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Case-based Instruction in Undergraduate Engineering: Does Student Confidence Predict Learning?*

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Research on the implementation of case studies in engineering has suggested that students find that cases allow them to see the relevance of engineering concepts to real world issues. Research has also found that students do not perceive cases to be beneficial to their learning while actual learning outcomes suggest otherwise. The goal of this study was to examine the relationship between students' perceptions of their learning confidence and engagement with their actual learning performance for case-based instruction and traditional lecture-based approaches. Thirty-five students enrolled in an undergraduate engineering course participated in the study. The study utilized a within subjects A-B-A-B experimental design with traditional lecture as the baseline condition and case-based instruction as the experimental condition. Participants completed a quiz to assess their learning and a survey to measure their perceptions of learning and engagement. Results suggested that students' perceptions about their own learning did not predict their actual learning outcomes while their perceptions of engagement predicted their conceptual understanding. We also found that cases can lead to significantly greater conceptual learning gains as compared to traditional lecture approach; however, case-based instruction does not influence measures of rote learning. Given that prior research on case studies in engineering has primarily focused on using student perceptions as proxies for actual learning outcomes, these results suggest that engineering educators need to be cautious when interpreting student outcomes based on their perceptions. Our results suggest that engineering education researchers should be careful when using student perceptions to assess the impact of curricular innovations.

Keywords: case-based instruction; student learning; student perceptions

1. Introduction

A report by American Society for Engineering Education (ASEE) [1] highlighted that to address a growing list of interconnected and complex global problems there is a need to train engineers capable of dealing with the multifaceted nature of the challenges they face in the 21st century. However, the lecture-based pedagogical approaches still remain dominant in engineering education, which leaves graduates ill-prepared to understand the complexities of the profession [2–4]. Specifically, the lecture-based approach emphasizes declarative and procedural knowledge and lacks the ability to sustain student's attention, which leads to low attendance rates [5, 6]. This means that students are not motivated to come to class nor are they retaining information from classrooms that emphasize declarative learning, memorization and recall [7]. This is problematic given that the emphasis on memorization rather than application does not provide students with opportunities to see the real-world application of their learning, which leads many students to drop out of engineering [8]. Furthermore, the traditional lecture approach does not provide engineering students with the so called soft-skills, such as communication, collaboration, people skills, design skills, etc. [9, 10].

The National Academy of Engineering also highlighted that today's engineering students are not being educated to address tomorrow's problems and therefore, it is imperative to refocus and reshape the undergraduate learning experience [11]. More recently, ASEE highlighted that while the attributes required for engineering graduates have expanded beyond just raw technical knowledge, "our engineering programs remain overly ambitious, tightly sequenced, and highly technical curricula is rooted in a paradigm from the 1960s" [2, p. 13]. As a result of the changing demands to train the engineers of the future, a paradigm shift is occurring within engineering education to incorporate more student-centered pedagogies [2]. These student-centered approaches, such as problem-based learning and design thinking have been hypothesized to provide students with opportunities to develop

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higher critical thinking skills and create problem solvers who are prepared to work in a complex and ill- structured professional field [3, 12]. Furthermore, these pedagogical approaches make the curriculum "relevant to the lives and careers of students, attractive to all students, and connected to the needs of society" [13, p. 185].

Case-based instruction is one promising instructional problem-oriented approach to engage engineering students and expose them to the complex nature of real-world [3, 4]. Specifically, during case-based instruction students work on "wicked" real world problems (i.e., case studies), draw conclusions with incomplete information, evaluate multiple pathways to different solutions, and make decisions on conflicting issues [12]. Learning from cases also allows students to integrate multiple sources of information as well as provides opportunities for them to grapple with the ethical and societal problems within their fields [14]. Prior work from cognitive sciences has suggested that learning happens from engaging in authentic activity and cases allow students to apply the knowledge that they are learning and makes more meaningful connections [15]. Furthermore, Kolodner [15, 16] argued that engaging in case-based reasoning allows students to learn from vicarious experience of solving problems and allows them to see the applicability of their learning to real-world context.

While case-based instruction has only recently been implemented in the STEM disciplines, it has a long and effective history in the business, law, and medical fields [5, 17, 18]. The case method of instruction originated in the field of law, in which cases helped guide instruction by providing law students with ill-structured domains that do not have consistent underlying theories [19]. Since then, the use of case-based instruction has spread to other domains such as medicine and business [19], and science and engineering education [20]. Prior research has suggested that science faculty find case studies to have positive instructional benefits, for students, including increased critical thinking, conceptual understanding of course ideas, and engagement in the course [14]. For example, Yalçnkaya and Boz [21] found that case-based instruction was an effective approach to increasing 10th grade students' understanding of gas concepts as well as removing their alternate conceptions about gases when compared to traditional lecture approach. In another study, Hoag, Lillie, & Hoppe [6] reported that using case studies in an undergraduate clinical immunology course significantly improved student attendance and also positively affected course organization, student-instructor interaction, and instructor involvement as measured by end of course student evaluations. The use of case-based instruction for improving student learning can be particularly valuable for the field of engineering that often involves problems that are complex, ill-structured, and lack a clear solution [3, 22].

2. Case-based instruction in engineering

In engineering, cases have been utilized since the 1950s with earliest implementation in Civil and Chemical engineering [23], followed by Mechanical engineering [24]. Since then, engineering cases have gained an increased popularity in engineering education [25, 26] and are often published in the Journal of STEM Education [27]. Cases in engineering depict a real or hypothetical complex problem or situation encountered by the engineer as it actually might happen; they reflect a myriad of engineering activities including failures and successes, old and new techniques, and theoretical and empirical results [28]. This stands in contrast to technical articles which depict findings and conclusions in a logical sequence and rarely reflect the processes utilized by the engineer to resolve the situation [28].

Engineering cases come in a variety of forms and the variations of engineering cases we provide are by no means an exhaustive list, but rather exemplars of engineering cases. Engineering cases may provide students with a history of the case, detailing the different phases of the project including the problems encountered and their outcomes, thereby providing the student with the full range of the engineering experience [29]. Engineering cases are also used to place the student in the context of an engineer faced with a complex problem that has multiple plausible solutions thereby exposing the student to situations they may face in their professional careers [24]. Alternatively, engineering cases may illustrate an engineering activity that students use to compare and contrast the information provided in their formal courses [28]. Engineering cases may also be used to help improve the student's skills in analysis by either having the student conduct the analysis outlined in the case or having them complete an unfinished analysis in the case [28].

Regardless of the format, researchers have reported that the use of case studies in engineering has several positive effects on students' learning including making learning challenging and motivating [28, 14], improving students' critical thinking and problem-solving skills [31, 32], and improving students' communication skills [32]. Previous research has indicated that use of case studies makes learning engaging for students allowing them to relate course concepts to real world situations [33]. For example, Vesper and Adams [24] used a questionnaire and open-ended questions at Stanford University to evaluate engineering students' perceptions of three teaching methods: case-method, traditional-method, and laboratory sessions. Of the three methods mentioned, the case method received the highest rating and students reported that case studies provided them with a realistic representation of engineering. In addition to the questionnaire and open-ended questions, Vesper and Adams [24] developed a checklist to capture the essential objectives of the case-method. They distributed the checklist to a sample of engineering students and professors and found that both professors and students were of the view that cases provided a realistic representation of what engineers do, developed skills to parse out essential and nonessential data, and allowed detecting and defining practical problems.

Raju and Sankar [30] evaluated engineering students' ratings on the effectiveness of case studies using four dimensions: usefulness, attractiveness, challenging, and clarity. The authors found that students rated cases to be effective along the four dimensions and reported the case studies were very useful and challenging since they brought real world problems to the classroom. More recently, Garg and Varma [32] investigated engineering students' perceptions of learning using case studies and lectures. Like other studies, students' perceptions of case studies were positive as they found them to be more effective at improving their communication skills, critical thinking skills, and their ability to apply concepts and skills in the course.

Research has also demonstrated that cases help improve student learning. For example, Yadav and colleagues [3] investigated the use of cases to improve students' conceptual learning. The researchers utilized case studies in conjunction with a survey measuring students' perception of their learning confidence and engagement to evaluate students' performance on conceptual understanding and traditional (procedural) questions. They found the cases to be as effective as lecture-based instruction in enabling students to apply their knowledge in problem solving. Students scored significantly higher on conceptual questions as compared to the traditional questions. The authors also found that cases were more effective at improving students' conceptual understanding of the topics. The survey results disclosed that students found that cases allowed them to appreciate engineering, see its relevance to real world issues, and to make more real-world connections when compared to traditional lecture. However, students did not find cases to significantly increase their learning and confidence in their ability to solve problems. Given prior work has suggested that student report that case studies do not influence their learning while the learning measures suggest otherwise, this study examined whether students' perceptions are an accurate predictor of their learning performance.

Prior research on whether students can accurately judge their own learning has found that students tend to be overconfident about their own performance [34, 35] and their perceptions might even be negatively related to their performance [36]. Majority research in this area has been around judgements of learning (JOL) in psychology and has involved paired-associative learning where learners are instructed to study a pair of words so that they recall the second word when prompted with the first word [37, 38]. For example, Nelson and Dunosky [37] used 60 unrelated concrete nouns (such as, ocean-tree) to examine accuracy of immediate and delayed JOLs on undergraduate students' recall performance. Students' judgement of learning was measured by asking how confident they were in their ability to recall the second word when prompted with the first in about ten minutes. The JOL item was given either immediately or was delayed after studying the item. The authors found that JOL accuracy was significantly higher for delayed-JOL items as compared to immediate-JOL items. Other research on judgement of learning related to recall of paired-associated words has also found that learners tend to be overconfident at the first trial and become under confident with repeated presentation of word list [38]. A similar line of research has been to examine how confident students feel in their ability to correctly answer exam questions. Lundeberg, Fox, and Punćochaŕ [35] examined students' confidence judgements in three different psychology courses by having students indicate their confidence (whether their answer was correct) after answering each question. Results suggested that most students were overconfident but adjusted their degree of confidence according to accuracy of their answer. The authors also found that undergraduate male students exhibited higher degree of overconfidence when they were incorrect as compared to female students. Overall, research on student perceptions of learning has suggested that student perceptions might not be the best measure of actual learning outcome.

Given that majority of research on case-based instruction in engineering has used student perceptions of learning outcomes, the goal of this study was to investigate whether those perceptions could be used as a proxy for actual learning outcomes and how they varied across lecture and case studies approach. Hence, this study addressed the following research questions.

(a) What is the relationship between students' perceptions and actual learning performance for lecture and case-based instruction?

(b) How do students differ in their perceptions of their learning confidence and engagement connections across lecture and case-based instruction?

3. Methods

3.1 Participants

Thirty-five mechanical engineering undergraduate students enrolled in a control systems course participated in the study. The majority of the participants were juniors (N = 23) and the remaining (N = 12) were in their senior year of the program. There were 31 males and four females who participated in the study. Participants included 31 Caucasian students, two African American, and two students identified as other. The average GPA of participants was 3.4.

3.2 Materials

3.2.1 Case studies

We used two case studies for two course topics (i.e., *hydraulic systems* and *electro-mechanical systems*). The cases were based on real life events and had been previously used by the course instructor, which has been documented in our prior work [3, 33]. The scenarios presented in the case were developed to help students understand complex dynamic models, develop/test hypothesis and mitigation strategies for component failure in complex systems. Each case study only covered the corresponding topic (*hydraulic systems* or *electro-mechanical systems*) to allow students to experience the case within the time constraint of two 50-minute class periods. The case studies provided students with a problem, technical information related to the case, and discussion questions related to the case. The students were required to read the case before coming to the class and during the class the instructor led a discussion surrounding the case study to brainstorm strategies for modeling the system(s), connecting mathematical models to the case study, connecting ideas from the case study to previously learned concepts (such as, force = mass × acceleration), and discussed alternative solutions to the problem presented in the case studies. A detailed overview of the two cases and pedagogical design has previously been discussed by Yadav and colleagues [3].

3.2.2 Quiz

In order to assess students' learning performance, they completed a posttest quiz following each phase of the study based on the topic covered (bode plots, thermal systems, hydraulics, and electro-mechanical). There was a total of four quizzes to assess student understanding of the four topics. Specifically, each quiz included two questions—a traditional question and a conceptual question. The traditional question assessed students' ability to solve a problem they would typically encounter in an engineering course. The conceptual question, on the other hand, was open-ended based on Mazur's paired problem task [39] to have students qualitatively explain the concept at hand in the traditional problem. Open-ended questions are well-suited to measure the nuances of student learning from cases [40, 41] and have long been used to assess students' conceptual understanding. For example, in order to assess students' understanding of electro-mechanical, the quiz asked the students to sketch schematic representation of important electro-mechanical systems and describe the electro-magnetic coupling phenomenon for the traditional question. To measure their conceptual understanding the students had to demonstrate understanding of steady-state DC motor behavior as function of applied voltage. (See Yadav and colleagues [3] discussion of the remaining questions in the quizzes).

3.2.3 Survey

Participants completed a survey at the end of each topic to assess their perceptions of learning and engagement from the two approaches (i.e., lectures vs. case-based instruction). The survey was adapted from the Student Assessment of Learning Gains (SALG) survey, which was designed "to summarize the learning gains that students perceive they have made, both as a consequence of particular aspects of class pedagogy, and of the teacher's pedagogical approach" [42, p. 1]. Previous research on the survey items had identified two factors: learning confidence (LC) and engagement connections (EC). Learning confidence factors included items that measured students' perceptions of their own learning and the engagement connections factor included items that measured students' perceptions of their engagement.

3.3 Procedure

This study utilized an A-B-A-B design with the lecture as a baseline condition (i.e., Phase A of the design) and case-based instruction as the experimental condition (Phase B of the design). Specifically, A_1-B_1-A_2-B_2 design consisted of four different topics, two were taught using lecture (i.e., bode plots - A_1 and thermal systems - A_2) and two were taught using case studies (i.e., hydraulics - B_1, electro-mechanical - B_2). The four topics chosen for the study have been found to require similar prior understanding and one topic is not likely to benefit from using case studies [33]. The A-B-A-B repeated measures within subjects design allowed us to be more confident in the findings due to repeated introduction and withdrawal of the experimental condition [43]. Following each condition students completed a posttest quiz and a survey.

3.4 Data analysis

Each question on the quiz was scored on a scale of 0-3 to measure students' learning performance with a score of zero showcasing lack of understanding of the concept being assessed while a score of three highlighting excellent understanding and students' ability to solve the problem clearly and succinctly (See [3, 33] for a detailed discussion on how the scoring measures students' conceptual understanding). The scoring rubric had previously been used to examine students' understanding of engineering constructs. Table 1 shows the detailed scoring rubric for the traditional and conceptual questions.

We began our analyses by conducting a descriptive analysis of the data across the four conditions and between the lecture and case conditions. Next, we conducted a repeated measures regression analysis using the general estimation equations (GEE) to account for the repeated nature of the data to investigate the extent to which students' perceptions of the learning confidence (LC) and engagement connection (EC) related to their performance on the traditional and conceptual questions across lecture and case conditions. Students LC and EC were derived from the student assessment of learning gains (SALG) survey. This survey was adapted, and its psychometric properties evaluated by Yadav and colleagues [3]. We used repeated measures ANOVA to assess the differences in LC and EC scores across the four conditions. We investigated the statistical assumptions of the data and found no serious violations that would significantly affect the analysis and all statistical tests at an alpha value of 0.05.

4. Results

4.1 Student perceptions of learning performance

The data were analyzed to examine whether students' perceptions about their learning and engagement predicted their actual performance on the traditional and conceptual questions. Table 2 shows the results from the repeated measures regression of students' learning confidence (LC), engagement connections (EC), and lecture vs case conditions as predictors of students' performance on the traditional and conceptual questions across conditions. The intercept represents the grand mean score for students on the Traditional or Conceptual questions when the predictors are set to zero. This is because, the lecture vs case predictor was dummy coded (lecture = 0 and case = 1); therefore, the coefficient represents the change in the estimated or predicted Traditional (or Conceptual) question score for the lecture condition (code = 0) relative to the case condition (code = 1) and is approximately equal to the difference between the lecture and case

Table 1. Rubric for scoring traditional and conceptual questions

	Traditional	**Conceptual**
0	No start to the problem and the mathematical relationships are not applicable.	The student did not attempt to explain or misinterpreted the questions.
1	Some of the mathematical expressions are correct, but incomplete not allowing continuation of the problem beyond 1–2 steps.	The students attempted to answer the question, but missing key concepts.
2	Most mathematical expressions correct and student able to attempt a final solution, but with notable errors.	The students attempted to answer the question, but has gaps in the reasoning and logic when addressing the conceptual understanding.
3	Students' solution process is coherent and easy to follow. And the solution is correct or exhibits minor computational errors.	Demonstrated a thorough understanding of the question and provided an accurate answer.

Table 2. Repeated Measures Regression for LC and EC as Predictors of Students' Scores on the Traditional and Conceptual Questions Across Conditions (df = 1)

Condition	**Coefficient**	***SE***	**Wald's Chi-Square**	***p*-value**
Traditional questions				
Intercept	1.36	0.33	16.85	**<0.001**
Learning Confidence	–0.08	0.19	0.18	0.672
Engagement Connections	0.14	0.09	2.16	0.141
Lecture vs Case	–0.04	0.31	0.01	0.908
Conceptual question				
Intercept	2.35	0.39	36.25	**<0.001**
Learning Confidence	0.17	0.17	0.89	0.345
Engagement Connections	–0.17	0.06	8.31	**0.004**
Lecture vs Case	–1.44	0.29	24.93	**<0.001**

conditions. Thus, a negative coefficient indicates that students' score on the lecture condition was lower than their scores on the case condition and vice versa. For the LC and EC scores, the coefficient represents the increase in outcome scores for a one-unit increase in the predictor while controlling for the other predictors in the model.

For the traditional questions, the mean score was 1.36 points (SD = 0.33) and was significantly different from zero ($p < 0.001$). Both students' LC and EC were not significantly related to their performance on the traditional questions, which suggests that students' perception of their LC and EC did not predict their performance on the traditional questions. Additionally, students' scores on the traditional question for the lecture conditions were lower than their scores in the case conditions (controlling for LC and EC), but the difference was not statistically significantly $\chi^2(1, N = 137) = 0.01$, $p = 0.908$. For the conceptual questions, the mean score was 2.35 point (SD = 0.39) and was statistically different from zero ($p < 0.001$). Similar to the traditional questions, LC was not significantly related to students' performance ($p = 0.345$) on the conceptual questions. However, unlike the traditional questions, students' perceptions of their EC were significantly related to their performance on the conceptual question $\chi^2(1, N = 137) = 8.31$, $p = 0.004$. This means that students' score on the conceptual question decreased by 0.17 point per unit increase in EC when controlling for the other predictors in the model. However, students' conceptual scores on the lecture conditions were significantly lower than their scores on the case conditions $\chi^2(1, N = 137) = 24.93$, $p < 0.001$ on the conceptual questions after controlling for their LC and EC. On average, students' scores on the lecture condition were 1.44 points lower than their scores on the case condition. Table 3 shows the detailed descriptive statistics.

Table 3. Descriptive Statistics of Traditional and Conceptual Questions

	Traditional		**Conceptual**	
Condition	**Mean**	**SD**	**Mean**	**SD**
Lecture 1	1.03	0.70	1.13	0.79
Case 1	1.41	1.10	1.88	0.83
Lecture 2	1.94	0.95	0.94	0.56
Case 2	1.72	0.81	2.72	0.63
Total Lecture	1.46	0.60	0.98	0.10
Total Case	1.58	0.25	2.31	0.60

Table 4. Descriptive Statistics of Engagement Connections and Learning Confidence Survey

	Engagement Connections		**Learning Confidence**	
Condition	**Mean**	**SD**	**Mean**	**SD**
Lecture 1	2.74	0.91	3.53	0.66
Case 1	3.74	0.70	3.31	0.76
Lecture 2	3.29	0.61	3.29	0.61
Case 2	3.32	0.74	3.06	0.79

4.2 *Student perceptions in learning from cases vs lecture*

Table 4 shows the descriptive results of students' ratings of their learning confidence (LC) and engagement connections (EC) regarding their performance on the traditional and conceptual questions across conditions.

Table 5 shows the results of the repeated measures ANOVA for the students' perceptions of their learning confidence and engagement connections across lecture- and case-based instruction. For LC, Mauchly test indicates that the assumption of sphericity was not violated, Mauchly's W χ^2 (5) = 3.06, $p = 0.69$. Overall, test was statistically significant $F(3, 102) = 3.85$, $p = 0.058$, $\eta^2 = 0.07$. Students' LC scores were significantly higher in the case 2 condition, compared to the lecture 1 condition. For EC, the Mauchly test indicates that the assumption of sphericity was violated, Mauchly's W χ^2 (5) = 13.54, $p = 0.019$, therefore we use the Greenhouse-Geisser correction for degrees of freedom. F (2.41, 102) = 10.93, $p < 0.001$, $\eta^2 = 0.24$. The mean difference indicates the difference in the mean scores between the two conditions. A *Positive* mean difference indicates that the mean score of the first group is greater than the mean score of the second group. A *Negative* mean difference indicates that the mean score of the first group is lower than the mean score of the second group.

Table 5. Repeated Measures ANOVA for Learning Confidence and Engagement Connections

	Learning Confidence		**Engagement Connections**	
Condition	**Mean difference**	***p*-value**	**Mean difference**	***p*-value**
Lecture 1 vs Case 1	0.22	>0.999	–1.00	**<0.001**
Lecture 1 vs Lecture 2	0.25	0.866	–0.55	**0.01**
Lecture 1 vs Case 2	0.47	**0.026**	–0.59	**0.015**
Case 1 vs Lecture 2	0.023	>0.999	0.45	**0.038**
Case 1 vs Case 2	0.25	>0.999	0.41	0.074
Case 2 vs Lecture 2	0.22	>0.999	0.04	>0.999

5. Discussion

One of the main findings from this study was that students' perceptions about their own learning do not predict their actual learning outcomes. Given that prior research on case studies in engineering has primarily focused on using student perceptions as proxies for actual learning outcomes [3], these results suggest that engineering educators need to be cautious when interpreting student outcomes based on their perceptions. In general, student perceptions of learning have been found to be problematic. For example, students' own judgments of learning are not correlated with actual learning outcomes [44] and they are generally overconfident in their performance judgement [35]. Specifically, students think they know more than they actually do and this is especially true after students have heard a lecture as opposed to when they are working through problems, such as case studies [23, 45]. Listening to lectures from instructors gives students a false sense of knowing as they mistake instructor's knowledge to be their own [46]. Along the same lines, Albanese and Mitchell [47] found in their meta-analysis of problem-based learning approaches that PBL students see themselves as less well prepared in the basic science than are their conventionally trained counterpart. Furthermore, it is quite possible that student perceptions about learning might not be accurate because course grades are typically based on the assessment that measures memorization of procedural knowledge rather than a conceptual mastery of the content [48]. As students learn from cases they might not perceive that they are learning much given their prior exposure to what they believe learning entails—factual or procedural knowledge. In summary, the results from this study provide an empirical basis that student perceptions about learning do not predict real learning outcomes.

Results also suggested that students perceived cases to be more engaging than lectures. Significant differences were found in favor of cases for Lecture 1 vs Case 1, Lecture 1 vs Case 2, and Case 1 vs Lecture 2. These results are corroborated by the research literature that indicates students find cases to be engaging, and better connects engineering concepts to real world issues [30, 33]. For Learning Confidence, there was a significant difference in one condition, Lecture 1 vs Case 2, in favor of the Lecture 1 condition. This result may be attributed to the nature of the content of Lecture 1 condition as compared to the content being covered in Case 2 condition. The results from this study indicate that across conditions cases strongly influences students' sense of engagement with the material rather than their learning confidence.

The results also suggested that cases can lead to significantly greater conceptual learning gains as compared to traditional lecture approach; however, the case-based instruction does not influence measures of rote learning (as measured by the traditional question). This finding corroborates prior work that while problem-based learning approaches, such as cases lead to better conceptual understanding, it does not influence learning as measured by traditional fact-based questions [3, 23, 47]. In a meta-analysis of problem-based learning approaches, Albanese and Mitchell [47] found that while PBL students score lower on basic science examinations, they perform better on the application of those concepts in clinical examinations. Within engineering education, Yadav and colleagues [3, 23] found similar results as students in problem-based learning and case-based instruction approaches significantly outperformed lecture-based approaches on conceptual learning, but there were no differences in procedural knowledge.

Finally, another finding from the study was that if the students reported as being more engaged, their conceptual understanding decreased; however, it was not related to their rote learning. While this is a surprising result, it should be noted that when controlling for learning confidence and engagement connections, students' conceptual understanding was significantly higher for case condition as compared to traditional lecture condition. We also found that student engagement was significantly higher for the case 1 condition when compared to both lecture conditions, but for case 2 student engagement was only significantly higher when compared to lecture 1 condition and not for lecture 2. Also, while students felt significantly more engaged in the lecture 2 when compared to lecture 1, their conceptual understanding score was lower for lecture 2. It is possible that the topic (thermal systems) for lecture 2 led students to be more engaged when compared to the topic for the lecture 1 (bode plots) and even matched their engagement for the topic (hydraulics) of case 2. This might help explain why overall an increase in student engagement predicted lower conceptual understanding. While a within-subjects research design allows researchers to evaluate instructional approaches, the use of four topics across the two conditions could be problematic. Below we discuss implications of these findings for future research.

6. Implications

These findings have important implications for engineering education research. It should be noted that this study utilized student perceptions immediately after each of the conditions. Future research should look at delayed benefits of cases, especially given that students have reported benefitting from problem-based learning approaches once they go out in the field [23]. Yadav and colleagues [23] discussed an example of how one professor invited students from previous semester to discuss misconceptions and benefits related to problem-based learning approaches like case-based instruction. Future research should examine how student perceptions of case studies change after working in the field and they have had opportunities to reflect on their learning.

The current research did not examine gender differences in students' perceptions of learning and how they relate to their actual learning. Given that prior research has found that undergraduate men tend to be overconfident in their learning performance than females, future research should explore these gender differences. Given the urgent calls to increase diversity in undergraduate engineering majors [2, 49], research about how different student groups perceive their own learning experiences might provide an insight into how to support traditionally underrepresented groups in engineering classes. Another area of future research could be using classroom observational data to examine student engagement during case-based instruction. This study used self-report survey data to measure student engagement, which asked students to reflect upon their experience in the case study and lecture-based conditions. Future research could use observation protocol to code student behaviors of engagement, such as task involvement in classroom videos. While there is a growing empirical evidence that case-based instruction leads to deeper understanding of course concepts in undergraduate engineering courses, we know little about how cases facilitate this learning. Future research could also examine processes students engage in during learning from cases both through lab-based studies as well as in-class observations.

Finally, the study had a few limitations based on the use of within subjects A-B-A-B design, which while a strong research design when a true experimental design is not possible has a potential weakness. The limitation of A-B-A-B design is the use of four topics across the two conditions, which could impact the results. Future research should consider using a quasi-experimental design with one instructor to remove any potential differences as a result of the topic. Given the contextual nature of this study in one course at a Midwestern university more research needs to be conducted to replicate the results and develop an empirical basis for the use of case studies in engineering curricula. As highlighted by the American Society of Engineering Education, the issue is not simply a need for more educational innovations but grounding them in confirmed learning theories and pedagogical practices and assessing their effectiveness in achieving stated objectives [2]. Building an empirical basis for the use of case studies would lead to an "effective engineering education from a scientifically credible and shared knowledge based on learning" rather than being based on mere intuition [1].

7. Conclusions

In conclusion, our results suggest that engineering faculty and researchers should be careful when using student perceptions to examine the impact of curricular innovations. In order to assess whether pedagogical approaches achieve their stated objectives, researchers need to also use learning measures in addition to student perceptions to get a better picture. Our results also provide evidence that faculty should look at other outcomes in addition to student perceptions given that how students feel about a particular teaching approach does not always align with what they learn. While students might not like how faculty teach, it could lead to significant gains in their learning or vice versa when students like a teaching approach, but it does not influence their learning. Thus, faculty who implement new teaching methods should not let student perceptions (positive or negative) dissuade them from pursuing pedagogical innovations.

References

1. ASEE, *Creating a culture for scholarly and systematic innovation in engineering education: Ensuring U.S. engineering has the right people with the right talent for a global society*, American Society for Engineering Education, Washington DC, 2009.
2. ASEE, Innovation with Impact: *Creating a Culture for scholarly and systematic innovation in engineering education*, American Society for Engineering Education, Washington DC, 2012.
3. A. Yadav, M. Vinh, G. M. Shaver, P. Meckl and S. Firebaugh, Case-based instruction: Improving students' conceptual understanding through cases in a mechanical engineering course, *Journal of Research in Science Teaching*, **51**(5), 2014, pp. 659–677.
4. J. E. Mills and D. F. Treagust, Engineering education—Is problem-based or project-based learning the answer? *Australasian Journal of Engineering Education*, 2003, pp. 2–16.
5. C. F. Herreid, *Start with a story: The case study teaching method of teaching college science*, National Science Teachers Association Press, Arlington VA, 2007.
6. K. Hoag, J. Lillie and R. Hoppe, Piloting case-based instruction in a didactic clinical immunology course, *Clinical Laboratory Science*, **18**(4), 2005, pp. 213–220.
7. C. F. Herreid, "Clicker" Cases, *Journal of College Science Teaching*, **36**(2), 2006, p. 43.
8. R. M. Felder, G. N. Felder and E. J. Dietz, A longitudinal study of engineering student performance and retention. V. Comparisons with traditionally-taught students, *Journal of Engineering Education*, **87**(4), 1998, p. 469.
9. M. F. Cox, J. Zhu, J. S. London, B. Ahn, A. T. Torres-Ayala and K. D. Ramane, *Recommendations for promoting desir-*

able characteristics in engineering Ph.D.'s: Perspectives from industry and academia. In 119th ASEE Annual Conference and Exposition. American Society for Engineering Education, 119th ASEE Annual Conference and Exposition, San Antonio, TX, United States, June, 10, 2012.

10. D. Q. Nguyen, The essential skills and attributes of an engineer: A comparative study of academics, industry personnel and engineering students, *Global Journal of Engineering Education*, **2**(1), 1998, pp. 65–75.
11. NAE, *Educating the engineer of 2020: Adapting engineering education to the new century*. The National Academies Press. Washington DC, 2005.
12. S. Kim, W. R. Phillips, L. Pinsky, D. Brock, K. Phillips and J. A. Keary, conceptual framework for developing teaching cases: A review and synthesis of the literature across disciplines, *Medical Education*, **40**(9), 2006, pp. 867–876.
13. L. D. Fink, S. Ambrose and D. Wheeler, Becoming a professional engineering educator: A new role for a new era, *Journal of Engineering Education*, **94**, 2005, pp. 185–194.
14. A. Yadav, M. Lundeberg, M. DeSchryver and K. Dirkin, Teaching science with case studies: A national survey of faculty perceptions of the benefits and challenges of using cases, *Journal of College Science Teaching*, **37**(1), 2007, p. 34.
15. J. L. Kolodner, Educational implications of analogy: A view from case-Based reasoning, *American Psychologist*, **52**, 1997, pp. 35–44.
16. J. L. Kolodner, *Case-based reasoning*, In K. Sawyer (Ed.), Cambridge handbook of the learning sciences, Cambridge University Press, New York, 2006, pp. 225–242.
17. K. K. Block, The "case" method in modern educational psychology texts, *Teaching & Teacher Education*, **12**, 1996, pp. 483–500.
18. J. A. Mayo, Using case-based instruction to bridge the gap between theory and practice in psychology of adjustment, *Journal of Constructivist Psychology*, **17**, 2004, pp. 137–146.
19. S. M. Williams, Putting case-based instruction into context: Examples from legal and medical education, *The Journal of Learning Sciences*, **2**(4), 1992, pp. 367–427.
20. C. F. Herreid, What makes a good case? Some basic rules of good storytelling help teachers generate student excitement in the classroom, *Journal of College Science Teaching*, **27**(3), 1997, pp. 163–65.
21. E. Yalçnkaya and Y. Boz, The effect of case-based instruction on 10th grade students' understanding of gas concepts, *Chemistry Education Research and Practice*, **16**(1), 2015, pp. 104–120.
22. D. Jonnasen, J. Strobel and C. B. Lee, Everyday problem solving in engineering: Lessons for engineering educators, *Journal of Engineering Education*, **95**(2), 2006, pp. 1–14.
23. A. Yadav, D. Subedi, M. A. Lundeberg and C. F. Bunting, Problem-based Learning: Influence on Students' Learning in an Electrical Engineering Course, *Journal of Engineering Education*, **100**(2), 2011, pp. 253–280.
24. K. H. Vesper and J. L. Adams. Evaluating learning from the case method, *Engineering Education*, **60**(2), 1969, pp. 104–106.
25. N. Fitzgerald, Teaching with cases, *ASEE Prism*, **4**(7), 1995, pp. 16–20.
26. L. G. Richards, M. Gorman, W. T. Scherer and R. D. Landel, Promoting active learning with cases and instructional modules, *Journal of Engineering Education*, **84**(4), 1995, pp. 375–381.
27. M. Prince and R. Felder, Inductive teaching and learning methods: Definitions, comparisons, and research bases, *Journal of Engineering Education*, **95**(2), (2006), pp. 123–138.
28. G. Kardos and C. O. Smith, On writing engineering cases, In *Proceedings of ASEE National Conference on Engineering Case Studies*, March, 1979, pp. 42–50.
29. H. O. Fuchs, Outside reality inside the classroom, *Journal of Engineering Education*, **60**(7), 1970, pp. 745–747.
30. P. K. Raju and C. S. Sankar, Teaching real-world issues through case studies, *Journal of Engineering Education*, **88**(4), 1999, pp. 501–508.
31. F. Dochy, M. Segers, P. VandenBossche and D. Gijbels, Effects of problem-based learning: A meta-analysis, *Learning & Instruction*, **13**(5), 2003, pp. 533–68.
32. K. Garg and V. Varma, A study on the effectiveness of case study approach in software engineering education. Paper presented at the *20th Conference on Software Engineering Education and Training*, Dublin, Ireland, 2007, pp. 309–316.
33. A. Yadav, G. M. Shaver and P. Meckl, Lessons learned: Implementing the case teaching method in a mechanical engineering course, *Journal of Engineering Education*, **99**(1), 2010, pp. 55–69.
34. A. Koriat, L. Sheffer and H. Ma'ayan, Comparing objective and subjective learning curves: judgments of learning exhibit increased underconfidence with practice, *Journal of Experimental Psychology: General*, **131**(2), 2002, p. 147.
35. M. A. Lundeberg, P. W. Fox and J. Punćochař, Highly Confident but Wrong: Gender Differences and Similarities in Confidence Judgments, *Journal of Educational Psychology*, **86**, 1994, pp. 114–121.
36. C. L. Townsend and E. Heit, Judgments of learning and improvement. *Memory & Cognition*, **39**(2), 2011, pp. 204–216.
37. T. O. Nelson and J. Dunlosky, When people's judgments of learning (JOLs) are extremely accurate at predicting subsequent recall: The "delayed-JOL effect", *Psychological Science*, **2**, 1991, pp. 267–270.
38. A. Koriat, Monitoring one's own knowledge during study: A cue-utilization approach to judgments of learning, *Journal of Experimental Psychology: General*, **126**, 1997, pp. 349–370.
39. E. Mazur, Moving the mountain: Impediments to change, In *Proceedings of The Third Annual NISE forum*, ed. S.B. Millar, Washington DC, 1998, pp. 91–93.
40. D. H. Jonassen, Design Problems for Secondary Students, *National Center for Engineering and Technology Education*, 2011.
41. M. A. Lundeberg and A. Yadav, Assessment of case study teaching: Where do we go from here? Part II, *Journal of College Science Teaching*, **35**(6), 2006, p. 8.
42. E. Seymour, D. Wiese, A. Hunter and S. M. Daffinrud, Creating a better mousetrap: On-line student assessment of their learning gains, In *National Meeting of the American Chemical Society*, March, 2000, pp. 1–40.
43. C. H. Kennedy, *Single-case designs for educational research*, Pearson A & B, 2005.
44. C. L. Townsend and E. Heit, Judgments of learning and improvement, *Memory & Cognition*, **39**, 2011, pp. 204–216.
45. A. Yadav and B. Barry, Using case-based instruction to increase ethical understanding in engineering: What do we know? What do we need? *International Journal of Engineering Education*, **25**, 2009, pp. 138–143
46. A. M. Glenberg and W. Epstein, Inexpert calibration of comprehension, *Memory & Cognition*, **15**(1), 1987, pp. 84–93.
47. M. A. Albanese and S. Mitchell, Problem-based learning: a review of literature on its outcomes and implementation issues, *Academic medicine*, **68**(1), 1993, pp. 52–81.
48. A. Lizzio, K. Wilson and R. Simons, University students' perceptions of the learning environment and academic outcomes: Implications for theory and practice, *Studies in Higher Education*, **27**(1), 2002, pp. 27–52.
49. L. Tsui, Effective strategies to increase diversity in STEM fields: A review of the research literature, *The Journal of Negro Education*, 2007, pp. 555–581.

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