Changes in Student Confidence, Strategies, and Reflection in a FE Review Course in Chemical Engineering

Sheima J. Khatib
Department of Chemical Engineering
Texas Tech University

Roman Taraban
Department of Psychological Sciences
Texas Tech University

William D. Lawson
Department of Civil, Environmental, and Construction Engineering
Texas Tech University

Abstract

The Fundamentals of Engineering (FE) exam is a nationwide, criterion-referenced, discipline-specific test. The present study focuses on chemical engineering seniors who completed a 3-credit course that reviewed major FE topics like mass transfer and fluid mechanics in order to prepare for taking the FE exam. Changes in students' confidence and reflective processing were measured through a weekly survey for which they received a small homework credit. Survey responses were submitted by approximately 100 students after each of eight weekly problem-solving homework assignments. Comparing survey responses submitted over eight weeks, we found significant gains in confidence after FE review activities, significant engagement with reflective processing during FE review, and relatively consistent levels of gains in confidence and in reflective activities. We consider how the present findings could aid instructors in the assessment of instructional practices.

Introduction

The Fundamentals of Engineering (FE) exam is a nationwide, criterion-referenced, discipline-specific test. Much can be said about the FE Exam including its origin and history, key changes over the years, the fundamental stated purpose for the FE exam, alternative uses of FE Exam pass rate data, such as evidence for ABET program accreditation, and more. Engineering students typically take the FE exam late in their senior year (within two long semesters of graduation). Students take the FE exam for a variety of reasons, most often as a first step toward engineering licensure as a Professional Engineer (PE). University programs may make the FE exam optional or obligatory.

Across the major engineering disciplines for which FE discipline-specific exams do exist – chemical, civil, electrical, environmental, industrial, and mechanical – the percentage of graduates who become licensed professional engineers varies. Indeed, most graduates in the USA are not required to take the FE. However, students who go on to jobs may be asked after two or so years to take the FE in their company. Also, helping students pass the FE also serves to remind students of

material they studied in the past years and to pull back the main points of those courses so that they get the chance to deal with all the material in a more holistic way.

The present study focuses on chemical engineering seniors who completed a 3-credit review course, in part to prepare for taking the FE exam, but also to review major topics in preparation for a capstone design course the following semester and, generally, for the chemical engineering profession. During the first eight weeks, the course reviewed major FE topics from chemical engineering courses, like mass transfer, heat transfer, and fluid mechanics. The course instructor used active learning methods during lectures and discussion sections, like Think-Pair-Share and Skeleton Notes. Students obligatorily took a half-length FE practice exam mid semester. The exam consisted of FE-type multiple choice questions targeting only the chemical engineering specific problems. Those who did not pass the practice test, where "passing" was identified as correctly answering 50 percent or more questions on the exam, took a second practice test at the end of the semester.

The present research focuses on changes in students' confidence, problem-solving strategies, and reflective (metacognitive) thinking as they worked through the lectures and homework across the semester. Problem-solving strategies are deliberate cognitive steps to proceed in specific ways at various points during problem solution in order to analyze, solve, and reflect on a problem [1, 2]. Reflective thinking is an intentional cognitive process in which an individual mentally revisits aspects of an experience, assigns meaning to the experience, and considers how the experience could guide future behavior [3, 4].

The following research questions were addressed:

1. Does students' confidence to solve FE problems change after reviewing each FE review topic?
2. Are students reflective about the review material?
3. Do students consistently achieve high confidence?
4. Are students consistently reflective?
5. Is confidence correlated with mock FE test scores?

Methods

The research was conducted in a senior-level FE review course in chemical engineering at a public Research I (Carnegie designation) university in the southwest of the USA. The course was led by one instructor who had taught the course several times before this study was conducted. In order to track students' gains in chemical engineering knowledge and problem solving, changes in metacognitions, and changes in attitudes, students submitted responses to a weekly survey instrument for which they received a small homework credit. See the Appendix for a copy of the survey.

The survey instructions to students were the following: *Research has demonstrated that using metacognition, or thinking about how you think, during the learning process can be a very effective tool to improve understanding and retention of course material. During this semester, we will delve*

into employing metacognition as you review material you were given in the Chemical Engineering core courses in past years, in order to pass the FE exam. Your reflections will also help me to better understand what is and is not working in the reviews.

Two questions using a 5-point Likert scale (Not At All Confident (1) – Very Confident (5)) asked students to rate their confidence in solving the weekly problem set 1) before solving the problems and 2) after solving the problems. A third question (also using a 5-point Likert scale) asked students to rate how reflective (metacognitive) they were while solving the problem set (Not At All Reflective (1) – Very Reflective (5)). Three open-ended questions asked students to 4) briefly state why their confidence did or did not change after solving the problem set, 5) briefly describe the problem solving strategies they used to solve the problem set, and 6) briefly describe how they would change their strategies, if at all, on the next problem set. Finally, student mastery of the technical content was established based on topic-level performance assessment through the practice exams.

Survey completion was assigned as a regular required homework assignment – i.e., all students participated in a manner consistent with course homework. Responses were submitted by approximately 100 students after each of eight weekly problem-solving homework assignments.

Each student submitted multiple responses to each question and thereby acted as his or her own control subject. In terms of a research design, this followed a repeated-measures method. The results presented here are only for the Likert ratings. We are currently analyzing responses to the open-ended questions regarding confidence and strategies, and therefore those findings are not reported here. The statistical methods of analysis are *t*-tests and Pearson correlations, using IBM SPSS Version 24[1].

Results and Discussion

The results are summarized in **Table 1**. To address the first research question, *Does students' confidence to solve FE problems change after reviewing each FE review topic?*, the mean values for Questions 1 and 2 were calculated, and were respectively 2.70 and 3.52. These values are significantly different and higher post-review. The corresponding *p*-values obtained from the *t*-tests for each week show that students expressed significantly higher confidence in the material after the class lecture/discussion and solution of the homework problems compared to their confidence prior to the FE review activities.

[1] https://www.ibm.com

Table 1. Mean Likert Ratings (standard error in parentheses) for Mean Confidence, Question 1 (Q1), and Question 2 (Q2), and Tests of Statistical Significance for Gains in Confidence (Q2 - Q1) by Week (See Appendix for full statement of questions.)

Week	Mean Confidence Rating	Pre-Confidence Rating (Q1)	Post-Confidence Rating (Q2)	*t*-value Q2-Q1	*p*-value*
1: MB**	3.45 (.09)	3.05 (.11)	3.85 (.10)	7.87	**.001**
2: EB	3.18 (.09)	2.63 (.11)	3.74 (.10)	10.82	**.001**
3: HT	3.45 (.10)	3.12 (.12)	3.77 (.11)	7.28	**.001**
4: MT	2.40 (.10)	2.05 (.10)	2.74 (.11)	7.55	**.001**
5: FM	3.67 (.09)	3.23 (.11)	4.11 (.09)	9.06	**.001**
6: RE	3.45 (.09)	3.14 (.11)	3.76 (.10)	6.23	**.001**
7: MS	2.91 (.12)	2.59 (.13)	3.24 (.12)	7.75	**.001**
8: PC	2.37 (.09)	1.77 (.11)	2.97 (.10)	12.34	**.001**

Notes. *p-values < .05 are bolded; **MB: Material Balance; EB: Energy Balance and Thermo; HT: Heat Transfer; MT: Mass Transfer; FM: Fluid Mechanics; RE: Reaction Engineering; MS: Material Science; PC: Process Control.

In order to address the second research question, *Are students reflective about the review material?*, mean values for Q6 were calculated and are shown in **Table 2**. The means show that students' reflective (metacognitive) processing exceeded a neutral value of 3 during each of the review weeks. These findings suggest that students engaged in significant levels of reflective thinking while solving the FE review problems. Reflecting on the process of solving problems has long been considered indicative of growth and development with a domain, as well as an ultimate characteristic of expert problem solvers [5]. Visual inspection of the means did not affirm a monotonic increase in means from Week 1 to 8.

Table 2. Mean Reflection Ratings for (Q6) by Week. (See Appendix for full statement of questions.)

Week	Mean Reflection Rating (Q6) (Standard Error in Parentheses)
1: MB**	3.60 (.09)
2: EB	3.82 (.09)
3: HT	3.74 (.11)
4: MT	3.52 (.13)
5: FM	3.68 (.11)
6: RE	3.72 (.10)
7: MS	3.62 (.10)
8: PC	3.55 (.12)

Notes. **MB: Material Balance; EB: Energy Balance and Thermo; HT: Heat Transfer; MT: Mass Transfer; FM: Fluid Mechanics; RE: Reaction Engineering; MS: Material Science; PC: Process Control.

By correlating Likert confidence ratings from the first week with confidence ratings in the final week, it is possible to assess the consistency with which the same students reach a similar level of confidence over time. This correlation addressed the third research question, *Do students consistently achieve high confidence?* A Pearson correlation coefficient between Q2 in the first and final weeks of $r(92) = 0.22$, $p = .032$ showed a significant correlation and suggested that students are relatively consistent in the levels of confidence that they gain across multiple topics of material in a course.

A similar analysis to that applied to research question 3 was applied to research question 4, *Are students consistently reflective?* A Pearson correlation coefficient between Q6 in the first and final weeks of $r(92) = 0.46$, $p < .001$ showed a significant correlation and suggested that students are relatively consistent in the levels of reflective processing that they engage in across multiple topics of material in a course.

In order to address the fifth research question, *Is confidence correlated with the mock FE test score?*, Spearman non-parametric correlations were applied separately to Question 1 and Question 2, as shown in **Table 3**. Pre-confidence ratings (Q1) correlated significantly with mock FE scores in 2 of the 8 weeks of review, suggesting that confidence in general—i.e., absent review—is a factor in mock FE test performance. Post-confidence ratings (Q2) were significantly correlated with mock FE scores in 5 of the 8 weeks of review, suggesting that confidence is a factor in mock FE test

performance. The observation (without statistical confirmation) that the majority of post-confidence ratings significantly correlated with mock FE test performance further suggests that the increase in confidence due to the review activities aided mock FE test performance, although this is speculative here and requires additional data for confirmation.

Table 3. Spearman Correlations (rho) Between Question 1 (Q1) and FE Test Score, and Question 2 (Q2) and FE Test Score. *P*-value for One-Tailed Tests of Significance in Parentheses (See Appendix for full statement of questions.)

Week	Pre-Confidence Rating (Q1) with mock FE score	Post-Confidence Rating (Q2) with mock FE score
1: MB**	.257 (**.005**)*	.260 (**.005**)
2: EB	.135 (.092)	.287 (**.002**)
3: HT	.081 (.213)	.195 (**.027**)
4: MT	.138 (.088)	.154 (.064)
5: FM	.145 (.077)	.256 (**.005**)
6: RE	.253 (**.006**)	.290 (**.002**)
7: MS	.085 (.203)	.026 (.398)
8: PC	.110 (.142)	.004 (.485)

Notes. *p-values < .05 are bolded; **MB: Material Balance; EB: Energy Balance and Thermo; HT: Heat Transfer; MT: Mass Transfer; FM: Fluid Mechanics; RE: Reaction Engineering; MS: Material Science; PC: Process Control.

Summary and Conclusions

In comparing survey responses submitted during eight weeks, we found significant gains in confidence after FE review activities, significant engagement with reflective processing during FE review, and relatively consistent levels of gains in confidence and in reflective activities. The results also suggest that the boost in confidence correlated with the performance on the chemical engineering specific mock FE exam. These results suggest that students achieved meaningful gains in the context of the FE course. A major element of this success that remains unknown in the present study concerns details of the classroom and out-of-class activities that precipitated the observed gains. Therefore, an important goal for future research is to gain more information regarding the FE review curriculum implemented by the instructor.

Simple ratings in the present study revealed significant change as well as stable performance traits in students. The ease with which these data can be collected and analyzed should encourage instructors to apply easily implementable assessment tools in order to monitor the effectiveness of their instructional practices.

The present analyses considered only the Likert-type ratings. As a next step we will analyze the data for Questions 3-5 (See Appendix) in order to learn in more detail about students' cognitions related to their sense of problem-solving confidence and the problem-solving strategies that they employed for FE review. Additional data and analyses may indicate that these findings are generalizable to other areas of engineering training.

Appendix

Please respond to the following questions briefly:

1) On a scale of 1-5, indicate how confident were you with your capability of solving (Material Balance (Week 1); Energy Balances and Thermo (Week 2); Heat Transfer (Week 3); Mass Transfer (Week 4); Fluid Mechanics (Week 5); Reaction Engineering (Week 6); Materials Science (Week 7); Process Control (Week 8)) problems before solving the FE practice problems? (Circle a number or a point in between two numbers.)

1 *(not at all confident)* **2** **3** *(confident)* **4** **5** *(very confident)*

2) On a scale of 1-5, indicate how confident you were after solving the FE problems. (Circle a number or a point in between two numbers.)

1 *(not at all confident)* **2** **3** *(confident)* **4** **5** *(very confident)*

3) Briefly describe why your confidence changed or did not change.

4) Briefly describe the problem-solving strategies you employed to solve the FE practice problems.

5) Briefly describe how you will change your problem-solving strategies on the next set of problems, if at all.

6) On a scale of 1-5, how reflective (metacognitive) were you when solving this assignment? (Circle a number or a point in between two numbers.)

1 *(not at all reflective)* **2** **3** *(reflective)* **4** **5** *(very reflective)*

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SHEIMA J. KHATIB
Sheima J. Khatib is Assistant Professor in the Department of Chemical Engineering at Texas Tech University. She received her Ph.D. in Chemistry in the area of heterogeneous catalysis from the Autonomous University of Madrid. Apart from her interests in chemical engineering and finding sustainable paths for production of fuels and chemicals, she is passionate about engineering education, application of active learning strategies and metacognition in the classroom.

ROMAN TARABAN
Roman Taraban is Professor in the Department of Psychological Sciences at Texas Tech University. He received his Ph.D. in cognitive psychology from Carnegie Mellon University. His interests are in how undergraduate students learn, and especially, in critical thinking and how students draw meaningful connections in traditional college content materials.

WILLIAM D. LAWSON
William D. Lawson is Associate Professor Department of Civil, Environmental, and Construction Engineering at Texas Tech University.