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Engineering Students' Experience of Surprise Caused by Test Performance in Foundational Courses

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When students who are confident in their abilities do not perform well in an important course, they are likely to experience surprise. This case study investigated engineering students' experiences of surprise caused by test scores in foundational courses. Students taking Engineering Statics reflected on their surprise after completing tests by following a template that asked questions about how surprised they were (experiential indicator of surprise), how much they liked their scores (affective indicator), and how much they expected such scores (cognitive indicator). An inductive analysis of the reflections showed that students were at least moderately unpleasantly surprised and moderately pleasantly surprised in 34.6% and 13.5% of the reflections, respectively. Among all reflections, 34.6% showed that students did not like their scores, and 25% showed that they did not expect such scores. A major cause of unpleasant surprise was the disparity between the students' high confidence in their understanding and their lower-than-expected scores. The other major cause was the disparity between the students' high effort in studying for the tests and their scores that were lower than expected. More than half of these students prepared for tests by reviewing materials. The emotions associated with unpleasant surprise included feelings of being disappointed, frustrated, and upset, and those associated with pleasant surprise were happiness and relief.

Keywords: surprise, engineering foundational courses, causes of surprise, liking, expectancy

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INTRODUCTION

Foundational engineering courses are typically required for almost all engineering students and cover content that is essential for students' learning in subsequent professional engineering courses. In some universities, these foundational courses are offered by engineering programs, while in other universities, some foundational courses are provided by science, mathematics, or computer science programs. Many students do not perform well in these courses. About a third of engineering students taking foundational courses do not earn the required minimum grade for the engineering major (at least a C) (Gainen, 1995; Summerville et al., 2018). Failure in foundational courses causes attrition from engineering (Call et al., 2015). Research shows that discouraging grades are a major factor in attrition from engineering programs (Geisinger & Raman, 2013), and, in particular, low performance in foundational courses is one of the main reasons students leave engineering programs (Huang & Pierce, 2015). Given that the attrition rate in engineering programs has been approximately 50% over several decades (Geisinger & Raman, 2013), students' performances in foundational courses should be improved. For students who choose to stay in engineering even after failing foundational courses, the likelihood of success in later engineering courses diminishes (Call et al., 2015; K. G. Nelson et al., 2015) and their completion of engineering degrees can be delayed. Failing foundational courses or earning unsatisfactory grades erodes students' motivation and confidence (Shew et al., 2019), and poor grades can impact students financially as they may lose scholarships and other forms of aid (Summerville et al., 2018).

Cognitive science and emotion research show that unexpectedness is accompanied by surprise (Gendolla & Koller, 2001; Meyer et al., 1997). The intensity of surprise is affected by the importance, valence, and unexpectedness of an outcome (Gendolla, 1997; Gendolla & Koller, 2001). Since (a) foundational courses cover content that is essential for students' learning in subsequent professional engineering courses, (b) failure in foundational courses leads to many consequences, as described above, and (c) college engineering students typically performed well during high school (Shew et al., 2019) and have a significantly higher confidence in their abilities than students in other majors (Veenstra et al., 2008), students are very likely to experience surprise caused by their test performance in foundational courses.

However, research shows that, compared with low-performing students, high performers tend to assess their own academic abilities more accurately and make more accurate predictions of their exam performance (Hacker et al., 2000, 2008; Miller & Geraci, 2011). This is because, in addition to a lack of content knowledge, low performers are lacking an awareness of what they do and do not know (Kruger & Dunning, 1999; Miller & Geraci, 2011). These individuals are "unskilled and unaware of it" (Kruger & Dunning, 1999, p. 1121). As a result, low performers overestimate their abilities. Engineering students, most of whom tend to be high-ability students, may not be surprised by low test scores because they may have already predicted their low performance.

In the current study, we examined whether undergraduate students experienced surprise in foundational engineering courses and, if they did, what were the causes. This study contributes to the surprise and engineering education literature in several ways. First, our study contributes to the small number of field studies on college students' feelings of surprise. Recently, there has been an increase in interest in surprise in cognitive sciences (Munnich et al., 2019), yielding a wealth of laboratory research on surprise focusing on its antecedents, consequences, procedural architecture, and other aspects (Gerten & Topolinski, 2019; Munnich & Ranney, 2019; Reisenzein et al., 2019). However, there are few field studies that have explored college students' feelings of surprise, except for studies examining students' college adjustment (Barber, 2010; Harper & Newman, 2016), students' reactions to a surprising solution to a mathematics problem (Marmur & Koichu, 2016), and the surprise computer science students experienced (Thomas et al., 2010). Specifically, Barber (2010) investigated the nature of undergraduate students' hometown and university cultures, the surprise they experienced during their matriculation processes, and how they responded to the surprises. Along a similar line, Harper & Newman (2016) examined Black undergraduate male students' college adjustment in the first year and how they tackled surprising transition issues. Marmur & Koichu (2016) examined undergraduate computer science and electronic engineering students' reactions to a surprising solution to a mathematics problem. The problem was designed in such a way that using familiar methods to solve it would lead to dead ends. After students encountered dead ends in class, the instructor showed a surprisingly easy solution. In Thomas et al. (2010), computer science students were asked to describe a computing concept that changed the way they perceived computing in short essays, which were analyzed to identify the types and causes of surprise students experienced. Students were surprised at concepts (e.g., modeling in object-orientation), techniques (e.g., including comments in the code), and their own performance. These various types of surprise were mainly caused by instructors, comparing what they were learning to what they had learned, the projects they worked on, and peer pressure.

Second, the current study contributes to causal analysis of surprise by adapting the framework of prior studies to facilitate students' reflections on surprise. Surprise only creates a tendency for causal analysis. It does not guarantee such an action analysis (Reisenzein et al., 2019; Stiensmeier-pelster et al., 1995). In fact, as indicated in the STEM literature, college students rarely read exam feedback after receiving graded exams (Andaya et al., 2017; Cherepinsky, 2011). To facilitate students' causal analysis of surprise in their reflections, the current study applied the surprise framework (i.e., experiential, affective, and cognitive indicators of surprise) that was used in laboratory studies to measure surprise (Gerten & Topolinski, 2019; Reisenzein, 2000). Students did reflect on their experience and the causes of surprise.

Third, this study contributes to the broader literature on improving engineering students' academic achievements in foundational courses. Engineering students are very likely to experience surprise, as detailed above. However, no studies have examined engineering students' experience of surprise caused by test performance in foundational courses. Thus, little is known about their surprise. For the engineering education community, an understanding of the surprise students experience can inform the design of instruction that can boost students' success.

Literature Review

Definition of Surprise

According to the expectancy-disconfirmation model (Meyer et al., 1991, 1997), people experience surprise in the event of expectancy disconfirmation. It is the first emotion to occur when people are confronted with events incongruent with their expectations (Muis et al., 2018; Vogl et al., 2019). While the initial affective reaction of surprise tends to be negative because of human beings' desire for consistency (Topolinski & Strack, 2015), surprise can be either positive or negative, depending on the valence of the outcome (Noordewier et al., 2016). The intensity of surprise is affected by the importance, valence, and unexpectedness of an outcome (Gendolla, 1997).

Working Mechanism of Surprise

The mental processes evoked by a surprising event begin with an appraisal of whether an event exceeds some discrepancy threshold (Gerten & Topolinski, 2019; Reisenzein et al., 1996). This is followed by the occurrence of the feeling of surprise and the interruption of other ongoing cognitive processes and, simultaneously, the allocation of cognitive processing resources to the surprising event to prepare for the analysis of the event (Meyer et al., 1997; Schützwohl, 1998). The analysis can then lead to a possible updating of one's knowledge structure (Schützwohl, 1998). The ultimate function of surprise is to gain effective control of the environment (Meyer et al., 1991; Schützwohl, 1998).

Surprise may transition into curiosity when the novelty and value of the discrepant information are high and the comprehensibility is also high. However, when the information is incomprehensible, surprise may be followed by confusion (Muis et al., 2018). Empirical studies show that curiosity and confusion have different impacts on causal search and student learning. Curiosity relates to exploratory behaviors (Litman, 2005) and predicts self-regulation, including planning, goal setting, and monitoring and evaluation of learning (Morton, 2010; Muis et al., 2015), but it also predicts shallow cognitive strategies (Muis et al., 2015). Confusion, on the other hand, does not significantly predict exploratory behaviors (Vogl et al., 2019). If appropriately regulated, it can lead to deep processing of information and become beneficial to learning (D'Mello S. et al., 2014). If not regulated, confusion can lead to frustration and disengagement (D'Mello & Graesser, 2012).

Rationale for Investigating Students' Feeling of Surprise

The causal analysis of surprise triggered by test scores in foundational courses has the potential to improve course outcomes. When students do causal analysis, they evaluate their current state, examine what influenced their performance, and then plan and monitor their cognition. Given the important role metacognition plays in STEM leaning (Schraw et al., 2006), these metacognitive activities can boost students' success. When students reflect on surprise and engage in causal search, they may form behavioral intentions, the specific plans to achieve goals, which can increase motivation and performance (Dyczewski & Markman, 2012). They may also adjust their expectations of future tests, which helps with emotion regulation. Additionally, the reflection on the concepts they did not master during causal analysis helps with future learning as the intensive causal processing of a surprise event leads to greater memorability (Hastie, 1984; Lassiter et al., 1991).

The Study Purpose

The purpose of this study was to investigate undergraduate students' experiences of surprise caused by exam scores in foundational engineering courses. We asked students to do causal analysis after each test. As mentioned earlier, students can reap the benefits of causal analysis in several ways. Additionally, for the engineering education community, an understanding of the surprise students experience can inform the design of instruction in foundational courses. Specifically, we examined whether engineering students experienced surprise when they found out their test scores, and if they did, what were the causes of surprise. Finally, as surprise involves an interaction between cognition and emotion (Foster & Keane, 2015), we also examined emotions associated with surprise in this engineering education context.

The following research questions were addressed:

1. Did students experience surprise in foundational engineering courses?
2. What were the causes of students' surprise?
3. What were the emotions associated with surprise?

METHOD

Research Design

A case study approach was used to investigate a complex phenomenon in its real-world context (Yin, 2014). The phenomenon was engineering students' experiences of surprise caused by test performance in foundational courses. The case was a foundational engineering course at a public university in the southeastern United States. Students wrote reflections after each of the three tests given during the course. The reflections were collected and analyzed to understand whether engineering students experienced surprise after they learned their test scores, the causes of their surprise, and the emotions associated with surprise.

Settings and Participants

The sampling method was convenience sampling. Participants were recruited from Engineering Statics, a foundational engineering course taught by one of the researchers at a public university in the southeastern United States. The topics included equilibrium of trusses, frames, machines, and forces and couples in two and three dimensions, in addition to other topics. For several years, the class had been a flipped class in which students watched video lectures before each class period. The class time was devoted to solving sample problems. There were two sections, and students met on Mondays, Wednesdays, and Fridays. Due to the COVID-19 pandemic, half of each section attended the class in person in the classroom on Mondays and Wednesdays, and the other half attended the class remotely via Zoom. All students were able to attend the face-to-face class on Fridays. Students took four exams, Test 1, Test 2, Test 3, and the final exam. Students worked on each exam for 40 minutes, during which time they had to solve four to five problems.

Data Collection

Participants took Test 1 in mid-September, Test 2 in mid-October, Test 3 around mid-November, and the final exam at the end of the semester. Participants reflected on each of the first three exams throughout the semester. Participants were assigned to one of the four groups: (1) the Reflection (R) group, (2) the Surprise Reflection (SR) group, (3) the Immediate Reflection (IR) group, and (4) the Immediate Reflection and Reflection Again (IRR) group. Each of the four groups comprised half of the students in each section of the course. Participants in the reflection group reflected on their exam performance after completing each of the first three exams. The SR, IR, and IRR groups used the same reflection template to reflect on their surprise. Surprise reflection data were collected from the SR, IR, and IRR groups. The timing of each group's reflection is detailed below.

Participants in the SR group reflected on their surprise after the instructor graded their exams. The IR students reflected on their surprise immediately after taking the exams, before the instructor graded their exams. The next day after each exam, the IR students received a scanned copy of their exam papers, a video that included the step-by-step processes of solving the exam problems, and a description of how many points each step was worth. After assessing their own exam papers, students reflected on their surprise. In addition to performing the steps of the IR group, the IRR group did a short reflection (post-reflection) after the instructor graded their exams, reporting the difference between their actual score and the score awarded by their instructor and their level of surprise at the instructor-awarded score.

This study was part of a larger project examining students' experience of surprise and how to effectively facilitate students' reflections on their surprise. For the larger project, we hypothesized that an immediate reflection would lead to a more accurate rating of surprise and a more effective causal analysis than a delayed reflection for several reasons. As evidenced by Schützwohl's study (1998), individuals' ratings of surprise are significantly affected by memory distortions. An immediate appraisal of surprise is likely to lead to a more accurate result. Also, from a cognitive-evolutionary perspective, people continually monitor the environment and update their mental models in order to accurately predict future events (Meyer et al., 1991; Reisenzein et al., 2019). What happens between the surprising event and the collection of ratings on surprise may influence students' reported feelings of surprise.

The SR, IR, and IRR students were provided with a reflection prompt (see Table 1) that guided them to report their feelings of surprise, examine what made them surprised or not surprised, describe other emotions associated with surprise, and form strategies they would use to improve their academic performance in the rest of the semester. To capture students' feelings of surprise, the reflection prompt included questions that assessed three indicators of surprise, including how surprised they were at their test scores (experiential indicator), how much they liked the scores (affective indicator), and how much they expected the scores (cognitive indicator). Students rated their surprise, liking, and expectancy levels on a 5-point scale (0 = not at all surprised; 1 = slightly surprised; 2 = moderately surprised; 3 = very surprised; 4 = extremely surprised). The three indicators of surprise were derived from the literature on surprise. Reisenzein (2000) examined the association between the four components of surprise: cognitive, experiential, behavioral, and expressive components. Reisenzein's study participants worked on a computerized test. They were provided with the solution to every item immediately after they completed the item. Some of the solutions were unexpected. The cognitive component was measured by asking participants to rate how confident they were about the correctness of their solutions. The experiential component was measured by asking participants to rate their levels of surprise after seeing the solutions. The behavioral component was measured as response delay. For the expressive component, the author recorded participants' facial expressions and scored them. Gerten & Topolinski (2019) examined the impacts of the levels of deviance of stimuli and the constraints of expectations on the behavioral, cognitive, experiential, and affective indicators of surprise. Their behavioral indicator of surprise was measured as response delay. For the other three indicators of surprise, they asked participants to rate how much they had expected the stimuli (cognitive), how surprised they were (experiential), and how much they liked the stimuli (affective).

Table 1
Reflection template

Reflection Prompt
Students feel surprised when their exams scores are different from their expectations. Now that you just learned about your exam score, we would like you to reflect on whether you were surprised by your score and what you are going to do in the future.
1. Please rate your level of surprise with your earned score. (0 = not at all surprised, 1 = slightly surprised, 2 = moderately surprised, 3 = very surprised, 4 = extremely surprised.)
2. Why are you surprised or not surprised?
3. How much do you like your score? (0 = not at all, 1 = slightly, 2 = moderately, 3 = very much, 4 = extremely.)
4. Why do you like or not like your score?
5. How much did you expect a score like the one you got? (0 = not at all, 1 = slightly, 2 = moderately, 3 = very much, 4 = extremely.)
6. Why you expected or not expect a score like the one you got? Please be specific. For example, if you expected to earn a high grade because you spent much time on the course, describe how you spent your time. If you thought you understood all concepts, but still scored low on the exam, describe what you did to understand the concepts.
7. What were the other feelings you experienced when you learned about your exam score?
8. What will you do to become more successful in the remainder of the semester?
9. How do you think your instructor can help you become more successful in the remainder of the semester?

Data Analysis

Although most participants submitted all three reflections, there were some students who submitted only one or two reflections. A total of 52 reflections composed by 20 participants in the SR and IRR groups were analyzed. There were 35 reflections composed from the SR group and 17 reflections from seven IRR participants. We did not analyze the reflections of the IR group because right after the exams, the IR group estimated their scores based on a scanned copy of their exam papers, a video that included the step-by-step processes of solving the exam problems, and a description of how many points that each step was worth. Although immediate reflection may lead to a more accurate report of levels of surprise, as indicated by Schützwohl's study (1998) and suggested by the cognitive-evolutionary perspective (Meyer et al., 1991; Reisenzein et al., 2019), the IR participants' estimated scores might be inaccurate, which may have affected their ratings of surprise, liking, and expectancy.

In addition to performing the steps of the IR group (i.e., reflecting on surprise immediately after assessing one's own test papers), the IRR group did short post-reflections after the instructor graded their exams. The IRR participants reported both the difference between their actual scores and the scores awarded by their instructor as well as their levels of surprise at the instructor-awarded scores. Five post-reflections indicated that participants were very or extremely surprised after receiving the instructor-awarded scores. This suggests that the estimated scores these five students gave to themselves were very different from the actual scores they received, which may have affected their levels of surprise, so we did not analyze those five reflections.

These reflections we analyzed were entered into a qualitative data analysis software, NVivo, to assist with thematic analysis of the reflections. Data analysis was inductive, which means that the data analysis was not a process of fitting the data into an existing coding scheme (Braun & Clarke, 2006). Instead, we looked for themes (e.g., causes of surprise) that emerged from the data.

To investigate the causes of surprise, we looked at the reflections holistically. Specifically, although there was a question in the reflection template that asked participants why they were surprised or not surprised, we also looked at participants' responses to other questions to obtain an in-depth understanding of the causes of surprise. In addition, when necessary, we read participants' other reflections to better understand ambiguous responses. For example, B14 stated that they changed their study habits, which seemingly resulted in a better score for Test 2, but B14 did not mention in their Test 2 reflection what study habits were changed. We went to B14's Test 1 reflection, which showed that the student did not do well on Test 1 and that B14 studied for Test 1 by reviewing homework problems and working out some textbook problems. In their Test 2 reflection, the student mentioned that they practiced all homework problems and did textbook problems. Here B14 also mentioned that, for the remainder of the semester, they would practice two extra book problems every day and redo homework without using notes. We inferred from this student's Test 1 and 2 reflections that for Test 2 they began practicing all homework problems, as opposed to only reviewing them.

When a student stated that they liked their score, we interpreted the surprise as a pleasant one. If this was not stated outright, however, we read the entire reflection to make a judgment on whether the surprise was pleasant or unpleasant.

Trustworthiness

We took the following measures to ensure trustworthiness. First, the first author analyzed 18 reflections and created a coding scheme. Three of the four researchers analyzed ten reflections independently and then met to refine the coding scheme. After that, two researchers independently analyzed six reflections. The inter-rater reliability was 0.65. We met to discuss our discrepancies. We then analyzed 12 reflections independently. The inter-rater reliability was 0.82. The first and third authors analyzed half of the reflections.

FINDINGS

RQ1: Did students experience surprise in foundational engineering courses?

As shown in Table 2, in 12 reflections, participants revealed that they did not experience surprise. In 27 reflections, participants indicated that they experienced unpleasant surprise. Out of these 27 reflections, participants revealed their surprise to be at Level 1 in nine reflections, at Level 2 in eight reflections, at Level 3 in six reflections, and at Level 4 in four reflections. This suggests that in 34.6% of the reflections, the levels of unpleasant surprise were 2 (moderately surprised) or above 2 (very surprised to extremely surprised). In 13 reflections, participants noted that they experienced pleasant surprise. Out of these 13 reflections, participants reported that their surprise to be at Level 1 in six reflections (11.5%) and at Level 2 in seven reflections (13.5%). No reflections revealed that the level of students' pleasant surprise was 3 or 4.

Out of all 52 reflections, participants' level of liking was zero in 15 reflections, one in three reflections, two in 13 reflections, three in eight reflections, and four in 13 reflections. In summary, the levels of liking were zero (not at all) or one (slightly) in 34.6% of the reflections. Participants' expectancy was at Level 0 in five reflections, at Level 1 in eight reflections, at Level 2 in 16 reflections, at Level 3 in 17 reflections, and at Level 4 in six reflections. So the levels of expectancy were zero (not at all) or one (slightly) in 25% of the reflections.

Table 2
Participants' ratings of their surprise, expectancy, and liking of test scores

	Unpleasant surprise	Pleasant surprise	Liking	Expectancy
Level 0 (not at all)* (12)	N/A	N/A	15 (28.85%)	5 (9.62%)
Level 1 (slightly)	9 (17.31%)	6 (11.54%)	3 (5.77%)	8 (15.38%)
Level 2 (moderately)	8 (15.38%)	7 (13.46%)	13 (25%)	16 (30.77%)
Level 3 (very much)	6 (11.54%)	0 (0%)	8 (15.38%)	17 (32.69%)
Level 4 (extremely)	4 (7.69%)	0 (0%)	13 (25%)	6 (11.54%)
Total	27	13	52	52

* 12 reflections indicated that the level of surprise was 0.

RQ2: What were the causes of students' surprise?

The main reasons why participants did not like their scores were that (a) their scores were too low or even a failing grade and (b) they thought their scores did not reflect their knowledge. The main reasons why participants liked their scores were that (a) the scores were high, (b) the scores showed that they understood the materials, and (c) they made a big improvement.

The reasons why participants expected good scores were that they understood the concepts, studied hard throughout the semester, and studied hard for the tests. Not many reflections (only five out of 52) mentioned that the participants expected low scores. The main reasons why they expected low scores were that they did not study much and they did not understand concepts.

When we tried to identify the causes of surprise, we focused on the reflections that indicated surprise levels greater than 1. There were 18 reflections showing that the levels of participants' unpleasant surprise were 2, 3, and 4. There were seven reflections suggesting that the level of pleasant surprise was 2. No reflections indicated a Level-3 or Level-4 pleasant surprise. The 18 reflections showed several causes of unpleasant surprise. First, ten out of the 18 reflections mentioned that the participants thought they understood the concepts, but they scored lower on the tests than they expected. Participants indicated in ten out of the 18 reflections that they studied hard for the test or felt prepared for the test, but their scores were lower than they expected. The majority of these participants indicated in the reflections that they prepared for the tests by reviewing notes, rewatching lecture videos, looking at the solutions to the problems in the in-class handouts, or going through the topic list provided by the instructor.

Participants were moderately pleasantly surprised because the scores were higher than they expected. Six out of the seven reflections emphasized that, in addition to reviewing materials, the participants practiced solving problems (i.e., redoing homework problems and solving extra problems from the textbook that were not assigned by the instructor) when they prepared for the tests.

RQ3: What were the emotions associated with surprise?

The emotions associated with unpleasant surprise included disappointment, frustration, and upset. For example, B7 noted in their reflection on Test 1 that "[I] only worked on the first problem for 30 minutes. That only left time for two more questions and I tried to write down as much as I could." The student also indicated that "it is really hard to study for test when there are still many homework assignments to keep up with. I watch all the videos and do all the assignments, and I understand everything as I go, but I'm having trouble trying to add more time to study on top of all the coursework for other classes." In the Test 2 reflection, the participant indicated that "I studied harder for this test than the first one, but I ended up doing a lot worse." They indicated that "I am just very upset, and I do not know what else to do to succeed in this class. I do not want to withdraw; however, I just want to work my hardest and do better on the next two tests." The student's Test 3 reflection suggests that they were frustrated because they did not do well on Test 3: "I am just really upset and frustrated because I really enjoyed this course and worked really hard for it, and I just can't seem to perform well when it counts."

When students experienced pleasant surprise, they felt happy and relieved. For example, B14 indicated in the Test 2 reflection that they were moderately surprised (Level 2) because "I knew I did better on this test than the last test before we got our grades back, but seeing it actually be true was a pleasant surprise." B14 liked the score very much (Level 4). The participant explained why they moderately expect such a score (Level 2), and then indicated that they were happy: "My score was 28 points higher than my last exam, so that makes me extremely happy." The participant also had "relief that I did well, but also the feeling of knowing I am up for the challenge of doing better every test."

DISCUSSION

Students did experience surprise after they found out their test scores. According to 34.6% of the reflections, students were moderately (Level 2), very (Level 3), or extremely (Level 4) unpleasantly surprised. In 13.5% of the reflections, the levels of pleasant surprise were 2 or higher. And the levels of liking were zero (not at all) and one (slightly) in 34.6% of the reflections. The levels of expectancy were zero (not at all) and one (slightly) in 25% of the reflections. These findings contribute to the literature on surprise and engineering education. There are few classroom studies that have explored college students' feelings of surprise, especially in the engineering education context. The engineering education literature shows that about one third of the students fail foundational courses. And laboratory studies show that the intensity of surprise is affected by the importance, valence, and unexpectedness of an outcome (Gendolla, 1997; Gendolla & Koller, 2001). Thus, an important failure triggers the highest level of surprise (Gendolla, 1997). However, no empirical studies have investigated whether students experience surprise after they get to know their test scores in foundational courses. The current study makes an important contribution in this regard.

Another contribution of the current study is that it shows that many of the students who were at least moderately unpleasantly surprised may have overestimated their knowledge, which contributes to the broader literature on improving engineering students' academic achievements in foundational courses. Among the reflections that showed that students were moderately, very, or extremely surprised, more than half (ten out of 18 reflections) showed that students thought they understood the concepts, but they scored lower than expected on the tests. Unskilled people tend to overestimate their abilities, which is known as the Dunning-Kruger effect (Kruger & Dunning, 1999). In the Dunning and Kruger (1999) study, students completed tests of humor, logic reasoning, and English grammar. The study found that the students who scored in the bottom quartile overestimated their ability and that the cause of the overestimation was a lack of metacognitive skills among the less-competent individuals. There is evidence for the Dunning-Kruger effect from classroom studies (Hacker et al., 2008; Miller & Geraci, 2011). The possible causes of low-performing students' overconfidence include their lack of content knowledge and the unawareness of what they do and do not know (Miller & Geraci, 2011; Saenz et al., 2019).

In the current study, students thought they had understood the concepts. This is a judgement of learning, which is a type of monitoring (T. O. Nelson & Narens, 1990). Monitoring affects students' control of learning, such as subsequent time investment and the search and implementation of learning strategies (Coutinho et al., 2020; T. O. Nelson & Narens, 1990; Son & Schwartz, 2002). The accuracy of monitoring plays an important role in the control of learning, which was stressed by Son and Schwartz (2002): "If monitoring is completely inaccurate, the issue of control becomes moot" (p. 17). Inaccurate monitoring can have a negative impact on students' learning outcomes because the monitoring will direct students' time and effort away from the materials they have not mastered (Coutinho et al., 2020). Research shows that monitoring accuracy is strongly correlated with long-term retention (Dunlosky & Rawson, 2012) and students' academic performance (Nietfeld et al., 2005).

The finding that students who were at least moderately unpleasantly surprised may have overestimated their knowledge provides an important implication on how to improve students' academic achievements in foundational courses. That is, it is important to enhance students' ability to assess their own knowledge. To improve students' self-assessment ability, instructors can have students complete "explain-a-problem" assignments (Hanson & Williams, 2008). This type of assignment asks students to detail the steps to solve a problem so that enables readers could replicate the solution. Students need to focus on how to solve problems, not how to plug numbers into formulas. Second, instructors can ask students to solve problems related to key concepts under a time constraint and without referring to any materials (i.e., textbooks, notes, homework problem solutions), which can serve as a way to assess whether students have mastered the concepts. The third strategy that can be used is to make students aware that people, particularly low performers, tend to overestimate their academic abilities (Saenz et al., 2019) and that it is important to improve the ability to judge whether they have mastered a concept.

The current study suggests that students who were at least moderately unpleasantly surprised may have used ineffective learning strategies, while those who were pleasantly surprised used more effective strategies. More than half of the reflections that showed that the levels of unpleasant surprise were 2 or above indicated that those students prepared for the tests by reviewing materials, including notes, lecture videos, the solutions to the problems in the in-class handouts, and the topic list provided by the instructor. These students also indicated in their reflections that they thought they studied hard to prepare for the tests. However, their scores were lower than they expected. This suggests that, in line with the findings of a meta-analysis of empirical studies by Bjork (2013), students often use ineffective learning strategies but believe them to be effective. This is known as metacognitive illusion (Karpicke et al., 2009). One ineffective strategy commonly used by students is reviewing materials, as shown by a laboratory study conducted by Karpicke et al. (2009). Replicating Karpicke et al. (2009) but in an engineering education context, Cervin-Ellqvist et al. (2021) found that reading course materials was among the four strategies that were most commonly used by engineering students in two calculation and two conceptual courses. Although reviewing materials is not necessarily ineffective all the time (Dunlosky et al., 2013), this strategy tends to be ineffective for engineering learning (Wojahn et al., 2020), especially when it is the only strategy students use to prepare for tests. In contrast, almost all students who were moderately pleasantly surprised indicated that they practiced solving problems when preparing for the tests. This finding is in line with what prior research has found: practice solving problems is an effective learning strategy in engineering (Cervin-Ellqvist et al., 2021; Dunlosky et al., 2013).

To help students who experience unpleasant surprise like those in the current study, instructors can use interventions to raise students' awareness of the strategies that can enhance learning in foundational engineering courses (Wojahn et al., 2020). If these strategies are shared by peers who did particularly well on the tests, students may be more inclined to use them. For example, one of the effective strategies revealed by many students in the current study was to do practice problems. In particular, one student who received a perfect score on the first two tests and an almost-perfect score on the third one indicated that they practiced the in-class examples more than 10 times each. Although research shows that practice solving problems is an effective learning strategy in engineering (Cervin-Ellqvist et al., 2021; Dunlosky et al., 2013), hearing this advice from high-achieving students can be especially persuasive to other students.

The current study contributes to surprise causal analysis by adapting the framework of prior laboratory studies (Gerten & Topolinski, 2019; Reisenzein, 2000) to facilitate students' reflections on surprise. The reflection prompts in the current study asked questions about the experiential, affective, and cognitive indicators of surprise. The reflections triggered a causal search and students' subsequent change of study strategies. For example, Student B1 revealed in their Test 1 reflection that they did not like the test score at all because they had never failed a test. B1 was very surprised because they thought that they understood the concepts since they were able to do the practice problems the instructor assigned. However, the wording of the test problems was different than that of the in-class and homework problems, so the student was not able to solve them. B1 went on to say that in the remainder of the semester, they were fully committed to do everything to raise their score. They would attend tutoring provided by the college and go to the instructor for future guidance. B1's Test 2 reflection showed that they extremely liked their Test 2 score (Level 4) and felt the score reflected the work they put into the test. The student expected to do well (expectancy level was 2) because of the time and effort put into preparing for the test. The student began studying for the second test much earlier than for Test 1, attended weekly tutoring, and followed the instructor's advice about taking notes when attempting a problem to retain the information and truly understand the concepts. Student B1 reported that the weekly tutoring and instructor's suggestion greatly helped. B1 felt that they understood the concepts better on Test 2 than Test 1. B1 was pleasantly surprised (Level 2) because they felt they did well but did not expect to do as well as they did. B1 concluded that they would continue the tutoring and preparing for subsequent tests early.

Surprise only creates a tendency for causal analysis. It does not guarantee such an action analysis (Reisenzein et al., 2019; Stiensmeier-pelster et al., 1995). In fact, as indicated in STEM literature, college students rarely read exam feedback after receiving graded exams (Andaya et al., 2017; Cherepinsky, 2011). If students do not review exam solutions, they will be unlikely to search for what caused their exam scores to be lower than what they expected. Also, the mental processes evoked by a surprising event include detection of schema discrepancy, interruption of ongoing activities and focusing of attention on the surprising event, analysis of the event, and schema revision (Meyer et al., 1997; Schützwohl, 1998). Analysis of the surprising event seems to be the most challenging and requires the most effort on students' part. Thus, facilitating students' causal analysis will be of utmost importance to help them take productive steps toward their learning.

LIMITATIONS AND SUGGESTIONS

The generalizability of the study findings is limited by the study sample size and the research context. Reflections from 20 students in one course were collected and analyzed. A larger sample size and data from multiple foundational courses are suggested for future research. The current research context was a foundational engineering course. As suggested by the literature, engineering students typically performed well in high school and have a higher sense of self-efficacy in their abilities than students in other majors. Research also shows that high performers can make accurate predictions of their test performance (Hacker et al., 2008). As the intensity of surprise is affected by the importance, valence, and expectancy of an event (Gendolla, 1997; Gendolla & Koller, 2001), these high-ability students' surprise experiences may differ from the surprises of students in other majors. Future classroom studies can explore the surprise experienced by students in other majors. Another limitation was caused by the COVID-19 pandemic. The data were collected in the first full semester after the outbreak of the COVID-19 pandemic. Students had to work through many academic challenges that were posed by online or blended courses as well as challenges in their personal lives (e.g., sickness, quarantine, or the loss of a family member), which significantly negatively affected their willingness to participate in research studies. As a result, we were only allowed to access a handful of students' test score data. If we had been able to use more participants' test scores, we would have conducted a phenomenographical study. As shown by the literature, high performers can make more accurate predictions of their test performance than low performers, and high performers' expected scores are likely to be more aligned with their actual scores (Hacker et al., 2000, 2008; Miller & Geraci, 2011). The levels and causes of high performers' surprise may be different from those of low performers' surprise. Future studies can take a phenomenographical approach that focuses on the variations in students' experiences (Case & Light, 2011).

CONCLUSIONS

About one third of engineering students do not earn a passing grade in foundational courses (Summerville et al., 2018). As the intensity of surprise is caused by the importance, valence, and expectancy of an event (Gendolla & Koller, 2001), engineering students who typically performed well in high school may experience surprise if they fail foundational courses. However, research shows that high performers can make more accurate predictions of their test performance than low performers

(Miller & Geraci, 2011). This suggests that many engineering students may be able to predict their scores and, thus, may not experience surprise. There are no prior field studies that have explored engineering students' experience of surprise. The current field study investigated whether engineering students experienced surprise and, if they did, what were the causes of their surprise. The study found that engineering students experienced surprise. Many students who were unpleasantly surprised may have overestimated their knowledge. Many of them may have used ineffective learning strategies such as just reviewing materials when preparing for the tests. The study also found that the reflection template that was adapted from the framework in prior laboratory studies (Gerten & Topolinski, 2019; Reisenzein, 2000) triggered students' surprise causal searches and their subsequent changes of study strategies.

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