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# Problem Solution Error Detection as a Means of Learning Assessment in Fluid Mechanics

**Dr. Thomas Shepard, University of St. Thomas**

Thomas Shepard is an Associate Professor at the University of St. Thomas in St. Paul, Minnesota. He teaches courses in the thermal/fluid sciences, aerodynamics, introduction to engineering and accompanying labs.

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## Introduction

The development of problem-solving skills can be accomplished in a variety of ways. Worked example problems are problems in which students are provided a problem statement followed by its solution and possibly an explanation of the steps and answer. This type of problem is commonly found sprinkled throughout textbook chapters to demonstrate the use of material as it is first presented. Instructors can also implement worked example problems in their lectures wherein they present a problem but walk students through the solution process instead of asking students to attempt the problem on their own. An erroneous example problem, or error detection problem, is one in which students are provided a problem statement and a completed step-by-step solution that contains mistakes. In these problems students are tasked with identifying the mistakes, and potentially correcting the mistakes to develop a correct solution. Conventional problem solving involves the presentation of a problem statement, known values and possibly a diagram and requires students to develop the full solution. This problem-solving modality is what is found in a typical end-of chapter problem set.

There have been numerous studies examining these different problem modalities from an instructional and learning viewpoint. Research on worked example problems have shown that they are particularly useful when first learning a topic as it reduces the cognitive load required on the student [1] and can be more useful than conventional problem solving in terms of learning achieved per unit time invested by the student [2-4]. However, worked examples become less beneficial to problem solving development as a student gains experience with a topic at which point having students develop full problem solutions becomes more beneficial [5-7]. The use of error detection problems is considered useful for student learning for multiple reasons. Past research has shown that when students see hypothetical errors it can help them to avoid similar errors while recognizing and correcting their own mistakes [8-11]. Additionally, it has been proposed that error detection problems can stimulate metacognitive impacts where students explain why something is incorrect [12]. Moreover, the positive impact of error detection problems has been found in students ranging from elementary school through medical school [9, 13-15].

Of these three problem modalities, conventional problem solving lends itself most frequently to assessment of student learning within engineering courses. Assessing student learning is commonly done via exams, among other techniques, and these exam questions can have various forms which differ significantly in terms of complexity. Many engineering problems require numerous sequential steps to solve and incorporate material from multiple chapters. These types of questions reach higher on Bloom's taxonomy and require students to demonstrate a deep understanding and synthesis of course material. Such questions which test higher levels of student learning also lead to challenges when grading based in large part due to the number of mistakes that a population of students can make on such problems. Attempting to make an exam easy to grade through heavy use of True/False or multiple-choice questions can also fail to adequately assess the amount of student learning [16]. Written exams come with a host of other undesirable attributes for the instructor and student alike [16-17] yet remain ubiquitous among undergraduate engineering courses. However, written exams also have benefits relating to the amount of course and instructor time required and the reduction/prevention of academic misconduct when proctored. Thus, efforts to develop exam questions that test student learning on complex problems while mitigating solution time and grading effort are a worthwhile endeavor.

While there have been studies detailing the impact of error detection questions on student learning, there is little discussion of their use during assessment via written exams. This study examined the use of error detection problems on exams and details the instructor experience, exam scores and student feedback. Discussion is provided on lessons learned throughout the process and practical advice for those considering the use of error detection problems in their courses. Note that the examples and pedagogical conclusions of these error detection-type problems outline above have come from outside of the engineering education, this further motivated the interest of exploring error detection questions within the engineering fields.

**Study Overview**

This study was conducted in a junior-level mechanical engineering introduction to fluid mechanics course at two universities. The University of St. Thomas (UST) is a medium-sized private liberal arts school in St. Paul, MN whereas the University of Minnesota (UMN) is a large, public university in Minneapolis, MN. There were 34 students taking the course at UST and 37 students taking the course at UMN. Both schools are on the semester system with 14 weeks of class during a semester. There was one instructor for each course at each institution.

Throughout the course lectures and problem review sessions students were introduced to error detection problems as in-class exercises. This was done typically after the topic had been completely covered and students had practice with fully solving computational problems on the topic. The students were told that error detection problems were fair game on the two midterm exams and final exam.

In presenting the general concept of error detection problems, the instructors explained to the students that the problems were being implemented for the following reasons:

- Literature suggests that seeing material both as an error detection problem and regular solution problem would improve their learning.
- It can be common for an engineer in industry to review a colleague's work for correctness. Thus, students would benefit from practicing a skill that may be used after graduation.
- It was believed that error detection problems would take less time for most students to solve on an exam which would effectively give most students more time for the other problems on an exam.

A representative error detection problem is shown in Fig. 1. Every error detection problem used, either as an example problem or as an exam question, shared common features. Following the problem statement, the students were directed to identify the number of mistakes in the shown solution and how they would correct those mistakes. Students were also directed to not actually show a correct worked out solution, only to find the errors. Students were told that errors in the problem solution could include mistakes related to units, algebra, incorrect assumptions, and incorrect procedures. Students were also told that all numeric calculations in the provided solution were correct, as-in they would not need to double check that a calculator mistake was made. It was explained that there wasn't necessarily a single correct answer to the number of mistakes made in a solution as it can be unclear how to account for an error that is propagated between solutions steps. Rather than worrying about specifying that number, students were directed to indicate where the mistakes were being made.

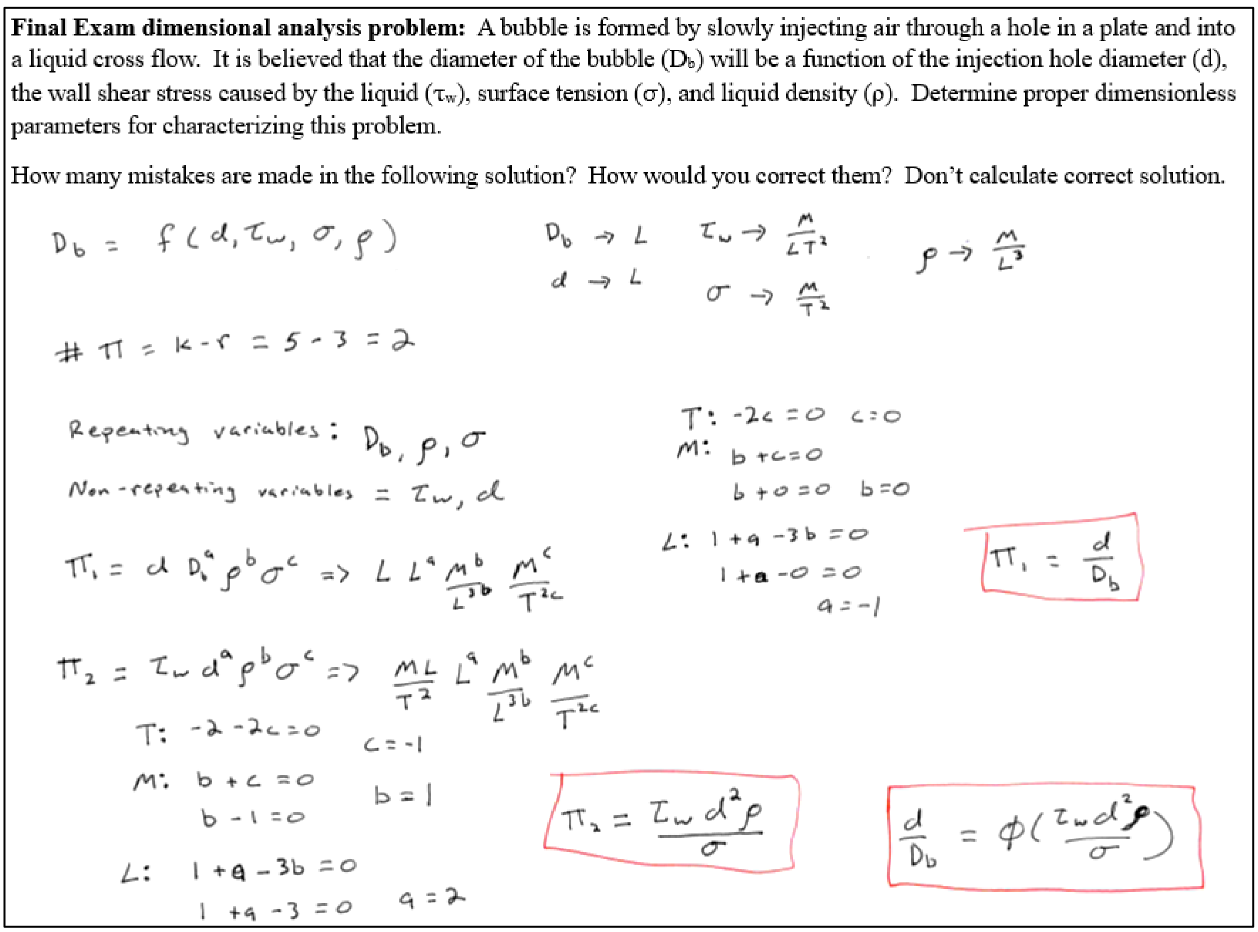



**Figure 1.** Example dimensional analysis error detection problem; there are four mistakes (see Appendix)

At UST there were three error detection problems used on exams: one on Midterm 2 and two on the Final exam. The topics covered in the error detection problems were the Bernoulli equation, pipe flow analysis and dimensional analysis. The topics of pipe flow analysis and Bernoulli equation were also covered in different exams wherein students had to provide a complete solution. Thus, the instructor assessed student understanding of those topics using both problem modalities. In addition to recording student grades on these problems, the instructor timed how long it took to grade the problem. At UMN there were three error detection problems used on exams: one on each midterm and one on the final exam. The topics covered in these error detection problems were the Bernoulli equation, dimensional analysis and drag. Understanding of the Bernoulli equation was assessed both using an error detection problem on Midterm 1 and as a full solution problem on the Final exam.

For the topics in which student learning was assessed using both problem modalities, a causal relationship between student performance and problem modality is not possible from the data collected. This is due to the timing of the questions. For example, the error detection pipe flow question from UST was used on Midterm 2 (Fig. 2) while the pipe flow question that required a full solution was used on the Final Exam (Fig. 3). As many weeks passed between the exams and students could learn from mistakes made on the midterm it is not possible to explain a difference in student performance as being solely related to question modality. A comparison of the problems in Figs. 2-3 shows that the solution procedure that would be used to solve each problem is almost identical: choose two points where the pressures are known, write the energy equation, cancel terms, identify knowns, and implement an iterative procedure using the Moody Chart.

At the end of the semester students completed a survey to provide feedback on their experience and thoughts related to the utility of error detection problems. The survey was administered using Canvas, the courseware system for the universities, and responses were anonymous. The response rate for the survey was 100% at each university. The survey prompts were:

1. *A student who is good at solving problems would also be good at correctly answering error detection problems on the same subject:*

   (1) Strongly Disagree (2) Disagree (3) Neutral (4) Agree (5) Strongly Agree

2. *In comparison to the time required to solve a calculation problem, an error detection problem on the same subject requires:*

   (1) Much less time (2) Less time (3) Same time (4) More time (5) Much more time

3. *Practicing error detection problems helps me avoid mistakes on calculation problems for the same subject:*

   (1) Strongly Disagree (2) Disagree (3) Neutral (4) Agree (5) Strongly Agree

4. *In my engineering curriculum, I would prefer to see:*
   (1) No error detection problems
   (2) Some error detection problems in each course (0-1 per chapter)
   (3) Many error detection problems per course (1-2 per chapter)
   (4) No opinion either way

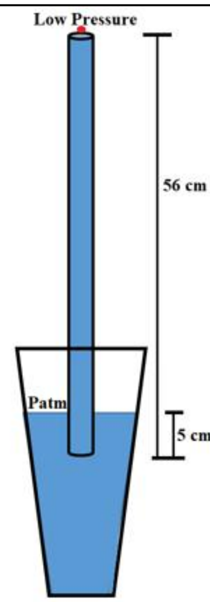
5. *What % of your other engineering/technical courses use error detection problems?*

6. *Any other general feedback on error detection problems? Perhaps something that you would want an instructor to know who is thinking about using them?*

**Midterm 2, pipe flow problem:** You plan to drink water from the comically long straw as shown. Your mouth would be at the point labeled "Low Pressure" and because of how thirsty you are, the pressure there is -9800 Pa. It is a smooth walled straw with a diameter of 6 mm. What is the velocity of the water in the straw? Assume steady state. For the solution shown:

a) How many mistakes are there in the solution?

b) What are the mistakes? What should be done to correct them?




$$\cancel{\frac{P_1}{\gamma}} + \cancel{\frac{V_1^2}{2g}} + \cancel{z_1} + \cancel{h_s} = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + z_2 + \frac{f l V^2}{2gD} + \cancel{\frac{K_L V^2}{2g}}$$


$$-\frac{P_2}{\gamma} - z_2 = \frac{V_2^2}{2g} + \frac{f l V^2}{2gD} = \frac{V_2^2}{2g}\left[1 + \frac{f l}{D}\right]$$

$$V_2^2 = \frac{2g\left[-\frac{P_2}{\gamma} - z_2\right]}{\left[1 + \frac{f l}{D}\right]}$$

$$V_2 = \sqrt{\frac{2 \times 9.8\frac{m}{s^2}\left[\frac{9800\,N/m^2}{9800\,N/m^3} - 0.56m\right]}{\left[1 + \frac{f \times 0.56m}{0.006m}\right]}}$$

$$V = \sqrt{\frac{8.624\ m^2/s^2}{1 + 93.33f}}$$

$P_2 = -9800\,N/m^2$

$\gamma = 9800\,N/m^3$

$z_2 = 0.56\,m$

$l = 0.56\,m$

$D = 0.006\,m$

$\varepsilon = 0$ = smooth

* iterative procedure

$Re = 1000\frac{kg}{m^3} \times \frac{V \times 0.006\,m\,m^2}{0.00112\,Ns}$

$\frac{\varepsilon}{D} = 0$

| Guess f | Calculate V | calculate Re | look up f |
|---|---|---|---|
| 0.01 | 2.11 m/s | 11,300 | 0.018 |
| 0.018 | 1.79 m/s | 9600 | 0.031 |

can stop after 2 iterations => $V = 1.79\ m/s$

**Figure 2.** Example pipe flow error detection problem; there are four mistakes (see Appendix)

**Final Exam, pipe flow problem:** In Maui's Iao Valley water is diverted from a pool in the main stream through a pipe to irrigate taro patches. A crude representation is shown in the schematic. The total length of the pipe is 200 m and the sum of all the minor loss coefficients is 4.2. If the pipe wall is smooth, what is the flowrate at the exit of the pipe? Give answer in $m^3/s$.

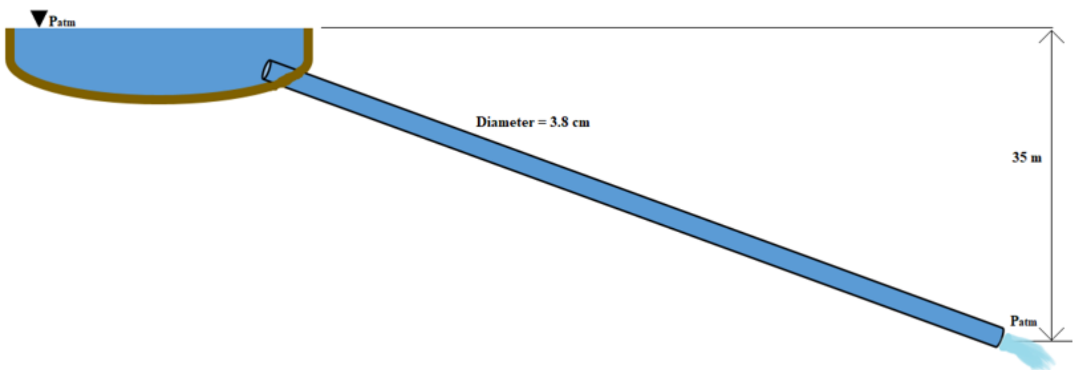



**Figure 3.** Example pipe flow problem requiring a full solution

## Results

The results from the error detection exam problems are provided in Table 1 in addition to relevant problem topics that were also assessed by students providing full solutions. It is noted that the grade time reported corresponds to the time required for the course instructor to grade that problem for all 34 students at UST. Grading was not timed at UMN as the grading was completed by more than one person. One hope for implementing error detection problems on the exam was that they might be faster to grade since the number of mistakes in the solution was limited. However, students completing error detection problems could still make any variety of mistakes in what they identified as an error. Additionally, it was found that error detection problems required students to write more text in their answer than a typical full solution problem. As many students have handwriting that is difficult to read, this was another confounding factor that could increase the amount of time required to grade. It was found that for the pipe flow problems, the error detection grade time was almost double that of the full solution despite the grades being similar. For the Bernoulli problem the grade time is much lower for the error detection problem, however the scores were much higher. As it takes much less time to grade a problem when the work is correct, it is more likely that this is the reason for the difference in grade time on the Bernoulli problems. One other potential concern when using error detection problems in place of full solution problems could be grade inflation caused by the problem modality. More specifically, would it be easier to hide one's lack of understanding on an error detection exam question? The data in Table 1 do not show evidence to support this concern. In fact, at UMN the average score on error detection exam problems was lower than the average score on full solution problems.

**Table 1.** Summary of pertinent exam question results

| University | Exam | Subject | Modality | Avg. Score (%) | Grade Time (min.) |
|---|---|---|---|---|---|
| UST | Midterm 1 | Bernoulli | Full Solution | 78.7 | 83 |
| UST | Final | Bernoulli | Error Detection | 95.2 | 11 |
| UST | Midterm 2 | Pipe Flow | Error Detection | 86.1 | 59 |
| UST | Final | Pipe Flow | Full Solution | 82.5 | 30 |
| UST | Final | Dimensional Analysis | Error Detection | 77.8 | 23 |
| UMN | Midterm 1 | Bernoulli | Error Detection | 56.5 | |
| UMN | Final | Bernoulli | Full Solution | 90.2 | |
| UMN | Final | Drag | Error Detection | 43 | |
| UMN | Final | Drag | Full Solution | 77.2 | |
| UMN | Midterm 2 | Dimensional Analysis | Error Detection | 77.1 | |

The survey results for each university are presented in Figs. 4-8. In Fig. 4 it is seen that a large majority of students (83% at UST and 74% at UMN) are in agreement that student performance on full solution problems should correspond with performance on error detection problems. This suggests that error detection problems may serve as a reasonable proxy for full solution problems on exams without facing resistance from the majority of students.

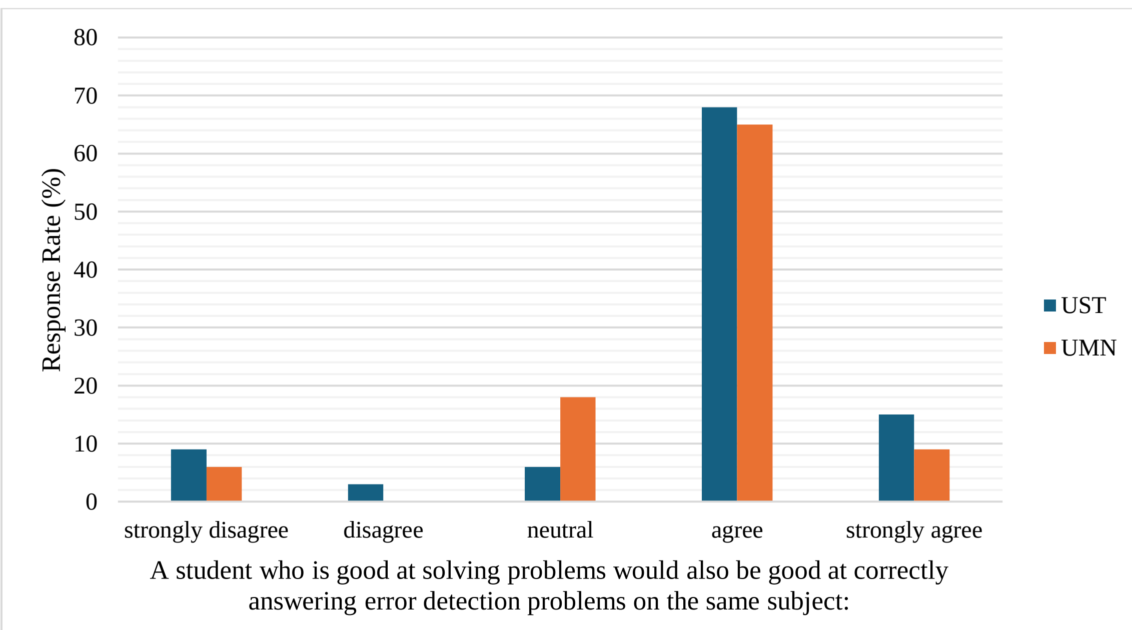



**Figure 4.** Student responses to survey question 1

Figure 5 shows a comparison of the student responses regarding the time required to complete an error detection problem vs. a full solution problem. There is a marked difference between the responses with students at UST concluding that error detection problems take less time whereas students at UMN believe that they required more time. One possible explanation for this could be that there was a slight difference in the instructions to the students at each university. At UST the instructor informed the students that for any error detection there would be at least one error in the provided solution while at UMN the students were told that a zero-error problem could be given.

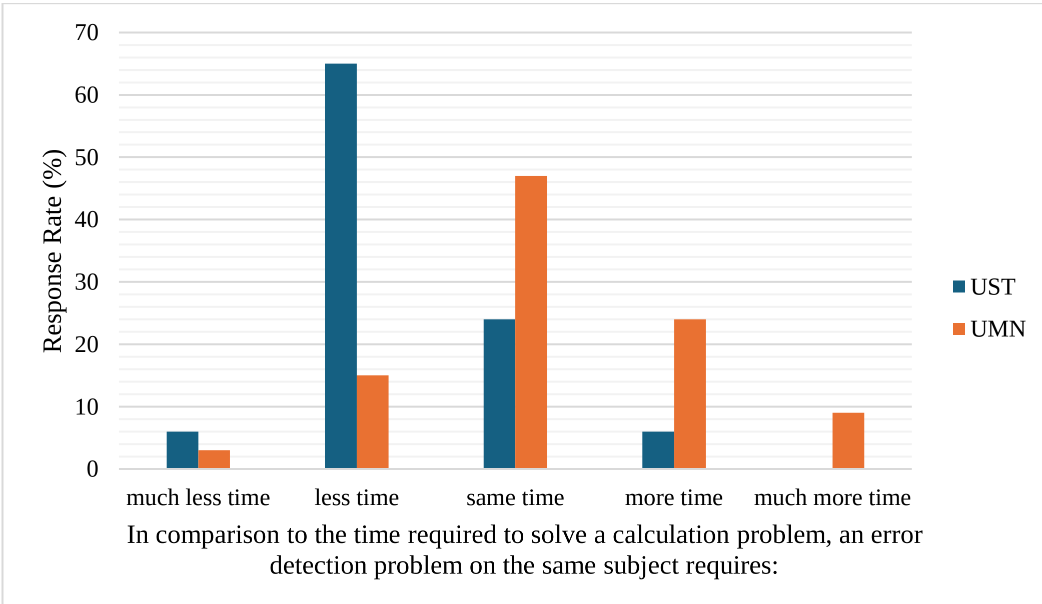



**Figure 5.** Student responses to survey question 2

Figure 6 shows that students at both universities largely agree that error detection problems are useful to use during lecture and problem-solving sessions. Additionally, Fig. 7 demonstrates the level to which students think error detection problems should be incorporated. Based on the prior research [11] that concludes that error detection problems are more useful to implement after students have built a base of knowledge for a subject, the instructors in this study incorporated these problems towards the end of a chapter, or during review sessions, and after students had worked similar problems by providing full solutions. The student responses suggest that this strategy was useful for the topics covered in fluid mechanics and instructors are encouraged to consider adding one error detection problem for each chapter. The fact that students do not feel more strongly about having more error detection problems suggests that they may feel there will be diminishing returns by increasing their use, which would also result in less time for full solution example problems.

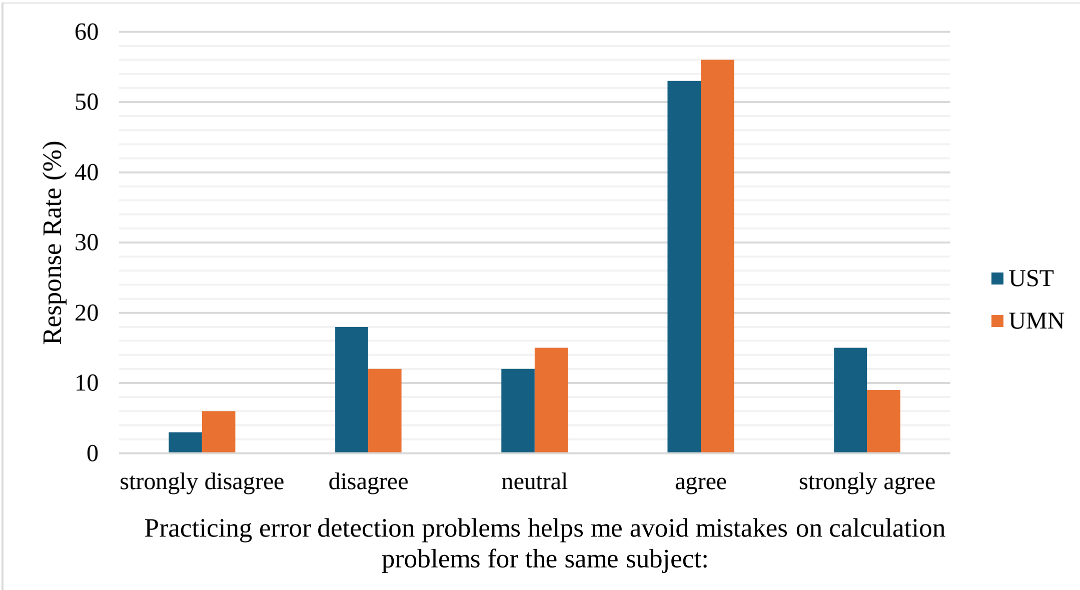



**Figure 6.** Student responses to survey question 3

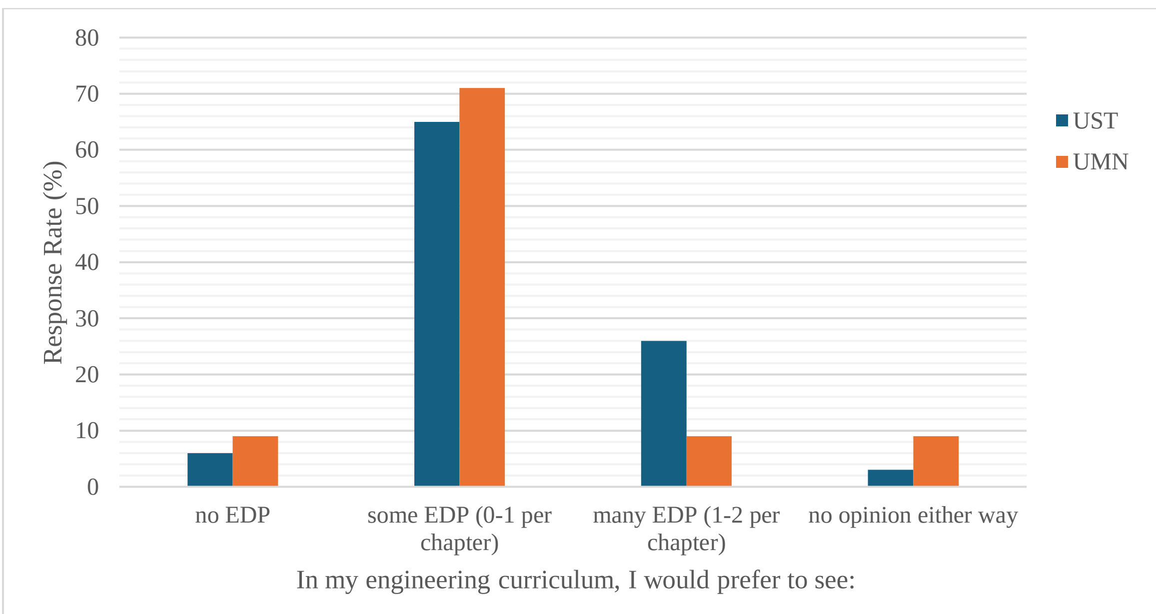



**Figure 7.** Student responses to survey question 4 (EDP = error detection problem)

Figure 8 provides results to help understand if error detection problems were being used in other engineering, math, physics, chemistry, or computer science courses that the students had taken or were taking. At both universities students indicated that the use of error detection problems in this study was largely a unique experience.

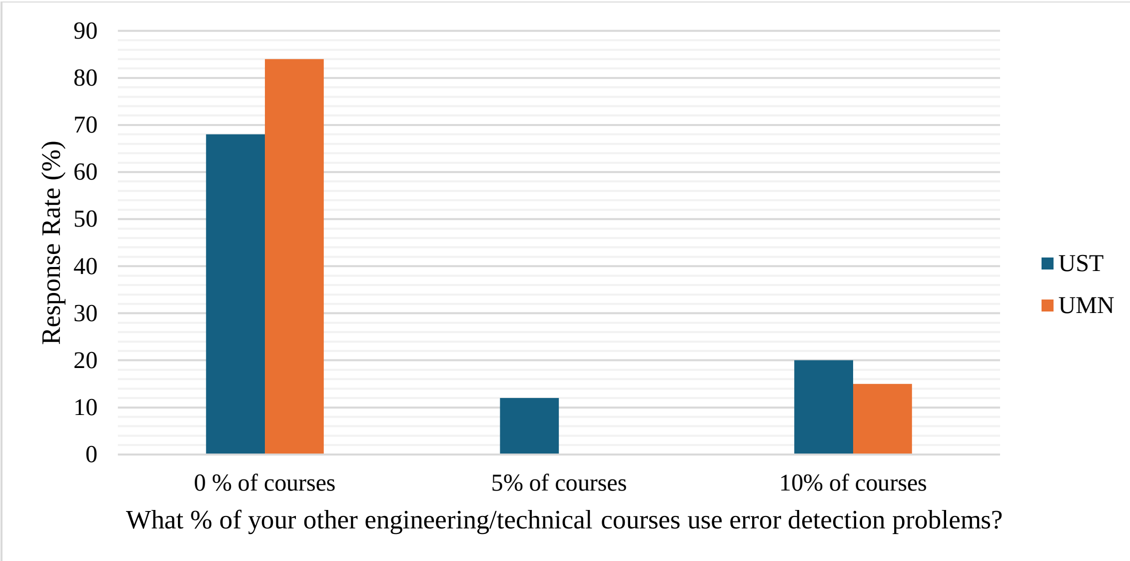



**Figure 8.** Student responses to survey question 5

The final survey question was open-ended and asked students to provide general feedback on their experience with error detection problems during the semester. To summarize the feedback provided a taxonomy was created to organize the comments into three categories: things they thought were good about using error detection problems, things they thought were bad about using error detection problems, and practical implementation ideas. There was incredible overlap in the comments provided by the students at each university and the collective feedback is summarized here:

**Student Feedback - Good things**

- Don't take too long to answer
- Allowed me to demonstrate knowledge of topic in time efficient manner (multiple students)
- Highly recommend, it works a different part of the brain than doing a full solution
- Seeing common mistakes helps me to not make those mistakes (multiple students)
- Effective at reinforcing solution process for complex problems (multiple students)
- I see the relevance for work in industry (multiple students)
- Very helpful!
- Personally, I liked them. It allows me to work on conceptually understanding material so I know what is feasible in a problem and how to solve any possible errors in these style problems. I would like to see more of these types of problems.
- I think they're good problems and would make a great addition to a lot of different curricula in the engineering department (multiple students).
- Error detection problems are very useful in making sure that we as students understand how to complete the problem. As well as understanding how the TA or professor grades our homework/quiz/midterms

**Student Feedback - Bad things**

- There were times I just re-solved the problem (multiple students) as I have a hard time following other people's work
- If student had practiced similar problems using a slightly different method, it could be confusing (multiple students)
- I tend to overthink, so it takes me more time than likely intended
- Hard to know when to stop looking for errors
- If the mistake is propagated in the solution, is that still just one mistake? (multiple students)
- I think I would miss mistakes if they were not ones I would be likely to make (multiple students)
- I think traditional problems are generally better at evaluating understanding of material. If you miss a small detail on a traditional problem, then you can generally still demonstrate your understanding of the material, but missing the relatively small error in and error detection problem can be easy to miss.

**Student Feedback - Practical implementation ideas**

- Very helpful when used in class (multiple students)
- Choose common mistakes as opposed uncommon mistakes that are hard to find
- Consider telling students the number of mistakes (multiple students)
- When lots of calculations are involved, they become tougher – (maybe focus them on problems done using just variables?)
- Prefer to not have errors in units, better in equations and diagrams
- Best suited for time-consuming problems
- Students also need to know how to work out a full solution - i.e. don't only use error detection problems in a course, or don't overuse them as the primary way of instructing a process (multiple students)
- The work in the error detection solution should be completely organized
- I prefer them as practice problems vs. exam problems
- More practice with them prior to an exam would be helpful (multiple students)
- Error detection problems should be given during homework assignments in order to practice for the exams. I think they're valuable, but during the exams I didn't really know how to annotate the problems. Would've liked to have had more practice prior to the exams.
- Make it clear if we should circle all mistakes, or just the main ones that lead to other mistakes
- Helpful, maybe better for quizzes.
- It would be better if you just left it as circling the errors present and then having students explain the error as opposed to counting the errors

## Discussion

At the genesis of this study, the authors were considering error detection problems with a view towards their inclusion on exams. In the process of reading the previously published studies and deliberating how to make sure students were prepared for error detection exam problems, the class structure also experienced a small change to the variety of example problems on which students practiced. The prior research and student feedback from the current study make a strong case for using error detection problems during lecture and review sessions. This would be true for most engineering courses, not just fluid mechanics. The results presented here suggest that error detection problems could be utilized at a rate of around once per chapter (and presented only after students have had practice completing full problem solutions). It is expected that greater use of error detection problems throughout the term will be useful for student learning but will also make them easier to implement on exams.

The experience of using error detection problems on exams was mixed and the student feedback will be particularly useful for future implementation. In terms of reducing the grading time, the results did not allow for strong conclusions. However, the instructor at UST who measured the grade time for a dimensional analysis problem related to the formation of similarity parameters believes that it was faster to grade this problem as an error detection problem compared to a full solution problem. As the method of repeating variables used in dimensional analysis allows for multiple correct but different answers to a given problem, the instructor historically would need to solve the problem using multiple variations of repeating variables. This adds to the time required to grade all the exams when students provide a full solution. Thus, it is believed that the utility of error detection problems on exams to reduce grading time will depend on the type of problem involved. It is possible that an audit of future exam problems including their time to complete (for the instructor), student performance and grade times may help identify problem topics that are most suitable for assessment via error detection problems. Ultimately, the instructors' experience and student feedback indicate that error detection problems could be implemented on engineering exams, in a limited but possibly impactful way, without receiving large pushback from students.

The results presented are from a pedagogical innovation that the authors ran in two separate classes to explore the idea of using error detection problems in a fluid mechanics course on exams. Note that this was not intended to be a rigorous experiment. The conclusions seen seem to show that there is value for both the students and the instructors in using error-detection problems. Future studies could leverage these results and further explore comparisons of student performance with a control group as well as assess how the scoring/grading criteria could affect the student performance and grading workload.

A common source of confusion, and suggestion for improvement, when using error detection problems on exams relates to whether the instructor should tell students the number of errors in each solution. This confusion is related both to the question of how to deal with errors that propagate from one step to another, but also to giving students guidance on when to know that they have completed the problem. It is believed that with greater incorporation of error detection problems prior to an exam, more clarity in the instructions and being more deliberate in the errors one includes these concerns could be reduced. However, when error detection problems are used solely as example problems as opposed to on high-stakes assessments such as exams these concerns may be moot.

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**References**

[1] Kalyuga, Slava, et al. "When problem solving is superior to studying worked examples." *Journal of educational psychology* 93.3 (2001): 579.

[2] Van Gog, Tamara, and Nikol Rummel. "Example-based learning: Integrating cognitive and social-cognitive research perspectives." *Educational psychology review* 22 (2010): 155-174.

[3] Sweller, John, Jeroen JG Van Merrienboer, and Fred GWC Paas. "Cognitive architecture and instructional design." *Educational psychology review* 10 (1998): 251-296.

[4] Sweller, John, and Graham A. Cooper. "The use of worked examples as a substitute for problem solving in learning algebra." *Cognition and instruction* 2.1 (1985): 59-89.

[5] Atkinson, Robert K., et al. "Learning from examples: Instructional principles from the worked examples research." *Review of educational research* 70.2 (2000): 181-214.

[6] Kalyuga, Slava, and John Sweller. "Measuring knowledge to optimize cognitive load factors during instruction." *Journal of educational psychology* 96.3 (2004): 558.

[7] Van Gog, Tamara, Liesbeth Kester, and Fred Paas. "Effects of worked examples, example-problem, and problem-example pairs on novices' learning." *Contemporary Educational Psychology* 36, no. 3 (2011): 212-218.

[8] Booth, Julie L., et al. "Using example problems to improve student learning in algebra: Differentiating between correct and incorrect examples." *Learning and Instruction* 25 (2013): 24-34.

[9] Durkin, Kelley, and Bethany Rittle-Johnson. "The effectiveness of using incorrect examples to support learning about decimal magnitude." *Learning and Instruction* 22.3 (2012): 206-214.

[10] Siegler, Robert S. "Microgenetic studies of self-explanation." *Microdevelopment: Transition processes in development and learning* (2002): 31-58.

[11] Große, Cornelia S., and Alexander Renkl. "Finding and fixing errors in worked examples: Can this foster learning outcomes?." *Learning and instruction* 17.6 (2007): 612-634.

[12] Melis, Erica. "Erroneous Examples as a Source of Learning in Mathematics." *CELDA* 2004 (2004): 311-318.

[13] Richey, J. Elizabeth, et al. "More confusion and frustration, better learning: The impact of erroneous examples." *Computers & Education* 139 (2019): 173-190.

[14] Chen, Xingliang, Antonija Mitrovic, and Moffat Mathews. "Learning from worked examples, erroneous examples, and problem solving: Toward adaptive selection of learning activities." *IEEE Transactions on Learning Technologies* 13.1 (2019): 135-149.

[15] Stark, Robin, Veronika Kopp, and Martin R. Fischer. "Case-based learning with worked examples in complex domains: Two experimental studies in undergraduate medical education." *Learning and instruction* 21.1 (2011): 22-33.

[16] Gharibyan, Hasmik. "Assessing students' knowledge: oral exams vs. written tests." *ACM SIGCSE Bulletin* 37.3 (2005): 143-147.

[17] Parsons, David. "Is there an alternative to exams? Examination stress in engineering courses." *International Journal of Engineering Education* 24.6 (2008): 1111-1118.

**Appendix**

The error detection problem in Fig. 1 has four mistakes. The textbook used for the course was A Brief Introduction to Fluid Mechanics, $5^{th}$ edition, by Young, Munson, Okiishi and Huebsch. In this text the method of repeating variables is presented as an eight-step process. The errors that occur in the solution shown in Fig. 1 are:

1. The dependent variable ($D_b$) cannot be used as one of the repeating variables.
2. The list of repeating variables must stay constant for each Pi term. Thus, when finding the second Pi term you cannot not swap d in for $D_b$ as a repeating variable.
3. In finding the second Pi term, not all of the exponents for the Mass dimension are correctly accounted for.
4. Because of mistake 3, the resulting second Pi term is not actually dimensionless. Step 7 of the method of repeating variables specifically tells students to double check this. The Pi term as shown would have dimensions of $ML^{-2}$.

The error detection problem in Fig. 2 has four mistakes. While not shown in this paper, the exam provided to the students included the Moody Chart as well as various tables and figures detailing different minor loss coefficients. The errors that occur in the solution shown in Fig. 2 are:

1. The solution ignores the fact that there would be one minor loss in the problem for the reentrant inlet condition into the straw.
2. While it is correct to say that the length of the pipe is 0.56 m, the elevation difference between point 1 and point 2 is 0.51 m (not 0.56 m) because point 1 is at the water free surface.
3. During the first step of the iterative procedure the student would need to look-up the friction factor (f) from the Moody Chart for Re = 11,300 and $\varepsilon/D = 0$. This would give a f = 0.027 while the solution shown incorrectly uses f = 0.018.
4. The iterative solution shown stops prematurely. One would stop iterating once the friction factor looked up was very close to the friction factor value guessed at the start of an iteration. Since f = 0.031 is not near f = 0.018 it is incorrect to stop the iterative procedure.