report of the semester. *The change refers to the addition of an oral report and discussion time before the written report due date.*

To evaluate whether this change in grade distribution represents a shift towards better data analysis and critical thinking skills as measured within the written report, we focused on several discussion questions within the distillation report. When writing the report, students are presented with a list of key report questions to address within the report. For preliminary analysis, two discussion questions were chosen from the distillation report. These questions were worded exactly the same in the two semesters studied. The randomized reports were evaluated using the grading rubric displayed in table 1.

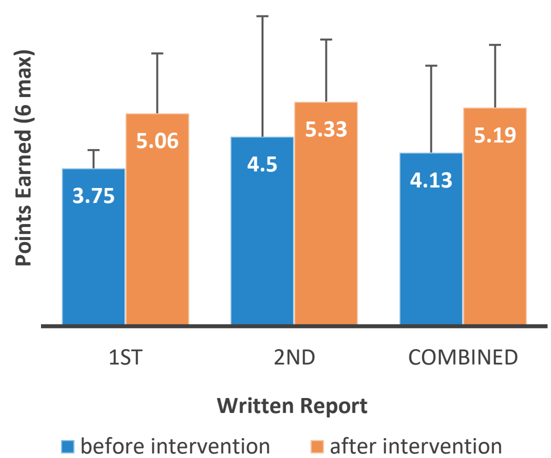

Figure 2 Total points *on evaluation of 2 discussion questions on the distillation report before and after intervention (6 points total possible). One tailed (equal variance) t-test on 1st, 2nd, and combined reports resulted in p< 0.021, p<0.11, and p<0.01, respectively. N=4 for each report before intervention and 8 for combined. N=9 for each report after intervention and 18 for combined.*

The evaluation focused on 2 questions dealing with column performance under total reflux over increasing heating power and boil-up rates. Figure 2 shows that there is a substantial difference in total points from before to after intervention for these 2 questions (6 points max possible). There is a small improvement in performance for each semester between the 1st and 2nd reports as would be expected as students learn within each semester. There is a significant increase in performance between before and after intervention for the first report ($p<0.021$) and for the combined 1st and 2nd reports ($p<0.01$). There is a small improvement for the 2nd report as well, but it is not statistically significant ($p<0.11$). It might be argued that the oral report feeds answers to the students. However, there is nothing to copy from the oral discussion and writing in one's own words is a means of increasing understanding (reflective writing). In the oral report, instructors are functioning as coaches, guiding students towards a more comprehensive analysis of their individual data and discussion. Felder and Brent[3] state that practice and constructive feedback are critical for student skill development, and they also recommend a student-centered approach where the instructor becomes the coach instead of the "sage on the stage". This is what our oral report strives to achieve, with some promising initial results.

Figure 3 breaks down the total score by individual question studied. All questions showed improvement with the intervention. When combining 1st and 2nd reports (increasing the sample size), the change is statistically significant. Some questions showed a more marked improvement than others, this may have to do with the fact that some questions covered simpler concepts than others. We will examine this further with a larger sampling of questions.

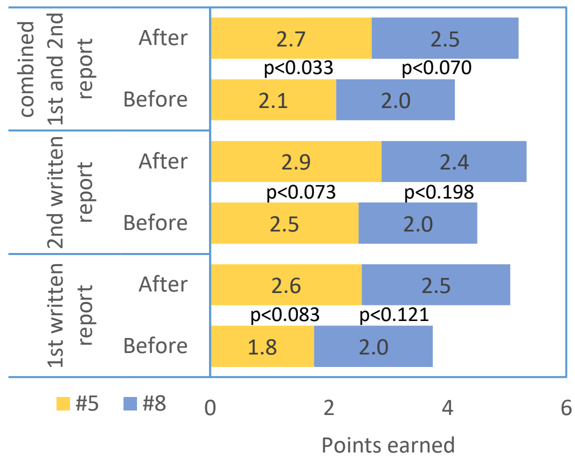

Figure 3 Points earned on individual questions in distillation report before and after intervention *(3 points max per question). One-tailed t-test p values are shown N=4 for each report before intervention and 8 for combined. N=9 for each report after intervention and 18 for combined.*

Incorporating critical thinking assessment in engineering education is difficult. Many have studied ways to incorporate it in the engineering curriculum[2-9]. Freeman[4] points out that critical thinking is not possible without creative thinking because the students need to get away from the one correct answer mentality. Traditional homework and test problems have a single correct answer. Typical real-life problems do not. The laboratory course offers a space where there is no "correct" answer. Instead, there are data and theory. Evaluation is not simply based on getting the correct result. Far more emphasis is placed on evaluating data and relating it to theory. The connection depends on assumptions made and experimental conditions used. No two teams get the same data. The laboratory offers a natural place to help our students and elevate their critical thinking skills.

To help promote intellectual development of our students into engineers able to critically analyze, it is important to provide constructive feedback on high-level tasks[2,3,5]. This requires modelling, practice and constructive feedback[3]. We provide practice and feedback with the oral report discussion. Zhao[1] found that adding an oral exam in a large class helps student understanding and instructor awareness of student weaknesses. This again fits in with the idea that intellectual growth depends on a student-centered approach to instruction where the instructor is more of a coach than an absolute authority.[3] During the question and answer session of the oral report, the instructor assesses the level of critical thinking development of the team and uses questions to prompt students to a next higher level in development. The level of prompting will differ depending on the starting level of the team on the critical thinking development spectrum, allowing all students to develop and move up the scale of critical thinking. This method allows more individual attention and feedback than otherwise available to a large class. With our oral report structure, the instructor becomes the coach.

In the control semester constructive feedback was given on written reports, but instructors often perceived that feedback was not being read or only superficially acknowledged. In a study on grading to promote critical thinking[6], Morse states that it is essential to use the "teachable moment" by giving feedback at a useful time. Morse showed that having students put in good faith effort for class and then having a discussion worked and saved instructor time. We followed a similar approach of having students prepare an oral report and giving in-depth feedback during it. The oral report is graded so that students put in a good effort. The following discussion is used to move students up in level on critical thinking and analysis with feedback, examples, and coaching. The students have another graded assignment (written report) on the same material afterwards, making the feedback helpful and relevant to the students. As shown in our preliminary data, the written report incorporates better and more cohesive data analysis and discussion.

The improvement observed in grades and discussion questions may be due to several factors. The oral report was added, but to make room for the additional reports for a single experiment, the number of total experiments was decreased. However, the total number of oral and written reports did not change. The reduction in number of different experiments performed by the student teams could arguably contribute to improved grades on the written report. More student time could be devoted to each experiment when there are fewer experiments to worry about. The authors believe that simply reducing the number of experiments without the coaching and "teachable moments" afforded by the added oral would probably not have resulted in the increase in depth of discussion that was noted here. However, giving students more time to spend thinking about a single experiment may help a little. Since this was not studied, the possibility cannot be ruled out.

Although it is common knowledge that personal attention works in education, we initially assumed it would be too difficult to accomplish in a large class. Our classes are large, often having over 100 students per semester. By dropping one experiment and keeping the total instructor graded deliverables the same, instructor time is managed. We did not increase the total number of oral reports, but placed them more strategically in the course. We did increase the time spend in discussion by about 15 minutes per team. In implementing this intervention, the authors discovered that instructor time was shifted from lengthy grading sessions to in depth discussions with students. Time focused on student discussions and analysis of data gives more productive results. Better written reports are much easier to grade. The time spent in oral discussion is fulfilling, while grading and commenting on written reports is much less so, especially when there is a sense that many of the comments are never read. It is also rewarding to watch light-bulbs go off in student minds as they come to realize the connection between lab data and theory and material from previous courses.

In conclusion, our work in progress shows promise that implementation of oral report and discussion period aids student critical thinking development and can be implemented in large laboratory courses. More work is planned in analyzing a more diverse sampling of discussion questions and in evaluating student self-perception of their critical thinking skill development.

References

1. Zhao, Y. "Impact of Oral Exams on a Thermodynamics Course Performance.". *2018 ASEE Zone IV Conference, Boulder, Colorado, 2018, March*. 2018, March.
2. Woods, D. R., Felder, R. M., Rugarcia, A., & Stice, J. E. (2000). The future of engineering education III. Developing critical skills. change, 4, 48-52.
3. Felder, R. M., & Brent, R. (2004). The intellectual development of science and engineering students. Part 2: Teaching to promote growth. Journal of Engineering Education, 93(4), 279-291.
4. Freeman, T. (2001, June), Critical Thinking, Communications, And Teamwork Paper presented at 2001 Annual Conference, Albuquerque, New Mexico. https://peer.asee.org/9058.
5. Felder, R. M., & Brent, R. (2004). The intellectual development of science and engineering students. Part 1: Models and challenges. Journal of Engineering Education, 93(4), 269-277.
6. Morse, J. (2001, June), Promoting Critical Thinking Skills Through Effective Grading Techniques Paper presented at 2001 Annual Conference, Albuquerque, New Mexico. https://peer.asee.org/9693
7. Prince, M. J., & Felder, R. M. (2006). Inductive teaching and learning methods: Definitions, comparisons, and research bases. Journal of engineering education, 95(2), 123-138.
8. Cooney, E., & Alfrey, K., & Owens, S. (2008, June), Critical Thinking In Engineering And Technology Education: A Review Paper presented at 2008 Annual Conference & Exposition, Pittsburgh, Pennsylvania. https://peer.asee.org/3684
9. Adair, D., & Jaeger, M. (2016). Incorporating critical thinking into an engineering undergraduate learning environment. International Journal of Higher Education, 5(2), 23.