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Assessing Students' Prior Knowledge and Learning in an Engineering Management Course for Civil Engineers

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Abstract

The objectives of this study were (1) to use a pre-test to assess the knowledge of Civil Engineering students at The Citadel in their understanding of engineering management topics prior to taking a required junior-level course in engineering management, and (2) to use a post-test to assess student learning as a result of various pedagogies employed though the course instruction. Additional insight into broader student performance indicators was accomplished by comparing post-test results with embedded indicator data, which is collected annually, evaluated against department standards and used in department assessment of student outcomes.

Introduction

Inclusion of engineering management within the curriculum provides beneficial learning experiences for undergraduate engineering students including expanded professional skills, preparation for successful careers, and bridging of competency gaps [1]. Development of professional and leadership skills has been shown to progressively improve through the college experience, when included as part of the curriculum [2]. Placing an emphasis on "softer" engineering skills can be used to compliment traditionally required technical curriculum, where most of the course material is focused on teaching students' analytical methods [3]. Competencies of graduates to be prepared to function as engineering managers is a strategically important topic for engineering educators and department assessment procedures to address [4]. Engineering management is an important course in the curriculum to engage students in developing lifelong learning skills, considering global economic issues and understanding the role of professional societies, beyond traditional analytical course material [5]. To prepare graduates with expanded professional skills, undergraduate programs are modifying curriculum and course material to meet the needs of the engineering profession [6].

Engineering Management Course at The Citadel

Engineering Management is a required three-credit hour course for undergraduate civil engineering students taken during their junior or senior year at The Citadel, and is a prerequisite for the two-course capstone design sequence. Engineering Management focuses on development of professional skills needed to prepare graduates for careers in consulting engineering, public works administration, and construction management. In recent years, the curriculum has been modified to incorporate expanded professional skill outcomes, as identified by American Society of Civil Engineers (ASCE) in "A Vision for Civil Engineers 2025,"and ASCE Body of Knowledge (BOK) 2 [7-9]. These landmark policy documents have influenced undergraduate engineering curriculums, across the U.S. and beyond, to include a more specific list of professional skills needed to prepare graduates to meet management and leadership challenges in their future career paths.

ASCE's "Vision for Civil Engineers in 2025" states graduates should be prepared to lead society in establishing a sustainable world and improve the global quality of life. Future practicing civil engineers are envisioned to be master builders, stewards of the environment, innovators, managers of risk, and leaders of public policy [7-9]. The ASCE Body of Knowledge (BOK) 2 provides an aspirational foundation for how engineering programs should prepare civil engineering students to meet ever increasing societal and public policy demands for engineering practice [10]. Based on this vision for future engineers set forth in ASCE BOK 2, faculty in the Department of Civil and Environmental Engineering (CEE) adopted 22 student outcomes, eight (8) of which are directly focused on developing student professional skills and competencies. As shown in Table 1, all eight (8) of these outcomes are included as course objectives in Engineering Management, identified with adopted levels of Bloom's Taxonomy. Assessing student achievement of fundamental course objectives is relatively straightforward through application of course Embedded Indicators [11, 12].

Table 1 – Engineering Management Course objectives and Bloom's Taxonomy

Course Objective	Bloom's Taxonomy
1. Explain lifelong learning skills needed for successful engineering careers.	3-Application
2. Apply key aspects of project management, and scheduling within an engineering context.	3-Application
3. Demonstrate the ability of multidisciplinary teams to effectively examine engineering solutions.	3-Application
4. Use key business concepts to illustrate effective approaches to business development, project relationships, proposal submittal, and consultant selection.	4-Analysis
5. Relate characteristics of effective communication to project design, alternatives evaluation, and recommended solutions.	4-Analysis
6. Recognize fundamental influences of public policy on engineering standards, design requirements, and professional practice.	2-Comprehension
7. Explain legal and ethical responsibilities of professional engineers.	2-Comprehension
8. Identify leadership principles and proficiencies use to address challenges within the engineering profession.	2-Comprehension

CEE Department Embedded Indicators

Departmental outcomes aligning the curriculum along professional skills were established to link course goals across a course-by-course strategy for student development. An essential component of this plan was adoption of Embedded Indicators, aligned with CEE Department outcomes, and mapped across all four years of the undergraduate curriculum. Embedded Indicators are mapped to appropriate Bloom's Taxonomy levels and organized sequentially to provide a progression of student learning and instructional development.

After students are exposed to instructional material, Embedded Indicators collectively measure student performance as determined by graded test questions, assignments, reports and projects commonly used by instructors to assess student learning. Prior to teaching a Civil Engineering course, faculty pre-identifies specific Embedded Indicator tools for use in measuring each goal contained in the course syllabus. Throughout the semester, students are assessed using pre-designated tools. If student performance averages for an Embedded Indicator is measured as 75% or higher, it is concluded students have collectively achieved appropriate learning requirements and met departmental standards. Example work from three representative students (good, average, poor) is included with an Embedded Indicator summary that provides an assessment of student performance and is mapped to reflect linkage with appropriate 1-22 program outcomes and Bloom's Taxonomy.

Pedagogical Techniques Employed in Course

Students learn more effectively by actively analyzing, discussing, and applying content in meaningful ways rather than by passively absorbing information [13]. Various teaching and learning techniques were employed to improve the student learning of key concepts in engineering management.

To assist students with learning course material, each student was required to teach a lesson during the semester. This method is equally beneficial for those students who are being taught and the peer teachers [14, 15]. Peer teachers can reinforce their own learning by instructing others and students feel more comfortable when interacting with a peer [14, 15]. Daily quizzes on assigned reading were administered at the beginning of class. These quizzes were given to increase students' attendance, preparation, participation, study habits and to improve exam scores. Short YouTube videos were shown daily to facilitate and stimulate some introductory discussions on each day's topic. One-Minute papers [16] were used to monitor student learning and address students' misconceptions and preconceptions. Students were typically asked to write a concise summary of the presented topic, write an exam question for the topic, or answer in 60 seconds a big picture question from the material that was presented in the current or previous course lesson.

In-class debates cultivate active engagement of students, placing responsibility of comprehension on the shoulders of the students [17]. Debates afford many benefits in addition to promoting active engagement and mastery of the content [17]. Because debates require listeners and participants to evaluate competing choices [17], they develop higher order critical thinking skills by advancing up levels of Bloom's Taxonomy [15, 17, 18]. For these reason, debates of ethical dilemma case studies were employed to further facilitate active learning and promote critical thinking skills. Students were provided with three ethical dilemma case studies. The class was divided into six teams; two teams were assigned to each case. The members of each team worked together to prepare a solution to their ethical dilemma, which they presented to the class. Students were required to devise a solution, explain and defend their solution through an ethnically-based argument. Each team was required to prepare a presentation consisting of three slides. Teams were assessed based on the strength and delivery of their ethical argument. Everyone was responsible to be familiar with all cases.

An icebreaker activity was used to facilitate the teamwork prior to beginning of the term project. Each team was asked to build the tallest free-standing structure in18 minutes, out of 20 sticks of spaghetti with one-yard of tape, one-yard of string, and one marshmallow. This activity was a great way for each team to get acquainted and dive-into the dynamics of effective teamwork.

To further influence understanding of engineering management concepts, students were asked to conduct an in-depth study of on-campus parking at The Citadel. The project was predicated on data demonstrating that the demand for parking has dramatically increased over the past few years and often parking facilities cannot meet the parking demand, resulting in a variety of problems that could be resolved through engineering-based solutions. Students were asked to prepare an engineering proposal to be submitted to the university decision makers and transportation engineering faculty in the CEE Department. Each team prepared a proposal containing a detailed scope of work; description of parking issues, preliminary evaluation of available data, identification of possible solutions, establishment of a project management plan; and schedule of tasks needed to develop project deliverables and engage stakeholders.

Assessment of Prior Knowledge and Learning

A commonly accepted assessment instrument useful for both diagnostic and formative purposes is the concept inventory [19, 20, 21], which refers to any kind of research-based assessment technique that measures conceptual understanding [19, 20, 21]. Use of concept inventories helps instructors measure the effectiveness of their teaching [20, 21] and determines if students have the correct understanding of important concepts on specific topics. When the same set of questions is used, concept inventories may help in evaluating students' pre- and post-knowledge on a subject. Pre-tests establish students' prior knowledge on a subject, and post-tests measure the learning at the end of the educational experience [19, 20, 22]. These types of tests are also helpful in distinguishing between learning and performance [22].

Students' academic performance, such as examination scores, as a proxy for learning [23-26] does not represent direct evidence of learning [26-29]. Learning is different from performance. Learning is the difference between what students know at the beginning of the semester compared with the end of the semester [22]. Performance is demonstrating mastery of course material such as correct answer to a question on the final exam. This distinction between learning and performance is important since students enter courses with unequal and varying levels of knowledge, skills, and educational experiences [22]. Consequently, pretests are useful in establishing prior knowledge, and post-tests are effective in measuring student learning [22].

An eight question pre- and post-test was developed based upon key concepts in engineering management course (see Table 2). The pre-tests were administered to measure students' prior engineering management knowledge and to identify student misconceptions at the beginning of the semester. The same short-answer test was administered on the last day of the term to assess knowledge gained as a result of the course experience. Each question was scored against an established correct answer. One of the authors graded the short-answer test for all sections to ensure uniform application of grading rubric. When grading the pre- and post-test instruments, a professor looked for key words, phrases and concepts. The professor scored each of the eight questions with a bracketed score of zero (no credit for incorrect answer or no answer), 0.5

(partial credit for partially correct answer), or one (full credit for correct answer). It is important to note neither the pre-test nor post-test counted toward the course grade.

Table 2. The short-answer questions for Engineering Management pre- and post-test (n=57)

No.	Question
Q1	Describe what critical path is in project management.
Q2	Define acronym RFP in engineering management.
Q3	What are the characteristics of a project? What are the three key project constraints?
Q4	Explain the need for lifelong learning and describe skills required of a lifelong learner
Q5	Describe the term multiplier, which is commonly used in the consulting business.
Q6	What are the consequences of uncompensated scope creep?
Q7	Explain the role of a leader and list important leadership principles and attitudes
Q8	What is the difference between Quality Control and Quality Assurance?

The list of questions for the pre-test and post-test are strategically mapped to course goals and learning objectives. Each of the eight-course goal are linked to support a specific student learning outcome, as part of the Department Assessment process. A list of 23 Student learning outcomes were developed and aligned with ASCE Body of Knowledge (BOK) 2 [7-9]. Course embedded indicators are used to measure overall student performance through an assignment or test question aligned with a student learning outcome, largely focusing on professional skills. Currently, the pre-test and post-test results are stand-alone measures of student knowledge growth, which are not used to support the Department Assessment process.

Results and Discussion

Research Question 1: To what degree do junior or senior Civil Engineering majors at The Citadel have exposure to engineering management prior to the introductory engineering management course?

Figure 1 shows the mean score (in percentage) for each question and analyzes students' performance on each question on the pre-test. The pre-test mean of overall scores ranged from 13% to 19%. The pre-test scores for individual students ranged from zero to 46%. All students scored below 10% on Questions Q1, Q2, Q5, and Q6. Student performance (at below 50% level) on all questions of the pre-test is an extremely poor performance, indicating little to no prior experience with these concepts. The highest score on the pre-test was Question 7 (explain the role of a leader and list important leadership principles and attitudes), which is an important theme in the Engineering Management course that the students successfully mastered. The lowest scores on the pre-test were Question 1 (critical path in project management); Question 2 (defining acronym RFP); Question 5 (describe the term multiplier) and Question 6 (consequences of uncompensated scope creep).

The pre-test standard deviation of overall scores range from 8% to 37% (Figure 2). The pre-test standard deviation for each question, a measure of student performance variation, is also shown in Figure 2 and ranges from zero to 30%. The pre-test standard deviation for Questions 1, 2, 3, 4, 5, 6, 7, and 8 range from 10% to 13%, 0 to 19%, 22% to 30%, 26% to 29%, 0 to 11%, 13 to 19%, 13% to 23%, and 21% to 25%, respectively.

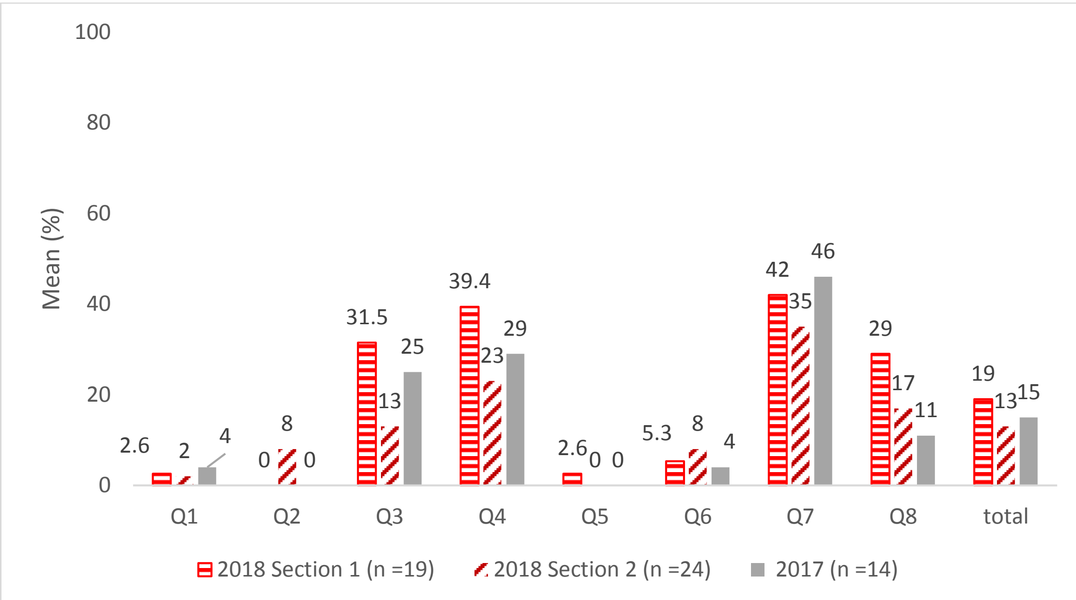

Figure 1. Mean score for each question on the pre-test

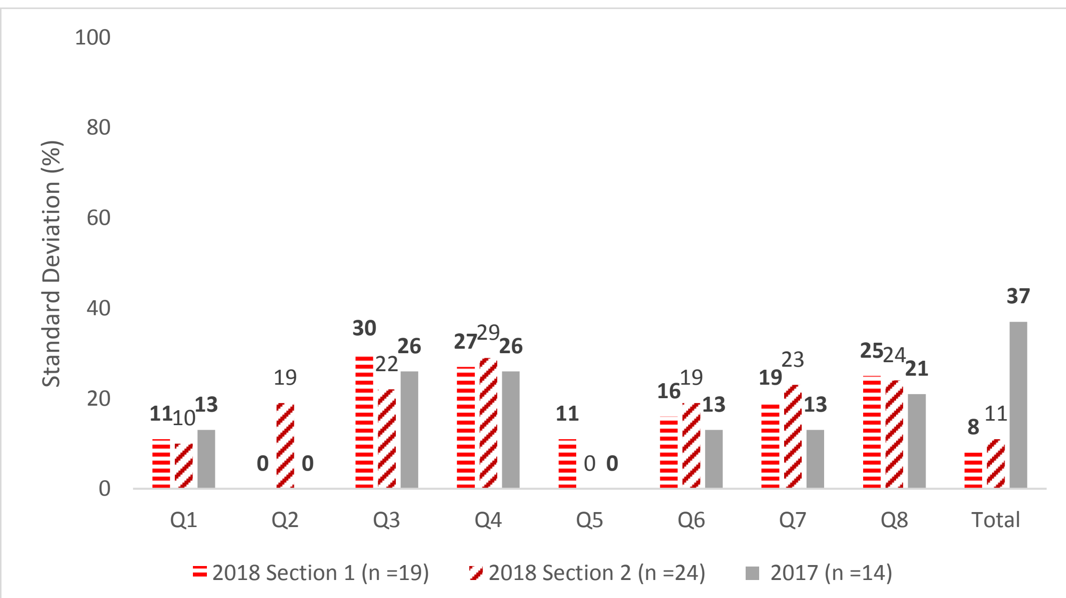

Figure 2. Standard deviation of each pre-test question

Research Question 2: What do the students gain in conceptual understanding about engineering management from the beginning of the course to the end?

The same short-answer test in Table 1 was administered on the last day of the term to assess knowledge gained as a result of the course educational experience. Figures 3 and 4 illustrate the mean and standard deviation of overall scores on the post-test in this study. The post-test student performance mean and standard deviation of overall 1-8 question scores range from 50% to 84%, and 10% to 23%, respectively.

Based on results summarized in Figures 1 and 3, students experienced considerable progress in gaining an improved conceptual understanding of engineering management concepts through completion of the engineering management course. Measured gains in students' conceptual understanding were 37% and 69% for 2018 and 2017, respectively. There was an increase from an overall average percentage correct of 16 % on the pre-test to an overall average percentage correct of 61% on the post-test, across all eight questions, and sample size of 57 students.

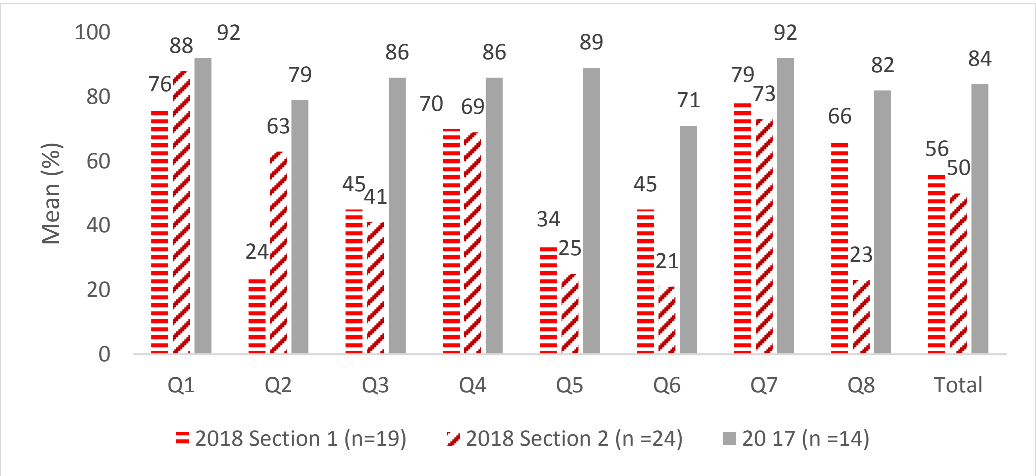

Figure 3. Mean score for each question on the post-test

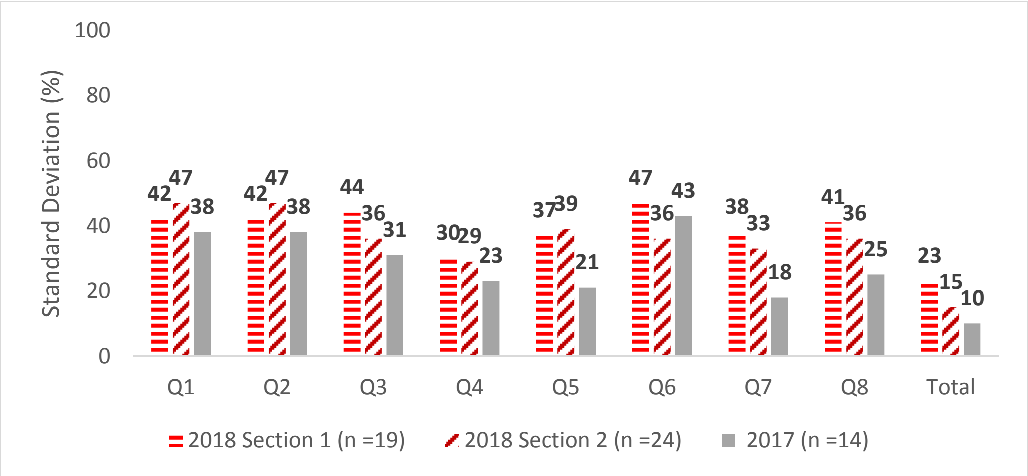

Figure 4. Standard deviation for each question on the post-test

A statistical analysis was conducted on all pre-test and post-test data to detect changes in students' understanding of the engineering management concepts over the course of the semester. Comparison of the pre- and post-test scores was completed using the paired t-test at five percent level of significance, and the results are shown in Table 3. The next step in analyzing pre- to post-test gains was to evaluate changes in correct responses for individual questions. The paired sample t-test was conducted for each question to test for statistically significant differences between pre- and post-test scores. Comparison of the student's performances in all sections showed that all students performed similarly on each question and overall score when measuring conceptual understanding from pre-test to post-test (see Table 3). All eight questions showed a statistically significant difference between the pre- and post-tests (all $p < 0.001$). The comparison of sections showed that the students in the Section 1 did not show significant gains in Question 3, the characteristics of a project and key project constraints, with $p > 0.05$ (see Table 3). Furthermore, the comparison showed that students in Section 2 did not show significant gains in Questions 6 and 8.

In an evaluation of post-test results for the combined 24 question responses, 21 of 24 demonstrated statistically significant differences between paired pre-test to post-test results (all $p < 0.001$), equating to an 87 percent effectiveness for identified course concepts, over the three section offerings of engineering management from 2017 to 2018.

Table 3. Paired-t test results for the pre- and post-test results

	Section 1 (df = 18)			Section 2 (df = 23)			Section 3 (df = 13)		
Measure	Mean Paired Diff (%)	t	p-value	Mean Paired Diff (%)	t	p-value	Mean Paired Diff (%)	t	p-value
Total	37	7.04	< 0.001	37	10.57	< 0.001	69	26.60	< 0.001
Q1	73	8.32	< 0.001	86	15.2	< 0.001	89	15.7	< 0.001
Q2	24	2.46	< 0.001	54	6.03	< 0.001	79	7.78	< 0.001
Q3	13	1.09	>**0.05**	29	4.37	< 0.001	60	5.67	< 0.001
Q4	40	6.43	< 0.001	46	6.26	< 0.001	86	8.0	< 0.001
Q5	31	3.31	< 0.001	25	3.14	< 0.001	89	15.7	< 0.001
Q6	40	4.03	< 0.001	13	1.54	>**0.05**	68	6.03	< 0.001
Q7	37	4.38	< 0.001	38	4.98	< 0.001	88	7.32	< 0.001
Q8	36	3.44	< 0.001	6	0.83	> **0.05**	71	8.27	< 0.001

Course Embedded Indicator Data and Analysis

Embedded Indicator data from 2017 and 2018 used for course assessment is tabulated and presented in Table 4. The following observations are noted:

- Relatively small variations exist in data tabulations for these eight-course outcomes over the two-year analysis period, with an overall student performance of 82.5%.
- A possible explanation for lower performing outcomes is likely related to the difficulty in explaining complicated engineering business and project management nuances needed for future successful careers to undergraduate students who have little experience or knowledge of real-world situations. Also, students knew in advance they would be receiving a grade for Embedded Indicator questions, typically implemented on tests and/or major projects, while pre-test and post-test results were not administered to students as graded assignments.

Table 4. Summary of engineering management embedded indicator outcomes

Outcome	Bloom's	Embedded Indicator Tool	Mean (2017) (n = 40)	Mean (2018) (n = 45)
Lifelong learning	3	Homework	77	85.8
Project Management	3	Final Exam	76	78.8
Inter-disciplinary Teamwork	3	CATME	83	89.2
Business Concepts	4	Proposal	55	87.6
Communication	4	Presentation	90	92.7
Public Policy	2	Final Exam	85	78.9
Ethical Responsibility	2	Assignment	86	76.7
Leadership	2	Final Exam	88	88.4

A comparison of the mean post-test and embedded indicators results is provided in Figure 5. Post-test combined results trailed Embedded Indicator combined results by an average of 21% over the two-year period. Concept inventories are widely credited as a viable means to provide reliable data and to positively influence pedagogical practices [21]. Results from the post-test concept inventory is helpful in distinguish between student learning and performance [22].

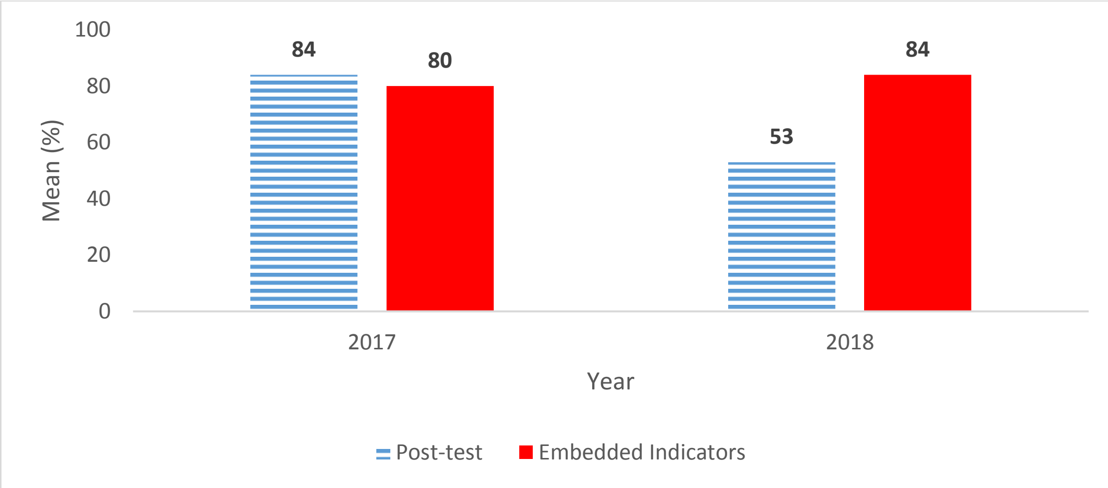

Figure 5. A comparison of post-test and embedded indicators results

Conclusions

Based on the pre- and post-test results, students experienced measurable gains in conceptual understanding of engineering management concepts during the course, across all three sections taught in 2017 and 2018, which includes a total sample size of 57 students. There was an increase from an overall average percentage correct of 16 % on the pre-test to an overall average percentage correct of 61% on the post-test, over the eight questions posed to students. In an evaluation of post-test results for the combined 24 question responses, 21 of 24 demonstrated statistically significant differences between paired pre-test to post-test results (all $p < 0.001$), equating to an 87% effectiveness for identified course concepts. Results indicated that since the post-test was unannounced, it provided a true measure of student learning. The pre-test to post-test changes in overall scores were influenced by a variety of pedagogical techniques used for the course, as described in this paper.

Future research should include expansion to include subsequent engineering management course offerings for the pre-test, post-test instrument, to increase the sample size for improved insight into student learning and performance across these important course subject matter. Additionally, post-test results should be compared with Fundamentals of Engineering subject area results and corresponding Senior Exit Survey questions mapping to program outcomes of interest. Lastly course professors should continue to identify and administer teaching techniques, instructional methods and strategic assignments and exercises to continue to improve student learning and performance.

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