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Student Confidence and Metacognitive Reflection with Correlations to Exam Performance in a FE Review Course in Chemical Engineering

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Student Confidence and Metacognitive Reflection with Correlations to Exam Performance in a FE Review Course in Chemical Engineering

Abstract

Metacognitive reflection and problem-solving confidence are important factors in the development of problem-solving skills. The present research focuses on chemical engineering seniors who completed a 3-credit course that, in part, reviewed major Fundamentals of Engineering (FE) Chemical 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 98 students after each of eight weekly problem-solving review sessions. Quantitative survey responses showed significant gains in confidence after FE topic review activities and relatively consistent benefits in FE test performance associated with confidence ratings and metacognitive reflection ratings. The present methods and findings provide a tentative model for ongoing course assessment that could aid engineering educators in strengthening instructional practices.

Introduction

One of the most influential models for problem-solving is Polya's [1] 4-step model: 1) Understand the problem, 2) Develop a plan, 3) Carry out the plan, and 4) Look back. The model requires problem-solvers to be deliberate, critical, and reflective in their behavior. More generally, each step requires problem-solvers to be metacognitive about the problem they are addressing, that is, to reflect on their anticipated, current, and past problem-solving steps with respect to the problem solution they are pursuing. More recent models of problem solving have built on Polya's work [2]. Griggs and Benson [3], for example, included the processes of planning, revising, monitoring, and evaluating problem solutions, which are within the category of metacognitive elements of problem solving. These processes are metacognitive in the sense that they require the problem solver to reflect on (think about) and evaluate their problem-solving processes. Further, reflection has been shown to be important to performance in a variety of tasks. For instance, Anseel and colleagues [4] assigned participants to an Internet-based task and provided them with feedback on their performance. Participants who were taught to reflect on thoughts and actions associated with the task showed significant improvement in subsequent performance. Ellis and David [5] found that Israeli soldiers improved their performance in navigation exercises after reflecting on the behaviors to change and those to continue without change.

Problem-solving confidence has also been a point of emphasis in discussions of problem-solving in the engineering education literature and other STEM domains. Problem-solving confidence relates to the emotions of the solver with respect to the problem. Confidence is an affective response, in contrast to the cognitive responses associated with metacognitive reflection. Confidence relates to the "I Can" factor in Wankat and Oreovicz's [6] problem-solving model. Woods et al. [7] [8] also include being positive, motivated, and confident among the characteristics of successful problem solvers, as do other educators with an interest in improving the confidence (or self-efficacy) of engineering problem solvers [9] [10]. Lester et al. [11] suggested that "students' success or failure in solving a problem often is as much a matter of self-confidence, motivation, perseverance, and many other noncognitive traits, as the mathematical knowledge they possess" (p. 75).

We incorporated the metacognitive and affective factors of reflection and confidence into a required chemical engineering course. Given the importance of these factors as demonstrated in the engineering education literature and beyond, we were interested in testing their utility in monitoring student cognitive and affective changes and in assessing the correlations of these variables with student test performance.

The FE Review Course

The course, called Chemical Engineering Review, among other goals, aims at preparing students for the Fundamentals of Engineering (FE) exam. The 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). From an instructional perspective, helping students pass the FE exam serves to remind students of material they studied in 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 course reviewed major FE Chemical topics like mass transfer, heat transfer, and fluid mechanics. This course was sequenced to be taken during the first semester of a students' senior year. The order of review topics roughly corresponded to the order of topics in the Chemical Engineering undergraduate curriculum. The course instructor used active learning methods during lectures and discussion sections such as Think-Pair-Share and Skeleton Notes, as described in more detail below. Students obligatorily took a half-length FE practice exam, referred to in this paper as the *mock* FE exam, near mid-semester. 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.

Research Design

In this research, we measured changes in students' confidence, reflective (metacognitive) thinking, and problem-solving strategies as they worked through the lectures and homework across the semester. Figure 1 conceptually depicts the research design. Our approach was to introduce a survey instrument during each of the eight weekly review sessions (by topic) and use this brief survey to monitor both quantitative and qualitative perceptions of student confidence and reflection associated with engineering problem solving. See the Appendix for a copy of the survey. Upon completion of all topic reviews, students took the mock FE exam to assess overall content mastery.

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. The nature and practice of reflective thinking have been presented in the context of engineering education [12] [13], as well as in other domains [4] [5]. Problem-solving strategies are deliberate cognitive steps to proceed in specific ways at various points during problem solving in order to analyze, solve, and reflect on a problem [14] [15].

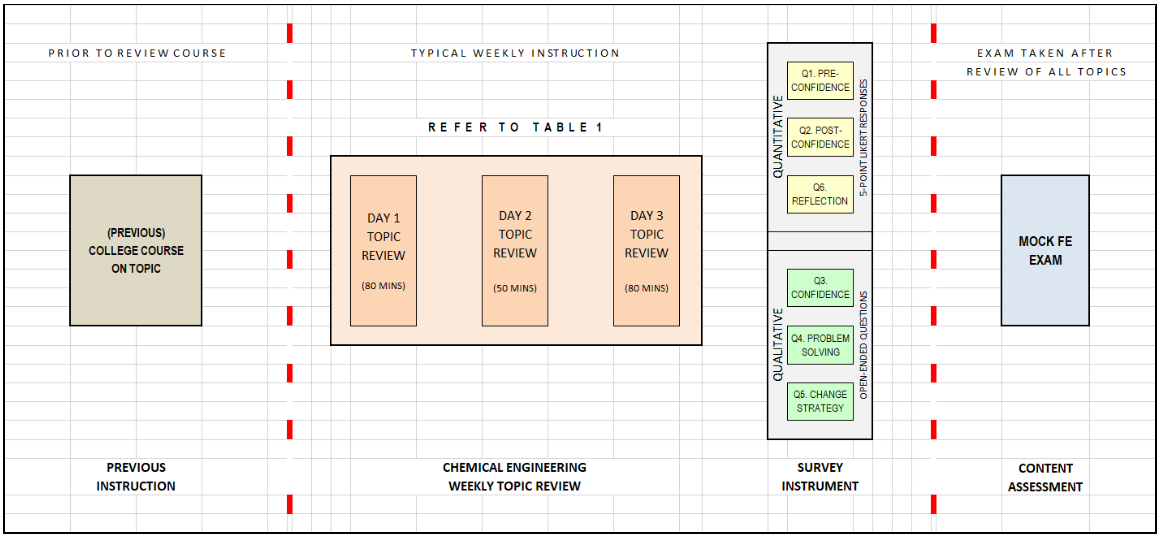

Figure 1. Conceptual Research Design

The present paper focuses on quantitative data obtained from Likert-type responses associated with confidence and reflection. Analyses of the rich body of qualitative data on problem-solving strategies that was collected as part of this research through responses to open-ended questions (qualitative) will be added to our findings in subsequent reports and are not analyzed in this paper, however, see the Discussion for sample responses to the open-ended questions.

This study was designed to address the following research questions, using quantitative analytic methods:

1. Does students' confidence increase with the number of weeks of review—i.e., is there a cumulative effect for confidence?
2. Does students' confidence to solve FE problems change after reviewing FE review topics?
3. Is confidence correlated with the mock FE test score?
4. Do students become increasingly reflective with each additional week of review—i.e., is there a cumulative effect for reflection?
5. Is reflection correlated with the mock FE test score?

Methods

Research Participants

The research was conducted in a required senior-level 3-credit review course in chemical engineering at a public Research I (Carnegie designation) university in the southwest of the USA. In the first part of the course, covered in about nine weeks, the goal was to prepare chemical engineering students for taking the chemical engineering section of the FE exam while simultaneously helping them review core-course material in preparation for a senior capstone design project. The second part of the course (about six weeks) was dedicated to reviewing simulation of major unit operations using HYSYS software in further preparation for a capstone design course the following semester. Total enrollment for the course was 101 students, and weekly attendance and responses associated with this research varied from 97 to 99 students. The course was led by one instructor who had taught the course several times before this study was conducted.

Educational Intervention – the Weekly FE Topic Review

The educational intervention associated with this research focused on the weekly topic reviews for eight chemical engineering core courses; namely, (1) Material Balances (**MB**), (2) Energy Balances/ Thermodynamics (**EB/T**), (3) Heat Transfer (**HT**), (4) Mass Transfer (**MT**), (5) Fluid Mechanics (**FM**), (6) Reaction Engineering (**RE**), (7) Materials Science (**MS**) and (8) Process Control (**PC**). Each week, students were exposed to a 30-45-minute mini-lecture reviewing the main concepts associated with the topic. The mini-lecture notes were uploaded on Blackboard[1] before class in the form of "skeleton notes" or notes with blanks, which the students filled out during the lecture. Next, the students were given handouts containing 15-20 FE-type multiple choice questions on the topic that was being covered in class that week. The rest of the lecture and discussion sessions were dedicated to solving these problems. Table 1 summarizes the activities that constituted a typical week of class when FE material was covered.

The format used in class to solve the FE-like problems was mainly think-pair-share[2]. For think-pair-share, students were given 30 seconds to read the problem, 1 minute to think and discuss solutions to the problem with their peers, and several minutes to discuss the different solution strategies in the class as a whole. The instructor encouraged students to share with the class alternative ways to solve problems. During the nine weeks, students were also given four formative quizzes (consisting of FE-type problems) on material that had been covered up to that point.

Table 1. Typical Learning Activities Associated with each Weekly Topic Review

	Day 1	Day 2	Day 3
Activity 1	20/30-minute lecture implemented with notes with blanks that students complete in class. Notes are previously posted for students to download or print before class. The lecture goes over main concepts of the topic covered on that week	50-minute class entirely dedicated to solving more FE-type problems, slightly more challenging than the ones presented on Day 1. For this exercise, the think-pair-share format was implemented, as instructor walked around class and answered individual questions during the thinking and pairing section of the exercise.	80-minute class dedicated to solving additional FE-type problems following the same format as Day 2. Occasionally more challenging Professional Engineer (PE) exam problems were included in the problem set provided on Day 3 to further stimulate student learning.
Activity 2	10-minute overview of equations related to the topic and their location in the *FE Supplied Reference Handbook*	Based on the different solution procedures that the instructor observed from different groups, she then asked some of the students to share their problem-solving strategies with the rest of the class.	
Activity 3	Class discussions on potential "muddy points" requiring extra explanations or more reviewing and clarification of concepts	Discussion on different procedures presented by students to solve problems	

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

[2] http://www.theteachertoolkit.com/index.php/tool/think-pair-share

Activity 4	First set of FE-type example problems (3-4 problems). Students were given 5-10 minutes to work on problems in groups as professor and TAs walked around answering individual questions. Class was then called to discuss the solution to each problem.	Additional think-pair-share activities based on questions and doubts arising from discussions on particular problems	
Activity 5	During discussion of solutions, students were encouraged to share different approaches to solving the same problem with the rest of the class, by presenting their work on the blackboard. Students were very enthusiastic about this approach of sharing alternative solution to problems, which sometimes led to a few more minutes of a class discussion/debate.		
Activity 6	These discussions led the instructor to informally implement encouragement of reflection during problem-solving.		Completion of the metacognitive survey as a "homework assignment"

Assessment of Content Mastery

The practice FE exam, referred to in class as the mock FE exam, consisted of a total of 40 FE-type multiple choice questions over the eight core chemical engineering topics covered in the review course. It is appropriate to note that this mock FE exam only assesses the *identified* topics and does not cover all 16 general knowledge and discipline-specific topics featured in the official Chemical Engineering FE Exam. The mock FE exam questions for each topic were provided by chemical engineering professors who taught the corresponding "parent" course in the curriculum at the institution, that is, by chemical engineering faculty subject-matter experts. This was done at the time the mock FE exam was designed, in 2008. The same mock FE exam is used every year, and to allow re-use of the exam from year to year, the exam is privately held and securely administered. Students are only exposed to the questions during the exam, and they are not allowed to see their work once the exam is taken, simulating the actual FE exam scenario.

Students were given a total of four hours to complete the mock FE exam, with no breaks. The average time given per problem was 6.0 minutes, which is about twice the time allotted on the actual FE exam (2.9 minutes/problem), however, on the mock FE exam students were given this extra time because they were required to show how they solved the problems. This requirement was included in order to encourage students to think about the problems and avoid simply guessing. If work was not shown, students did not receive points for their answer. The mock FE exam was administered on a Saturday after completion of all eight topic reviews, before moving on to the second part of the course. Students who passed the mock FE exam received all the required points for this section of the course. Students who did not pass (12 percent of the class) were given a second chance to retake the exam during finals at the end of the semester. The second-chance results were not used in this research. While the second exam was also open to students who had passed and simply wanted to repeat the exam, in the past five years that the instructor has taught this course, no passing students have volunteered to retake the practice exam during finals.

Monitoring Confidence and Reflection
In order to track students' perceptions about their chemical engineering knowledge and problem solving during the weekly topic reviews, as well as changes in metacognitions, and changes in attitudes, students submitted responses to a brief survey instrument for which they received a small homework credit. 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 – Very Confident) 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. These questions provided quantitative data on confidence and reflection. Three open-ended questions provided additional, qualitative data. These 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. Student mastery of the technical content was gauged based on topic-level performance through the formative bi-weekly practice exams and ultimately the summative (end of review) mock FE exam.

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 98 students after each of the eight weekly problem-solving topic reviews. Each student submitted multiple surveys (i.e., one for each of the eight topics) and thereby acted as his or her own control subject. In terms of a research design, this followed a repeated-measures method. All statistical tests were conducted using IBM SPSS Version 24.[3]

Results

The general statistical model used here applied a mixed-methods design in which temporal changes, from one topic to the next, were between-subjects factors, and pre-review to post-review changes in confidence were a within-subjects factor in which participants acted as their own control subjects. More specific statistical tests applied paired-sample *t*-tests and parametric and non-parametric correlation coefficient calculations.

The mean confidence ratings, by topic, and by question, are presented in Table 2. An analysis of the mean confidence ratings using the GLM procedure was conducted with Topic (1-8) and Question

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

(Q1: confidence rating pre-review, Q2: confidence rating post review) (within-subjects) as independent variables and Likert-ratings as the dependent variable. The results showed significant differences for Topic [$F(7, 595) = 37.46$, $p < .001$], for Question [$F(1, 85) = 190.30$, $p < .001$], and for the Topic by Question interaction [$F(7, 595) = 7.05$, $p < .001$]. The main effect for Topic indicates that there were significant differences between the mean confidence ratings by Topic, however, visual inspection clearly shows that there is not a monotonic increase in mean confidence by Topic. Therefore, the data do not affirm the first research question, *Does students' confidence increase with the number of weeks of review—i.e., is there a cumulative effect for confidence?*

Table 2. 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 Topic (See Appendix for full statement of questions.)

Topic	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/T	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. *Significant *p*-values ($p < .05$) associated with *t*-test are bolded.

The main effect for Question was also significant, indicating that the mean value for Question 1 (mean = 2.70) was significantly different from the mean value for Question 2 (mean = 3.52). This result provides an affirmative response to the second research question, *Does students' confidence to solve FE problems change after reviewing FE review topics?* In order to follow up on the interaction, paired-sample *t*-tests were conducted for each topic, as shown in Table 2. As indicated by the *p*-values associated with each of the *t*-tests, there was a significant gain in confidence after the review activities in each of Topics 1-8. The interaction effect in the GLM procedure was presumably due to some topics showing larger gains than others.

In order to address the third 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. Post-confidence ratings (Q2) were significantly correlated with mock FE scores in five of the eight topics of review, suggesting that confidence is a factor in mock FE test performance. Pre-confidence ratings (Q1) were significantly correlated with mock FE scores in two of the eight topics of review, suggesting that confidence in general—i.e., absent review—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 boost in confidence due to the review activities aided mock FE test performance, although this is speculative here and requires additional data for confirmation. We return to this issue in the Discussion.

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

Topic	Pre-Confidence Rating (Q1) with mock FE score	Post-Confidence Rating (Q2) with mock FE score
1: MB	.257 (**.005**)*	.260 (**.005**)
2: EB/T	.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.

The fourth research question addressed metacognitive reflection on the review activities: *Do students become increasingly reflective with each additional week of review—i.e., is there a cumulative effect for reflection?* The mean reflection ratings, by topic, are presented in Table 4. An analysis of the mean reflection ratings using the GLM procedure was conducted with Topic (1-8) (within-subjects) as the independent variable and Likert-ratings as the dependent variable. The results showed significant differences for Topic [$F(7, 602) = 2.37$, $p = .022$]. Although there were significant differences between some of the topics, as indicated by the main effect for Topic, visual inspection of the means did not affirm a monotonic increase in means from Topic 1 to 8. Therefore, the results do not support an affirmative response to the fourth research question.

Table 4. Mean Reflection Rating (Q6) and Spearman Correlations (rho) Between Q6 and Mock FE Test Score, by Topic. *P*-value for One-Tailed Test of Significance for Correlation in Parentheses (See Appendix for full statement of questions.)

Topic	Mean Reflection Rating (Q6) (Standard Error in Parentheses)	Q6 with mock FE score (*p*-value in parentheses)*
1: MB	3.60 (.09)	.141 (.083)
2: EB/T	3.82 (.09)	.215 (**.016**)
3: HT	3.74 (.11)	.175 (**.042**)
4: MT	3.52 (.13)	.149 (.071)
5: FM	3.68 (.11)	.094 (.178)
6: RE	3.72 (.10)	.190 (**.030**)
7: MS	3.62 (.10)	.118 (.124)
8: PC	3.55 (.12)	.208 (**.021**)

Notes. *p-values < .05 are bolded;

The final research question concerned the correlation of reflection and mock FE test scores: *Is reflection correlated with the mock FE test score?* In order to address this question, Spearman non-parametric correlations were calculated for each topic, as shown in Table 4. As indicated by the *p*-values associated with each of the correlations, there were significant positive correlations of reflection with mock FE test scores in four of the eight topics of review. These positive correlations suggest that greater engagement in metacognitive reflection was associated with higher mock FE test scores and support an affirmative response to the research question.

Discussion

In summary, the questions in this study concerned the effects of problem-solving confidence and metacognitive reflection on preparation for a mock FE exam and performance on the exam. The FE review sequence was divided into eight topics. Each topic was covered across three class days, with active learning transpiring throughout, as detailed in Table 1. The instructor implemented a weekly survey that provided the quantitative data reported here. The self-reported Likert-type ratings allowed the instructor to track changes in confidence and reflection over time.

The results showed that students expressed significantly higher confidence in their problem-solving ability after the class lecture/discussion and solution of the homework problems compared to their confidence prior to the FE review activities and homework. This significant gain in confidence appeared in each of the eight weeks of review activities. Post-review confidence was significantly correlated with mock FE test performance across the majority of reviewed topics. The strong correlations between confidence and problem-solving performance are consistent with the didactic admonitions of Wankat and Oreovitz [6] and the instructional practices implemented by Woods and colleagues [7] [8] in engineering education.

Although the correlations between confidence and test performance are strong in the present research, some gaps in the results deserve further attention. Table 3, for instance, shows null correlations between post-review confidence and mock FE test performance for review of Mass Transfer, Material Science, and Process Control. Upon reflection, it was not clear to the instructor why students did not feel confident with Mass Transfer (Topic 4) since the instructor dedicated extra classes to that topic. However, not all students had taken the Materials Science course prior to the FE review course and therefore may not have felt confident about that topic. One way to address this issue is to set the Materials Science course as a prerequisite for the review course in future years. Further, Process Control (Topic 8) is a course that is taught during the same semester as the FE review course. This topic was sequenced for the end of the review, the intent being that students will have covered at least some of the material by then. It was the instructor's sense that students felt very insecure about this topic, and the instructor dedicated a special lecture (crash course) covering the material needed for the FE (which was far smaller in scope than what students cover in the actual Process Control course).

The relationship between confidence and performance is well-documented in the research literature. However, because the present results are correlational, it is not possible to know the mechanism by which confidence affected mock FE test performance. One possibility is that the teacher-led activities (See Table 1) directly increased students' sense of self-confidence. Cervone and Peake [16], for example, showed that boosting students' self-confidence (through false feedback) resulted in higher test performance. The relationship between confidence and performance may, however, be more complicated. It is possible, for example, that through the teacher-led activities students gained self-confidence in solving FE-type problems, and, subsequently, the gain in self-confidence led to higher mock FE test performance. That is, problem mastery may have mediated the effect of self-confidence on test performance. This possibility is supported in Druckman and Bjork [17], for instance, who reported that "Research has supported that the strongest and most durable determinant of self-confidence is the experience of mastery or performance accomplishments" (p. 197), combined with the findings in Cervone and Peake.

It was not clear in the present study whether the mean level of self-confidence would increase as students progressed through the topics. As shown in the Results, there was no cumulative increase in self-confidence across topics. In retrospect, we note that the full topic review sequence (viewed as a whole) was not uniform in problem complexity across topics. Therefore, gains in confidence are confounded with differences in topic and lesson complexity, in terms of statistical analysis. Therefore, student confidence may have increased as they progressed through the reviews, however, that trend could have been masked by differences in topic difficulty.

This study was also concerned with students' reflective activity and the relationship of reflection on test performance. 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 [1]. The findings showed that students engaged in mean levels of reflective thinking that exceeded the neutral value of 3 for each of the eight FE review topics. Further, for four of the eight topics, self-reported reflection correlated significantly with mock FE test performance. The positive correlations between reflection and problem-solving are consistent with research findings in the literature, e.g. the work of Kauffman et al. [18].

The instructor's detailed description of the review format and activities (See Table 1) allows one to reflect on plausible causes related to the instructor's pedagogy that could account for students' significant gains in confidence. However, further empirical exploration of causal connections between the curriculum and gains in confidence are warranted. The present study also leaves a number of unanswered questions regarding the mechanism underlying the significant correlations between self-reported confidence and mock FE test performance, and self-reported reflection and mock FE test performance. Therefore, an important goal for future research is to gain more details regarding the FE review course implemented by the instructor and its effects on students.

We note that the instructor in this course was not directly teaching students to be confident or reflective problem solvers, although the weekly surveys prompted students to consider and respond to those variables. The central method in this study was to monitor how problem-solving confidence and strategies changed over the course of instruction. A motivation for this approach was to assess the value of monitoring students' self-reports of reflection and self-confidence on the effectiveness of instruction. The Likert-type rating data collected in the course illustrate that such (measurement) effort need not be highly burdensome. Importantly, the present study demonstrates that ongoing collection of students' reactions across the semester has the potential of providing instructors with evidence-based motivation for keeping some teaching activities the same and for changing others, in order to make teaching most effective.

We would be remiss not to mention the extensive database we created through the open-ended questions that were part of the weekly survey that students completed. Sample student responses are provided here:

- for question 3 (Briefly describe why your confidence changed or did not change.),
  "My confidence changed due to the fact that I had forgotten a lot if the material and after the refresher this past week really helped me out."
- for question 4 (Briefly describe the problem-solving strategies you employed to solve the FE practice problems.),
  "The first strategy I employ is thoroughly understanding the question. After that, thinking about the technique to solve the problem with. Following that technique through and verifying the steps are done properly."
- for question 5 (Briefly describe how you will change your problem-solving strategies on the next set of problems, if at all.),
  "I believe the only strategy I will change is incorporating more practice problems into my preparation. Working on more problems will give me more of the confidence I need to take on the next set of problems."

We anticipate that completion of the analysis of these qualitative data will significantly complement the results reported here involving Likert ratings and aid in developing a more complete description of changes in students' problem-solving confidence and development of problem-solving strategies.

Conclusions

Significant insights into the effectiveness of instruction can be gained from simple survey data collected as part of course instruction. The ease with which these data can be collected and analyzed should encourage instructors to implement easily administered 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.

When complete, we anticipate that the findings from this project will generalize to other areas of engineering training. The challenge of monitoring students' progress over the course of the semester and dynamically adjusting instruction to students' cognitive and affective needs extends to courses beyond chemical engineering.

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[4] 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 *(very confident)*⑤

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 *(very confident)*⑤

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 *(very reflective)*⑤

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