Self Reflection of Engineering Majors in General Chemistry II

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Introduction

Research has demonstrated that active and collaborative instruction coupled with various means to encourage student engagement can lead to better student learning outcomes irrespective of major or academic discipline [1], [2]. A key strategy for improving student learning is to prompt students to reflect on what they do or do not understand [2], [3], [4]. These reflection practices, known more formally as metacognitive strategies, have been integrated into quizzes, homework assignments, and exam preparation to foster a second nature method of practice [3].

As part of the NSF Foundations project, faculty at Stevens Institute of Technology, who teach the core courses in Engineering and Sciences worked together, in cohorts, for three years to change their instructional practices with the goal to increase the use of active learning and evidence-based teaching practices [5]. The curriculum for General Chemistry I and II was redesigned starting in Fall 2017 to facilitate increased student engagement and interaction with the content with the goal to promote deeper and transferable learning. Large lectures and recitation were replaced with smaller class sizes of approximately 55 to 60 students which met three times per week with increased opportunities for peer interaction, group problem solving, self-assessment and reflection. General Chemistry II, the focus of this study, covers the following topics: Kinetics, Solutions, Equilibrium, Acid-Base Equilibrium, Buffers, Titrations, Thermodynamics (i.e., Entropy, Gibbs Free Energy), Electrochemistry, Nuclear Chemistry, and Transition Metals.

General Chemistry II is a required course for chemical engineering and biomedical engineering majors and satisfies a required science elective for other majors including mechanical, electrical, software, computer engineering, as well as engineering management and engineering physics. Typically, 300 to 375 students take General Chemistry II each Spring semester. In addition to the engineering majors described above, the class includes science and math majors, and a small number of business, quantitative finance, and liberal arts majors.

In Spring 2020, the course incorporated opportunities for students to think about and reflect on their learning and understanding of the content throughout the semester. Reflections, incorporated at the end of the online weekly quiz, asked students to answer questions on what they learned and what remained unclear to them from the material covered during the week. Through these questions, students became aware of what they personally need to focus on. In addition, faculty and course assistants could review the student reflections to determine material students were struggling with; material that was revisited in subsequent classes and online assignments.

The focus of this study is first year engineering majors (n=320 students) enrolled in one of eight sections. For Spring 2020, 87% of those enrolled in this course were engineering majors with smaller numbers of science, mathematics, and business majors. Key questions of interest include: What is the nature of student responses (conceptual or procedural)? Do responses vary by course week and/or gender? What is the relationship between student response (conceptual or procedural) and their performance on the exam?

Background

Metacognition is defined as the purposeful thinking about one's own thinking [6], [7]. To promote metacognition in the classroom, many different strategies have been employed in many foundation courses which includes pre assessments, "muddiest point" identification for a lecture or series of lectures, reflective journals, one-minute papers, and exam "wrappers" (surveys given to students after the exam prompting them to reflect on their exam preparation) [1], [3], [8], [9]. General Chemistry classes in large part commonly use the one-minute paper, muddiest point, and exam wrapper methods because they are relatively quick and easy, as well as provide formative assessment and information to both the instructor (to improve teaching) and the students (to improve learning) [1], [8], [9], [10]. For the "Minute Paper" the instructor takes a few minutes at the end of class for students to answer two questions, generally what they learned and what question(s) remains unclear/unanswered. The instructor can review the comments and address the most common comments in the next class as well as quickly assess a student's learning and understanding [8]. Eliciting information from students on the topic that is most confusing, or the "muddiest point", has been applied for years in many different classrooms including General Chemistry [8], [9], [10]. For example, King [10] used clicker questions in a large enrollment General Chemistry course to have students anonymously identify the "muddiest point" from a selection of topics which allowed for rapid detection as well as remediation in class. Training students in metacognition techniques has been proven to improve performance on exams [11], [12].

Methods

Metacognitive Questions. Strategies for self-assessment and reflection were embedded in weekly quizzes delivered via the course's learning management system. These quizzes consist of a series of multiple-choice conceptual and calculation-based (procedural) questions. The students have three-and one-half days to complete the quiz and two attempts are granted so, if they choose, they can retake the quiz after additional study and review. To encourage students to reflect on what they learned over the week and what they still need to focus on, students are asked to answer two questions, labeled as a weekly report: "What did I learn this past week [from list of chapters covered that week]?" and "What remains unclear to me and that I need to review further [from a list of chapters covered that week]?" The questions, asked at the end of each quiz attempt, serve to prompt students to reflect on what they have learned and how well they understand the topics covered during the past week. A graduate course assistant read all reflections and provided summaries of the topic areas with which the students were struggling. With this information, some in-class questions and group worksheet problems were designed to address these problematic areas.

The student responses to Question 2: "What remains unclear to me and that I need to review further [from list of chapters covered]?" was examined for weeks 1 through 14 over the semester.

Baseline Survey First Week of Classes. A survey was conducted the first week of the semester to establish a baseline of students' attitudes and background in Chemistry. The survey had them reflect on their background and why they were planning to take the course, what subjects they found important and interesting, how they felt about chemistry and what benefits the course provided to them after hundreds of hours of time invested in learning the material.

Sample. This analysis focused on all engineering majors: chemical, biomedical, mechanical, electrical, civil, engineering physics, software engineering, engineering management and computer engineering. The science majors were removed from the analysis and only the engineering majors were studied. The total sample size of engineering majors was 320 students with a response rate of on average 86%. The percentage of females to males was 33% females and 67% males. Gender demographics were gathered from self-identified student information provided for admission into the University.

Coding. Responses were read and categorized into eight categories (All Clear, Conceptual, Both, Generic, Non-specific, No response, Other, and Procedural). See Table 1 on the next page. All responses to Q2 were coded independently by two project staff. Codes were compared and discrepancies resolved. The Inter-Rater Agreement between the coders was 94% overall.

Exam Administration. The American Chemical Society (ACS) standard exam was used at the end of the semester as part of the final. Since the exam was administered online during the COVID-19 pandemic, the items for the final exam were chosen from the ACS exam database. The students had 60 minutes to answer 40 multiple choice questions online through the Learning Management Systems. They were not allowed to use any other resources other than a calculator and an online cover page provided by ACS. They signed an Honor Pledge at the beginning of the exam.

Table 1. Codes and Examples of Responses.

Codes	Definition	Example Responses--Q2 What remains unclear to me and that I need to review further for the exam?
AC	All Clear (no problems)	There's not much that is bothering.
B	Both concepts and procedures	I need to further review the integrated rate law and graphing of the different rate orders.
C	Concepts	What remains unclear to me is how or why the vant' hoff factor varies theoretically vs experimentally.
G	General or Generic: Not specific concept or procedure	So far nothing seems unclear to me however I definitely need to memorize the formulas and calculations since there is a huge amount present in this week's chapter.
NR	No Response	
NS	Non-Specific: Response could refer to concepts or procedures, which aspect of a topic is troubling not specified.	Enthalpy of solutions still remains unclear to me.
O	Other: Generally off topic.	I am not confused about anything currently. (For question 10, I got 0.02 but that's not an answer choice).
P	Procedures & Calculations	The only thing that I need to review further is the equation that we use to calculate what the order of the reaction is when given the concentrations and rate values.

Results and Discussion

Baseline Survey Responses: To provide a baseline on the attitude and background in Chemistry, at the beginning of the Spring 2021 semester, all students were encouraged to complete a first week survey in which they received a few points for completion. Approximately, 300 engineering majors completed the survey with 94% of the students being first year students. The survey had them reflect on their background and why they enrolled in were planning to take the course and what subjects they found important and interesting. 44 % of the students were taking the course to fulfill a requirement for their major (chemical engineering, biomedical engineering, or civil/environmental engineering) and 56% to fulfill a science requirement (included mechanical, software, computer, and electrical engineering as well as engineering management and engineering physics). Students taking General Chemistry II to meet a science elective choose chemistry for many reasons which included enjoying, liking, or being interested in chemistry; scheduling reasons; fulfilling a lab science elective; to build a strong foundation in chemistry and 25% of the students preferred chemistry to biology (one of the other science electives available for first year students.)

What is the nature of student responses (conceptual or procedural)?

Student responses to the Metacognitive questions in the weekly quizzes were coded for weeks 1 to 14. On average 86% of the engineering students provided reflections each week and 14% no response.

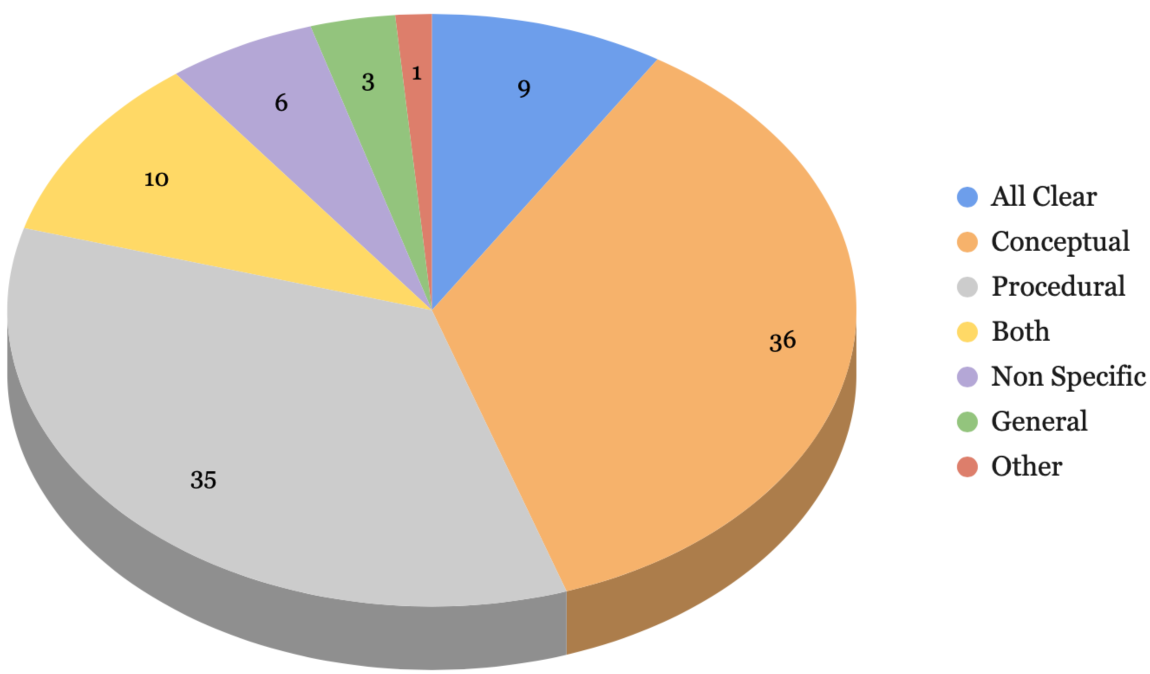

Figure 1. Distribution of engineering students' metacognitive responses across all weeks.

Of those that provided reflections, 10% of the students provided generic or nonspecific responses. 9% of the students over the 14 weeks provided responses of all clear. 81% of the students that responded, categorized their difficulties with the material as conceptual, procedural or both. 10% of the students were struggling with both conceptual and procedural. There was an almost even split of students struggling with either conceptual (36%) or procedural (35%) as shown in Figure 1. Based on these responses, the remaining analysis focused on the four main categories of conceptual, procedural, both and all clear. This reduced the sample size to 245 students over the 14 weeks with 32% females and 68% males.

Do responses vary by course week?

The metacognitive responses of conceptual, procedural, both and all clear were then analyzed by week as shown in Figure 2. Even though overall student's identify conceptual or procedural issues, there was large variation in metacognitive response from week to week. This variation depended on the material being covered.

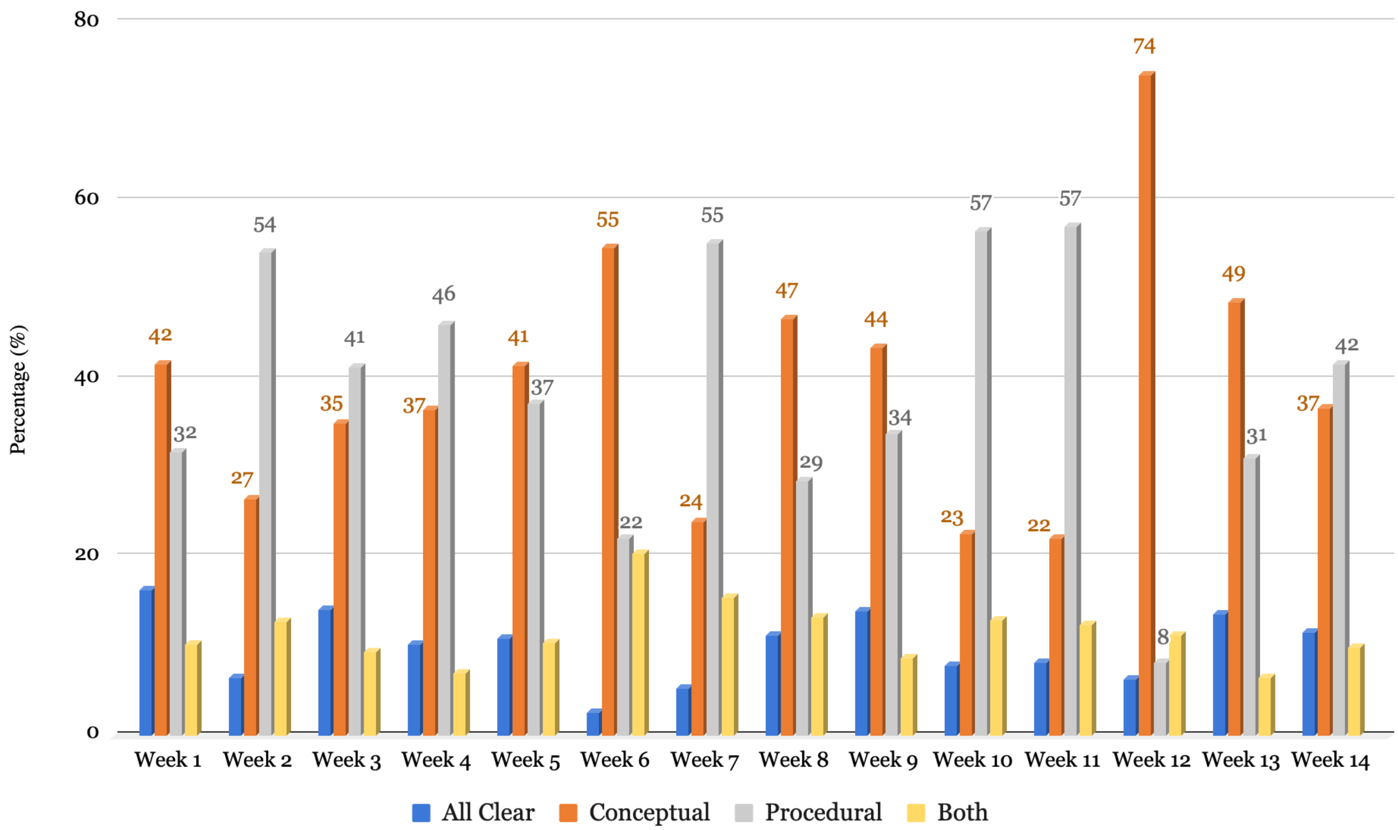

Figure 2. Engineering Students' Metacognitive Responses by Week.

Weeks 6 and 12 had the highest percentage of conceptual responses compared to other weeks (55 % or higher). Weeks 2, 7, 10 and 11 had the highest percentage of procedural responses (54% or higher).

Week 6 covered weak acid and base equilibrium as well as polyprotic acids and identification of salts and acids and bases. Students struggled with these concepts. For instance, a common response seen was: *"One thing that remains unclear for me is how to instantly recognize what chemical is an acid or base and if it is strong or weak."* Other students highlighted the need to review based on the following two frequent comments *"I need further review with salts and ions as acids and* *bases." "I definitely feel that I need to review the ionization/dissociation of salts, as I can get confused as to whether they are basic or acidic."*

As shown in Figure 2, week 12 had the highest percentage of engineering students indicating a conceptual response at 74%. This was the week that had the highest response. For this week, two completely different topics were being studied: electrochemistry in particular batteries and a review electrolysis as well as coordination compounds and complex ion solubility. Two different topics were being studied in one week based on the calendar and trying to incorporate the concept of coordination compounds before they were covered in the laboratory class.

Examples of student responses in week 12 reflect the conceptual confusion on the coordination compounds. Student 1 stated "*What remains unclear to me is how to name complex ions, ligands, and determining which are cis-trans*." Student 2 noted: *"Identifying the coordination number (number of attached ligands), oxidation states of metals in the coordination compounds, and NAMING simple compounds. Naming is especially difficult."* Also, the confusion to the topic on batteries is highlighted by responses such as "*The lesson on batteries still confuses me, so I will need to review that*." Many students commented that if they continued to practice they would improve their understanding as per this statement: "*I still have a bit of trouble naming coordination compounds; however, with practice, I will improve on this skill*."

The large percentage of procedural responses included material that was heavily focused on calculations. Week 2 content included reaction mechanisms and catalysis and solution composition, week 7 on buffers and titrations, week 10 on free energy calculations, equilibrium constant and Gibbs Free Energy and balancing oxidation/reduction reactions, and lastly week 11 on balancing oxidation/reduction reactions, determining reactions in galvanic cells and electrode potentials.

Week 10 responses were closely analyzed because of the larger percentage of procedural responses (57%). Examples of students in week 10 reflect the lack of understanding the procedural nature of the material.

One student reflected on their struggles by stating: *"I'm still confused on redox reactions: how to find what is reduced or oxidized or how to find the reducing agent or oxidizing agent."* Another common response was the students struggle with using equations as reflected in this frequent comment: "*I still have trouble with how to use the equation for the Temperature Dependence of the Equilibrium Constant."* Many students reflected on having to review how to balance and calculate: *"I have to review how to balance oxidation-reduction equation and formula to calculate free energy changes."*

In Spring 2020, the semester drastically changed in week 7 due to the COVID 19 pandemic. Switching to an online environment with synchronous lectures via zoom did not seem to affect either the response rate or nature of responses. Students were still submitting responses that reflected on their understanding.

Do responses vary by gender?

To explore if there were possible differences in the way students responded to the metacognitive strategies based on another variable, gender, the data for all weeks 1 to 14 was analyzed based on the nature of the response (conceptual, procedural, all clear, or both) as shown in Figure 3. A slightly higher percentage of female students on average were struggling with either conceptual or procedural items as compared to males, (84% as compared to 76%). Almost the exact same percentage of male and female students were struggling with both conceptual and procedural on average (12% males and 11% female). 13% of the males noted "all clear" on average over the 14 weeks as compared to 4% of the females. This indicates females were less likely to indicate being "all clear" and tended to answer that they were struggling with conceptual or procedural problems.

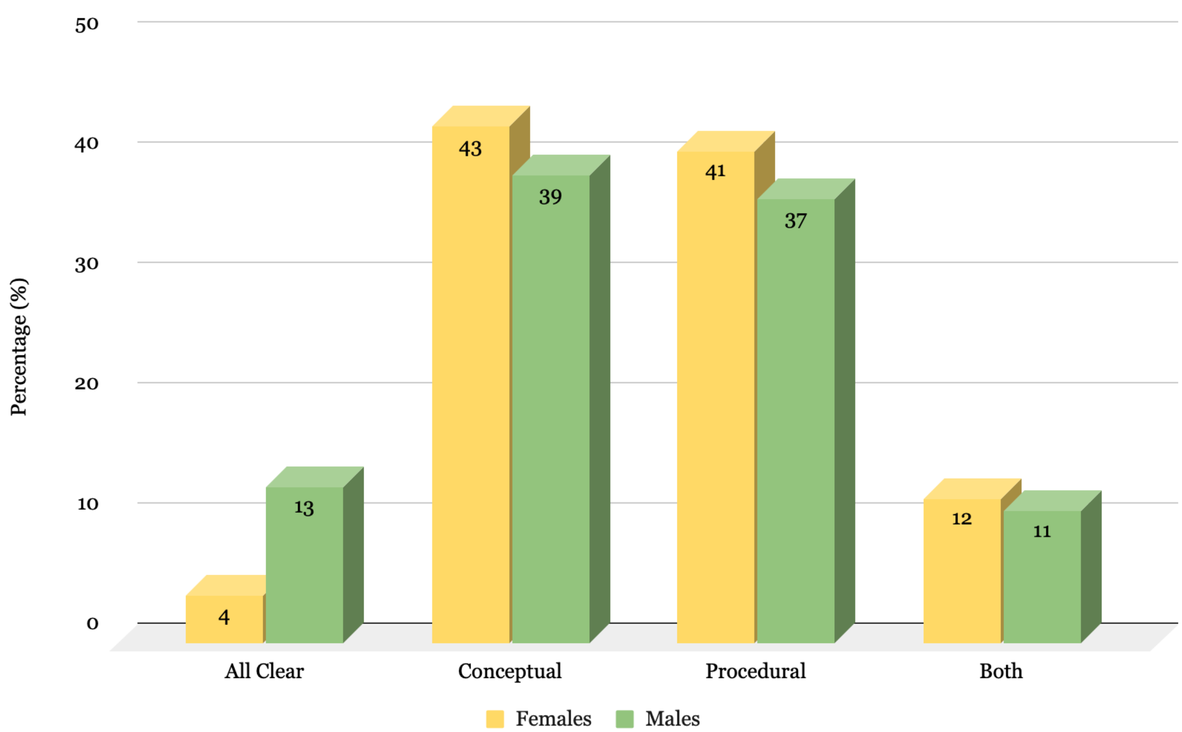

Figure 3. Engineering Students' Distribution of Metacognitive Responses by Gender. Average percentage of nature of response over all fourteen weeks.

What is the relationship between student response (conceptual or procedural) and their performance on the exam?

The ACS final exam questions were categorized using the weekly metacognitive response codes. The 40 questions consisted of 19 conceptual, 7 procedural, and 14 both. The overall results of the

ACS exam were not fully examined, given the uneven distribution of content assessed by the exam. In addition, a broad range of weekly metacognitive responses and response rates were observed. Here we examine the association between student response and final exam questions mapped to each weekly quiz with a focus on weeks where conceptual or procedural responses were the highest. ACS exam item #19 was analyzed with conceptual material from week 6 and ACS exam item #31 was associated with procedural material from week 10.

A series of Chi-square tests for independence were employed to examine the relationships between performance on a week 6 conceptual question and week 6 reflections based on gender and by week. These results helped discover that variations observed on exam performance $\chi 2$ (1, N=239) =1.280, p =.258) and metacognitive responses $\chi 2$ (3, N=239) =2.993, p =.393), did not show statistically significant associations based on gender for the item and student responses related to content covered in week 6. Similarly, the results helped discover that variations based on metacognitive responses $\chi 2$ (3, N=239) =.405, p =.939), were not statistically significant associations by week.

Comparably, a series of Chi-square tests for independence were performed to examine the relationships between performance on a procedural question, from week 10 material to week 10 responses based on gender and week. It was discovered that the variations on performance $\chi 2$ (1, N=270) =7.070, p =.008) and metacognitive responses $\chi 2$ (3, N=270) =7.849, p =.049) had statistically significant associations with gender for the item and student responses related to content covered in week 10. The results also showed that metacognitive responses $\chi 2$ (3, N=270) =2.179, p =.536) did not have a statistically significant association by week.

When asked what remained unclear week 10, a greater number of participants who identified as males reported all clear ($n_{\text{All Clear}}$=20) and procedural ($n_{\text{Procedural}}$=102) compared to females whose self-assessed responses were lower, $n_{\text{All Clear}}$=1 and $n_{\text{Procedural}}$=51. Nevertheless, a greater number of females answered the exam item correctly when compared to males.

Table 2. End of Semester Survey Results from Spring 2020 and Spring 2019 Evaluating Student's Self Assessment of the Learning Outcomes.

			Spring 2020 n=160			Spring 2019 n=136*	
Learning Outcome	Week Covered	Strongly Agree/ Agree	Neutral	Disagree/ Strongly Disagree	Strongly Agree/ Agree	Neutral	Disagree/ Strongly Disagree
I can determine reaction rates and use rate laws for a reaction.	1	91.9	0.0	1.3	89.7	6.6	3.7
I can determine how far a reaction will progress. In other words determine the chemical equilibrium for a reaction.	2	83.1	14.4	2.5	82.4	10.3	7.4
I can determine and express Equilibrium Constants for reactions.	4	87.5	11.9	0.6	81.6	14.7	3.7
I can identify acids and bases and solve acid and base problems.	5, 6, 7	88.1	10.6	1.3	80.9	15.4	3.7
For a chemical reaction, I can determine if a reaction will occur and is spontaneous or non spontaneous.	8, 9	91.3	7.5	1.3	89.2	6.7	4.2
I can calculate the change in entropy and Gibbs free energy for a reaction.	8, 9, 10	91.3	8.1	0.6	94.9	2.2	2.9
I can describe a galvanic cells and can calculate the electrical cell potential.	10, 11	83.8	13.8	2.5	86.0	11.0	2.9
I can identify a coordination compound and be able to determine the complex ion and the counter ion.	12, 13	81.3	13.8	5.0	78.3	15.0	6.7
I can identify and determine the half life of a radioactive process.	14	83.1	14.4	2.5	85.9	11.0	3.7

* Note: For Spring 2019 for two learning outcomes, only 120 students responded: " For a chemical reaction, I can determine if a reaction will occur and is spontaneous or non-spontaneous." and "I can identify a coordination compound and be able to determine the complex ion and the counter ion"

Table 2 shows the results of the end of the year survey with respect to learning outcomes in Spring 2020 (when metacognitive strategies were used) and Spring 2019, (when they were not used). Students are explicitly asked in the survey to rank how well they can perform each learning outcome, on a scale of 0 to 4, 0 being strongly disagree and 4 being strongly agree. The learning outcomes were mapped to the week covered. Please note, the learning outcome for week 3 was not reviewed in the end of the year survey. Also, less than 45% of the students participated in the survey each year anonymously, so the results cannot be tied directly to students' metacognitive responses or exam performance. However, for many weeks it can be implied that more students who completed the survey in Spring 2020 were confident with their abilities to achieve the learning outcome. For weeks 4, 5, 6 and 7 content, a slightly higher percentage of students in Spring 2020 strongly agreed or agreed they could achieve the learning outcome. Also, the percentage of students that disagreed that they could achieve the learning outcome was less over all weeks in Spring 2020 when compared to Spring 2019.

Summary and Conclusions

In this study, students were prompted to reflect on their understanding of course material on a weekly basis. On average, approximately 88% of all responses were from engineering students and 86% of the engineering students provided thoughtful reflections each week; with 10% generic, non-specific or other. Four main response categories observed were conceptual, procedural, both and all clear. The majority of these four categories were split between conceptual and procedural over the 14 weeks. Percentage of reflections by category varied across weeks. Students may have been unclear about concepts one week but unclear about procedures the next week. This varied drastically by student depending on the gender, and content or topics covered. In terms of exam performance, variations were also observed. Therefore, no definitive associations/relationships could be attributed to all weeks; every week was unique based on the aforementioned factors.

The weekly metacognitive reflections gave students the opportunity to stop, think and self-assess in order to, determine what they were struggling with in hopes of enabling them to become self-directed learners. These reflections were designed to allow students to discover that the quiz could have a multi-layered nature and serve as a tool for self-assessment. Students should be able to clearly articulate what they do not understand. However, students do not have experience with identifying issues and have trouble articulating exactly what they do not understand. Students need opportunities to practice this technique of metacognition as well as receive feedback.

Based on this study, in Spring 2021 the weekly metacognitive questions were changed to better capture the specific difficulties. We limited the responses so that students would focus and identify the specific learning objectives they were having trouble in mastering. The students are also asked to directly identify if they are struggling with concepts, procedures, or both. Implications for future practitioners suggest that they should provide guidance to their students on the type of metacognitive response and should be strongly related to the learning objectives.

Implications for Practice. It was observed from this project, that students had difficulty succinctly articulating what content remained unclear to them. A recommendation would be that at the beginning of the term, practitioners should guide students and/or provide clear examples of useful metacognitive responses. These responses should be strongly related to the learning objectives. A more structured approach to metacognition has been developed and implemented by other researchers. For example, the work done by Alison Flynn in her Growth and Goal's Module.

Implications for Learning. Research indicates that integration of metacognitive instruction with discipline-based learning can enhance student achievement and facilitate self-directed learning. Students should actively participate in knowledge monitoring to assess whether they understand or do not understand course material. These practices allow students to learn the material more deeply and build a stronger foundation. The goal of this method is for students to take action on an on-going basis to address topics they do not understand either by reviewing the topics and/or asking the instructor or others for clarification.

Implications for Future Research. Further studies are needed to evaluate the individual responses of students and the overall performance as a measure to see how individual week's responses influence students' overall performance. Future work will investigate directly how an individual's metacognitive response improves performance or understanding.

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