Student Use of Anchors and Metacognitive Strategies in Reflection

Anu Singh, Heidi A. Diefes-Dux
University of Nebraska-Lincoln
Corresponding Author Email: heidi.diefes-dux@unl.edu

Abstract

Context

Self-regulation, a skillset involving taking charge of one's own learning processes, is crucial for workplace success. Learners develop self-regulation skills through reflection where they recognize weaknesses and strengths by employing metacognitive strategies: planning, monitoring, and evaluating. Use of anchors assists learners' engagement in reflection.

Purpose or Goal

The purpose of this work was to gain insight into students' use of anchors when reflecting on their learning. The two research questions: (1) To what extent do students link their self-evaluation and learning objective (LO) self-ratings to their reflections? and (2) What dimensions and level of metacognitive strategies do students use in their self-evaluation of and reflections on weekly problem-solving assignments?

Methods

Data were upper-division engineering students' anchors (self-evaluations, LO self-ratings) and reflection responses for one assignment. Self-evaluations and reflections were analyzed for the presence of references to LOs. The number of students who linked the anchors to their reflection were tabulated. Additionally, a revised *a priori* coding scheme was applied to students' written work to determine type and level of metacognitive strategies employed.

Outcomes

Few students linked both anchors to their reflections. Students employed low to medium levels of the metacognitive strategies in their self-evaluations and reflections, even when they linked their anchors and reflections. The evaluating strategy dominated in the self-evaluations, while planning and monitoring dominated in the reflections.

Conclusion

Students have limited understanding of the use of anchors to guide their reflection responses. Students overall level of engagement in the metacognitive strategies indicates a need for formal instruction on reflection.

Keywords**—** Learning Objectives, Metacognition, Reflection

I. INTRODUCTION

Self-regulation is one of the critical skills required for workplace success in the 21st century (Rios et al., 2020). In the workplace, employees are expected to respond to changes that emerge due to global societal, economic, and technological transformations (Hager, 2004). To keep oneself prepared for changing situations, individuals must be able to regulate their learning by identifying their learning needs and monitoring their learning progress (Lord et al., 2009). ABET, the engineering program accreditation mechanism used by many institutions worldwide, emphasizes the need for engineering students to develop this skill with its Student Outcome 7: "an ability to acquire new knowledge as needed, using appropriate learning strategies" (ABET, 2023).

For a student to be a self-regulated learner, they must develop an understanding and awareness of their learning processes (or metacognition) and use that knowledge to control their learning processes (Colthorpe et al., 2019). Metacognitive skills can be developed in students by engaging them in activities that promote development of three metacognitive strategies: Planning, Monitoring, and Evaluating (Fridman et al, 2020). Reflection is one such technique that assists in shifting students' thinking from self-centeredness to self-awareness (Siewiorek et al., 2010); it provides opportunities for students to learn from their experience using their cognitive and metacognitive skills (Wegner et al., 2015). Hence, reflection takes students a step closer to being self-regulated learners.

However, there is evidence that in engineering classrooms, students need to improve their ability to reflect. Students' reflections show a lack of awareness of their performance and task knowledge, indicating their low metacognitive engagement (Seppanen, 2023). More precisely, students' engagement in all three metacognitive strategies (i.e., Planning, Monitoring, and Evaluating) are limited to low to medium levels while responding to weekly reflection prompts (Singh & Diefes-Dux, 2022). Reflection is a complex, rigorous, intellectual, emotional, and time-consuming process (Rodgers, 2002), but students' ability to reflect can be developed by providing multiple opportunities to reflect using anchors throughout a course.

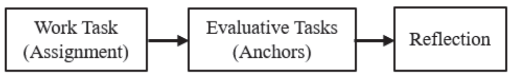

Fig. 1. Position of anchors in the sequence of activities

An anchor is a reference point that focuses the reflection activity. An anchor may be a work task providing a concrete experience on which to reflect. Anchors may also be formal self-evaluation tasks done between the work task and the reflection on the completed work task (Fig. 1). For instance, as in this study, the instructor used self-evaluation of the work task and learning objective (LO) self-ratings as anchors for reflection. During self-evaluation of the work task, the learner evaluates their work against a given standard (Tillema, 2010) and identifies what exactly they need to work on. During LO self-ratings, the learner rates their ability with an LO on a scale, which gives them opportunity to evaluate their proficiency with that LO. Overall, the use of anchors allows students to take a step back and identify specific knowledge, skill, and abilities that need improvement. Hence, the use of anchors set the stage for students to engage in deep reflection.

Studies have tended to only analyze either students' responses to self-evaluation (e.g., Baisley et al., 2022), LO self-ratings (e.g., Opanuga & Diefes-Dux, 2023), or reflection responses (e.g., Fong et al., 2023) in isolation. Separate analyses of anchors and reflections might not provide sufficient insights into students' learning challenges, metacognitive engagement, and self-regulation ability (Opanuga & Diefes-Dux, 2023; Singh & Diefes-Dux, 2023). Hence linking students' responses to the anchors (self-evaluating and LO self-ratings) and their reflections could assist in a better understanding of students' self-regulation ability.

The purpose of this quantitative-based qualitative study was to investigate the extent to which students link their work on anchoring activities to their reflections on their learning processes and to identify the dimension and level of metacognitive strategies used by engineering students during self-evaluation and reflection. Knowledge of students' propensity for linking the anchors to their reflection responses and their use of metacognitive strategies could help instructors design better instruction around the reflection activities.

II. THEORETICAL FRAMEWORK

Metacognition and self-regulated learning are theories used to guide the reflection intervention and analysis of students' work. Each theory is briefly described below.

Metacognition is commonly referred to as "thinking about thinking." Strong metacognitive skills typically result in better predicating, monitoring, and reflecting ability (Vogel-Walcutt, & Fiore, 2010). According to Flavell (1979), the two components of metacognition are knowledge of cognition and regulation of cognition. Knowledge of cognition refers to knowledge of one's own cognitive process and knowledge of strategies required to effectively perform the task, while regulation of cognition refers to strategies implemented to control one's cognitive processes: Planning, Monitoring, and Evaluating. Both components of metacognition are essential and interact with each other while performing a task (Schraw & Moshman, 1995). Overall, metacognition is important in self-regulation as "it enables individuals to monitor their current knowledge and skill levels, plan and allocate limited learning resources with optimal efficiency, and evaluate their learning state" (Schraw et al., 2006, p. 116). The present work focused on the regulation of the cognition component because its three elements (i.e., Planning, Monitoring, Evaluating) are crucial for self-regulated learning (Kittel et al., 2021).

Self-regulated learning (SRL) is a process wherein learners take responsibility for their own learning and metacognitively, motivationally, and behaviorally engage themselves in the pursuit of pre-determined goals (Zimmerman, 1989; 2002). The present study used Zimmermann's (2000) model of SRL, which considers SRL a cyclic process in three phases: Forethought (refers to phase before starting of the task and involves goal setting and strategic *planning*), Performance (refers to phase during the task where learner engage in *monitoring* their cognitive process, includes self-observation) and Self-reflection (refers to phase after completion of the task, where learners decide on the quality and impact of their performance or choices, includes *evaluating* and observing of oneself). The three phases of the SRL cycle indicate involvement in the three regulation of cognition elements (Planning, Monitoring, Evaluating, respectively). Anchoring (e.g., self-evaluation and LO self-rating) activities provide a means for students to engage in self-observation in a structured manner. Hence, integrating anchors and reflection activities can provide opportunities for students to use all three metacognitive strategies and engage deeply in an SRL cycle.

Reflection can be considered to be a self-regulation activity (Sandars, 2009) that supports the development of students' higher-order thinking and deep learning of skills (Wegner et al., 2015). In the learning context, reflection assists students in combining new learning with existing knowledge and skills (Mann et al., 2009) and prepares them for the workplace, where they must manage their learning according to task requirements (Schön, 1983). While reflection can provide opportunities for the learners to engage in all three metacognitive strategies, students do not automatically engage in deep metacognition, but they can be taught (Wedelin & Adawi, 2014) by providing suitable opportunities throughout a course.

III. LITERATURE REVIEW

Instructors can use a variety of activities to engage students metacognitively in a course (Lin, 2001). However, the present review will only focus on studies that investigated the use of self-evaluation, LO self-ratings, or self-reflection with an aim

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of preparing students to become self-regulated learners. A few such studies are discussed below.

El-Maaddawy (2017) studied the impact of self-evaluation on students' grades. The author had students self-evaluate their work after receiving minimal feedback and a tentative grade on their submitted work. The self-evaluation activity, which was completed before revision of their work for a final grade, included identifying possible sources of errors and suggesting corrections. To set the standard for self-evaluation, the instructor discussed and provided model responses from previous assignments, including examples of excellent, good, and poor work. Analysis of students' homework assignments and in-class work using the above self-assessment paradigm improved students' grades throughout the semester, and students' perceptions collected through a survey showed that students agreed that the self-assessment technique improved their learning and developed self-regulation skills.

Ugulino and Ferreira (2021) studied the impact of students' self-ratings in combination with mentor feedback on course pass rates. They asked students to self-rate their proficiency on list of challenges provided by instructors for that week's topic covered in the classroom. Students rated their proficiency on the topics using a rubric consisting of three levels of proficiency (Entry, Medium, and Target). The results showed that the students' self-assessments, followed by mentors' feedback on submitted self-assessed work, resulted in an increase in the number of students who passed the course, indicating improvement in students' awareness of their learning. Opanuga and Diefes-Dux (2023) analyzed students' LO self-ratings on weekly assignments in isolation and suggested that the LO self-ratings be analyzed side by side with students' reflective responses to achieve a more in-depth understanding of students learning challenges.

Studies described above only analyzed students' self-evaluation responses and LO self-ratings in association with mentor feedback. However, these studies did not include reflection.

Reflection activities can be used in a course to achieve different objectives: metacognition, competency, and personal growth and change (Reflection Activities, n.d.). A few studies have implemented a guided reflection exercise called Exam Analysis and Reflection (EAR) in a mechanical engineering course (Benson & Zhu, 2015), an electrical circuit course (Claussen & Dave, 2017), and a microelectronic course (Clark & Dickerson, 2018) to investigate the effectiveness of reflection on students' performance and learning. The results of Benson and Zhu (2015) and Claussen and Dave (2017) emphasized the need for a more thorough integration of the reflection activity in the course, whereas Clark and Dickerson (2018) concluded that the effectiveness of reflection is sensitive to exam problem type.

The above studies focused on students' content learning and looked for depth in reflection responses. These studies did not examine students' use of metacognitive strategies during reflection. With the objective of gaining insight into students' metacognitive engagement and improvement in students learning, Diefes-Dux and colleagues (Stratman & Diefes-Dux, 2022; Singh & Diefes-Dux, 2022) analyzed students weekly reflection response using an *a prior* coding scheme based on Ku and Ho's (2010) reflection-in-action rubric. Stratman and Diefes-Dux (2022) examined the effect of differently worded reflection prompts on the level and metacognitive regulation strategy present in students' reflections. Results showed that students employed metacognitive strategies according to the reflection prompt. When the reflection prompt focused on using instructional team feedback to improve performance, students used Planning, Action, and Evaluating strategies. Whereas when the reflection prompt focused on one's proficiency with the LOs, reflections predominantly yielded use of the Monitoring strategy. Singh and Diefes-Dux (2022) identified the three metacognitive regulation strategies employed by upper-division engineering students in their reflections. The result showed that students predominantly employed low to medium Planning and Monitoring strategy, and a limited number of students were engaged in low to medium level Evaluation. In a follow-on study to better understand students' engagement in all three metacognitive strategies, Singh and Diefes-Dux (2023) analyzed both students self-evaluating comments and their reflection responses using an expanded coding scheme with four levels for each metacognitive strategy. Results of the study showed that pairing of self-evaluation and reflection activities provided opportunities for students to engage in the complete set of metacognitive strategies, though still at low to medium levels.

Overall, the studies described above underscore the effectiveness of using self-evaluation and LO self-ratings on students' learning and self-regulation ability. However, none of the above studies analyzed the link students make between the anchors and their reflection wherein a student would identify an error or a lack of proficiency with an LO and then reflect in depth on that finding. As a result, examining students' responses to the anchor activities and the extent to which they link those activities to their reflection will provide insight into students' ability to employ the anchors as they engage in metacognition.

IV. RESEARCH QUESTIONS

The study aims to address following research questions:

1. To what extent do students link their self-evaluation and LO self-ratings to their reflections?
2. What dimensions and level of metacognitive strategies do students use in their self-evaluation and reflections on weekly problem-solving assignments?

V. METHODS

This is a quantitative-based qualitative study (Chi, 1997). Specifically, students' self-evaluations and reflections are qualitatively coded for metacognitive strategy and level and presence of references to relevant LOs. The coded results are then treated as quantitative data.

A. Setting and participants

The study was set in a junior level process engineering course at a Midwest R1 U.S. university in Spring 2021 (N= 28). The course was required for some students and an elective for other students depending on each student's major and degree program. The course duration was shortened from 16 to 14 weeks and the delivery mode was synchronous via Zoom due to COVID-19 pandemic. Course instructional materials (e.g., videos, readings, list of learning objectives (LO), assignments, standards solution key, self-evaluation template file, and reflection prompts) were shared with students through Canvas, the learning management system. The study used convenience sampling, as this was a course in which reflection activities were being implemented.

B. Intervention

The course was divided into four modules: 1) Conservation of Mass, 2) Fluid Flow (Pipes, Fittings, and pumps for Newtonian and Non-Newtonian fluids), 3) Fan Selection, and 4) Thermal Preservation. Each unit of the course consisted of a minimum of three assignments called Trainings (TR). Each training consisted of parts A and B. Part A involved solving a computational problem set in an authentic context using Excel. After submission of part A, the instructor released a solution key. Part B consisted of two steps, self-evaluation and reflection as explained below.

1) Self-Evaluation (B.1): Students were asked to compare their solutions to the key and annotate their Excel work with comments on their errors or things they learned or needed to work on. To further assist students, the following prompt was provided.

When your method or answer is incorrect or either could be improved, you need to track down where the issues are and comment on what you figured out.

TABLE I
LO RATING SCALE (OPANUGA & DIEFES-DUX, 2023)

Scale	Text Options Provided to Students
5	I can do this on my own without referring to resources
4	I can do this on my own if I refer to some resources
3	I need more practice with this
2	I need someone to help me understand and do this
1	I am not sure what this means (I am very lost)

2) Reflection (B.2): After submitting their annotated Excel sheet, the reflection activity became available to students. In this activity, the students self-rated their abilities with the course learning objectives and responded to an open-ended reflection prompt.

LO Self-Ratings: Students were asked to rate their abilities with the training relevant LOs. The LO self-rating assignments were administered through Canvas-graded surveys. For each training-relevant LO, students were required to select one of the five text phrases that best described their proficiency level with the LO (Table I). The scale of 1 to 5 was for research purposes only and was not shown to students.

Open Ended Reflection Prompt: Students were then asked to respond to three open ended reflection prompts. The first prompt focused on students' plans to improve their learning; this one was analyzed in this study. The prompt asked students to reflect on the LOs using the corresponding proficiency indicators (Table II).

TABLE II
SAMPLE LEARNING OBJECTIVES AND PROFICIENCY INDICATORS FOR TR 3.3

Learning Objective		Proficiency Indicators
PS 01.00	**Employ a robust problem-solving process that clearly documents engineering work (PS 01.00-01.08)**	
PS 01.01	Write a clear problem description that contains some context and an indicator of what the goal of solving the problem is	• Sufficient context is provided to understand the nature of the problem • The goal indicates the result(s) that are being sought
FF 02.00	**Use the law of conservation of mass to find stream mass flow rates and compositions**	
FF 02.06	Perform material balances when measures of throughput, other than mass flow rates, are given	• Write material balances in terms of average velocity • Write material balances in terms of volumetric flow rate • Convert between mass flowrate and volumetric flow rate • Convert between mass flowrate and velocity • Identify whether the problem is solvable (degree-of-freedom analysis) • Select, with rationale, the independent equations needed to solve the problem • Complete problem using standard problem solving process
FF 02.08	Determine the operating point for a single fan or multiple fans given the system characteristic curve and the manufacturer's fan curve	• Overlay a system characteristic curve on a manufacturer's fan curve (single or multiple) • Determine the operating static pressure and volumetric flow rate
FF 03.00	**Characterize fluid flow**	
FF 03.01	Compute the Reynolds number for Newtonian fluids flowing in pipes	• Correctly use the Reynolds number formula to obtain a dimensionless number • Perform computations in SI or English units
FF 03.02	Classify fluid flow using the Reynolds number for Newtonian fluids flowing in pipes	• Classify fluid flow as laminar, turbulent, or transitional
FF 03.03	Determine the system characteristic curve for a fan used in a grain drying process	• Employ the six step process described in TR 3.2.3

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Proficiency indicators were developed by the instructor to guide students about the aspects that constitute successful demonstration of LO. The first open-ended prompt read as follows:

For those learning objectives that you are not able to do on your own, what do you plan to do to improve your abilities? Refer to specific learning objectives and indicators of proficiency and be specific about your planned actions.

If there is nothing which you feel you need to improve upon, practice describing your newly acquired or strengthened skills (as if to a future employer or superior). What is the skill? How do you see that skill being useful in your work as an engineer?

When looking at the various tasks, the training serves as the experience on which the student reflects. The self-evaluation of work serves as the start of the reflection as students identify errors with the potential of connecting their successes and difficulties to the LOs. The self-evaluation also serves as an anchor for the open-ended reflection prompt. The LO self-ratings also serve as an anchor for the open-ended reflection prompt. When responding to the reflection prompt, the student optimally draws on what they learned about their learning from the experience and anchors.

C. Data collection

Students' self-evaluation of their computational work, their LO self-rating and their responses to first open-ended reflection prompt were collected from the Fan Selection (FA) unit. This module consisted of three trainings (TR 3.1-3.3). The data from TR 3.3 were used in the present work. For TR 3.3, students rated themselves on eight LOs; a few of them are shown in Table II. The data from TR 3.3 were used in the present work. For TR 3.3, students rated themselves on eight LOs; a few of them are shown in Table II. Students had access to the proficiency descriptions shown in Table II through the course list of LOs posted on Canvas.

TABLE III
BINARY ASSIGNMENT OF LOS ADDRESSED IN SELF_EVALUATION (ERROR) COMMENTS AND REFLECTIONS AND LO SELF_RATING FOR ONE SAMPLE STUDENT

Type	PS 01.00	PS 02.02	PS 03.01	FA 02.06	FA 02.08	FA 03.01	FA 03.02	FA 03.03
Error	1	1	0	0	1	0	1	1
Reflection	1	0	0	0	0	0	0	0
LO Rating	3	3	4	3	2	3	3	3

D. Data analysis

Students' self-evaluation comments (from B.1) on their computational work were submitted in a pre-defined Excel format. These comments were extracted and placed in a single Excel file for coding. Students' self-ratings of their proficiency with the LOs and responses to the open-ended reflection prompt were downloaded from Canvas and saved in Excel file. Data collected from students' self-evaluation comments, self-rating of LOs, and reflection responses were then analyzed in two steps to answer each research question. Twenty-five (*n*=25) of the 28 students enrolled in the course completed all three tasks.

TABLE IV
METACOGNITIVE STRATEGIES CODING SCHEME (ERTMER & NEWBY, 1996; KU & HO, 2010; SINGH & DIEFES-DUX, 2023)

Dimension	Description
Evaluating (E): Student's comments represent an assessment of their thoughts or performance influenced by outside factors (grades, feedback). Student identifies a problem/solution related to a task or goal (Ku & Ho, 2010).	
Low (EL)	Identifies a problem without any indication of trying to solve the problem (Ku & Ho, 2010). Comments identifying a solution but not the problem it helped solve. Acknowledgement of difference between students work and solution key by referencing to specifics of problem.
Medium (EM)	Identifies a solution(action) that was taken
High (EH)	Identifies a problem and a solution, and how the solution changed their thinking or something they can now do because they found a solution (Ku & Ho, 2010)
Very High (EVH)	Provides an assessment of the action(s) taken or describes obstacles overcome (Ertmer & Newby,1996)
Monitoring (M): Student's comments relate to task comprehension as a form of self-reflection (not influenced by outside factors). Response indicates an understanding/lack of understandingor known/unknown information (Ku & Ho, 2010); related primarily to course content.	
Low (ML)	Indicates an awareness of level of understanding, with no reference to a general topic or learning objective
Medium (MM)	Describes evidence or experience or things tried with topic or learning objective
High (MH)	Indicates an awareness of level of understanding with reference to specifics on theproficiency list for a learning objective
Very High (MVH)	Describes evidence or experience with reference to specifics (e.g., details concerning a learning objective)
Planning (P): Student comments on preparation for one's continued/improved learning or future task execution; related to course content learning or learning strategy (Ku & Ho, 2010)	
Low (PL)	Indicates an awareness of the need for planning (Ku & Ho, 2010)
Medium (PM)	Specifies an action a student plans to take and/or a clear goal (performance) they hope to achieve with indication of evidence of achievement
High (PH)	Specifies an action a student plans to take and/or a clear goal (learning) they hope to achieve with indication of evidence of achievement
Very High (PVH)	Given specific action(s) and clear goal, acknowledges potential obstacles or provides an explanation for choices being made to move forward (Ertmer & Newby, 1996)

1) Linking anchors to reflection

Students' self-evaluation (Error) comments and reflection responses were analyzed to determine whether students referred to the TR 3.3 related LOs, the primary anchor of concern in this study. The process of identifying these LOs within students' self-evaluation and reflection responses involved mapping the terms students used in their comments with proficiency indicators associated with each LO. Based on the presence of a reference to an LOs the response was assigned a 1 (present) or 0 (not present). For example, Table III shows the reference of the LOs addressed by a single student in their self-evaluation (error) comments and reflection response. The students mentioned LOs PS 01.00 and PS 02.02 (technical plotting) as well as FA 02.08, 03.02, and 03.03 (determine the system characteristics curve for a fan used in a grain drying process) in their self-evaluation. The students mentioned only PS 01.00 in their reflection. For the LO self-rating, the student rated their proficiency for each LO using the scale shown in Table I. The text options were converted to a scale of 1 to 5 (Table I).

Based on the information presented in Table III, three categories were created to track the references students made to the LOs in the self-evaluation and reflection. The first category, "Error+Reflection," indicates that students addressed an LO in their self-evaluation (Error) and their reflection, regardless of their self-rating of the LO. The next two categories take into consideration only LOs the students self-rated below 3 (Table I), which indicates a need for improvement with the LO. The second category, "LO<3+Reflection," indicates that a particular LO self-rating was below 3 and that LO was referenced in the reflection but not in the self-evaluation (Error) comments. The third category, "Error+LO<3+Reflection," indicates and that LO was rated below 3 and was referenced in both the self-evaluation (Error) comments and the reflection. Counts of comments in each category were made.

2) Self-Evaluation and Reflection Response

Students' self-evaluation comments and reflection responses for TR 3.3 were qualitatively analyzed in a deductive manner using a revised *a priori* coding scheme based on Ertmer and Newby (1996) and Ku & Ho (2010) with revisions by Stratman and Diefes-Dux (2022) and Singh and Diefes-Dux (2023) (Table IV). During analysis of students' self-evaluations and reflection responses, the texts were coded for the highest level of metacognitive strategy employed by students.

To ensure reliability of the developed coding scheme, two coders, one with experience in coding a dataset collected in the process engineering course and another coder with experience with a dataset collected in a first-year engineering course, coded ten training samples from the first-year engineering course dataset. After coding, both coders compared their coding results and calculated the similarity percentage; that is similarity achieved by coders on identification of dimension and level of metacognitive strategies. During the first round of coding, 60% of similarity rate was achieved. Coders agreed on the metacognitive strategy dimension, but differences emerged on assignment of the levels for a dimension. The difference in coding of levels was due to one coder's limited familiarity with the first-year context. Discussion and clarification on differences resulted in a similarity percentage of 80%.

VI. RESULTS

Results are presented to address each of the research questions separately.

A. Links to LOs

For each LO for TR 3.3, the frequency count of instances for "Error+Reflection," "LO<3+Reflection," and "Error+LO<3+Reflection" are shown in Fig. 2. Each category indicates the links students made between their work on the anchor activities and their reflection for TR 3.3.

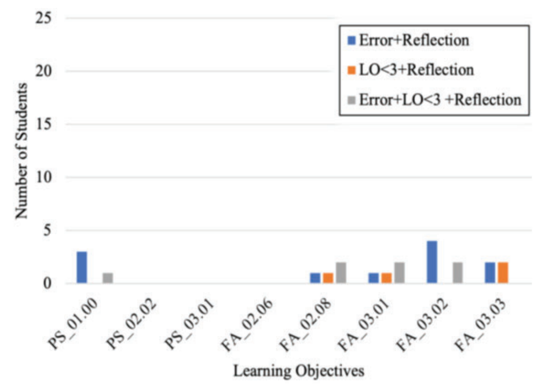

Fig. 2. Number of comments linking anchors and reflection for each TR 3.3 relevant LO.

Overall, only seven of the 25 students that completed the three parts of the assignment linked what they found in the anchor activities to their reflections. Three LOs (PS 02.02, PS 03.01, and FA 02.06) were neither commented on in the self-Among all three categories, the "Error+Reflection" category had the highest frequency counts (PS 01.00 and FA 03.02). This anchor-reflection link means students mentioned the LO in their error comments, rated themselves high (=3 or >3) on the LO, but reflected on the LO in their reflection response.

Few "LO<3+Reflection" and "Error+LO<3+Reflection" category anchor-reflection links were made for the Fan Selection LOs.

B. Metacognitive strategies

To address the second research question, the distribution of metacognitive strategies and highest-level of each metacognitive strategy employed by students in their self-evaluation comments and reflection responses are shown in Fig. 3 and 4.

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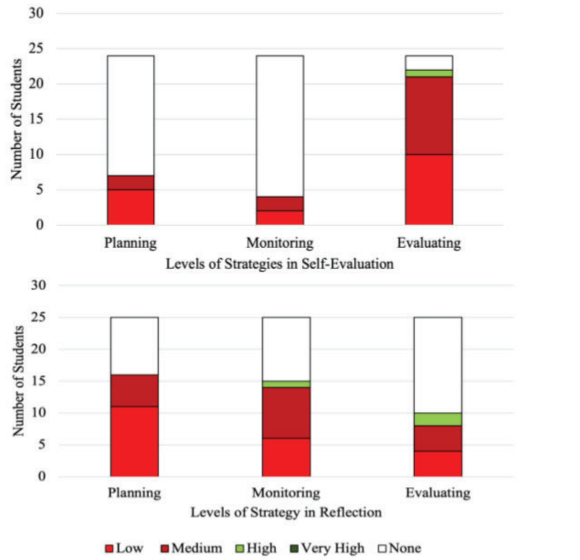

Fig. 3. Highest level of metacognitive strategies in self-evaluations and reflections.

Overall, among all three metacognitive strategies, students predominately used the Evaluating strategy during self-evaluation, whereas they used the Planning and Monitoring strategies during reflection. In addition, Fig. 3 shows the distribution of the levels of the metacognitive strategies employed by students in Self-Evaluation and Reflection.

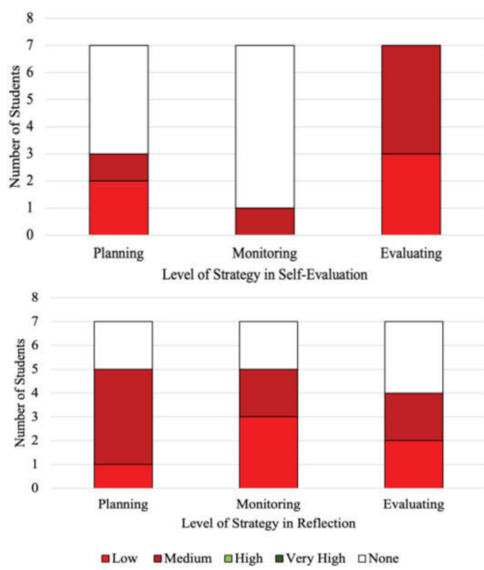

Fig. 4. Highest level of metacognitive strategies used in comments from Error+LO<3+Reflection category (*n*=7).

Overall, student engagement was mainly limited to the Low to Medium levels for all three metacognitive strategies, with one or two students engaging at the High level of the Monitoring and Evaluating strategies.

Fig. 4 shows the level of metacognitive engagement of students who commented on LOs in their self-evaluation, rated their proficiency low on those LOs, and mentioned them in their reflection ("Error+LO<3+Reflection"). While only seven students linked the anchors and reflection, they did not necessarily achieve higher levels for each metacognitive strategy. The one exception is Planning. These students had more medium level comments in their reflections than the class as a whole.

VII. DISCUSSION

With the aim of preparing students to be self–regulated learners, two anchors (i.e., self-evaluation and LO self-rating), were integrated with reflection into an engineering course. The study investigated (1) the extent to which students linked the anchors to their reflection responses and (2) the level of metacognitive strategies used by students during self-evaluation and reflection. Each research question is discussed below.

Regarding the first research question, results showed that only a few students linked both anchors to reflection, which means that these students mentioned the LOs that they needed to improve upon in their error comments while completing the self-evaluation, they then self-rated these LOs low, and finally reflecting on those LOs in their reflection response. The percentage of students with LO self-ratings at 3 or above for the eight LOs ranged from 52% to 96%. One of the reasons for high self-rating ratings of LOs on the scale could be students' low ability to evaluate their skills (Andaya et al., 2017) due to a lack of understanding of the what the skill should entail, which could have resulted in differences in their performance and their perception of those LOs. Also, students might have rated themselves high on the LO self-rating scale because completion of the LO self-rating activity contributed minimally to their course grade. As a result, students may not have thought through the activity and just completed the task. Or students perceived a risk to admitting their low ability with the LOs.

For the second research question, in the self-evaluation activity, one of the reasons for the predominance of Evaluating comments in the self-evaluation could be the nature of the assignment. Students compared their solution to the standard solution key provided by the instructor. However, the prompt provided for self-evaluation activity asked students to comment on things they missed, learned, and needed to work on. The prompt was intended to encourage engagement in the other metacognitive strategies. Perhaps students' lack of engagement in all three metacognitive strategies and their low level of engagement indicates students' lack of understanding of what they should do in response to the given instructions in the assignment. In academic settings, failure to follow instructions can hinder general learning, development of desired proficiency, and indicates low self-regulation ability in students (Dunham et al., 2020). It may not be completely an issue of the

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ability to follow instructions as much as knowing what it means to sufficiently follow the instructions.

In the reflections, students predominantly employed low to medium levels of the Planning and Monitoring strategies rather than the Evaluating strategy. The levels of metacognitive strategies seen here were similar to those observed in the first two units of the course (Singh & Diefes-Dux, 2022, 2023). One of the reasons for the planning and monitoring emphasis in their work could be the first reflection prompt provided to students, which focused on discussing their learning proficiency with the LOs and strategies to improve on those LOs as needed. The prompt does not explicitly hint at a need for further evaluation. The instructor provided a single reflection prompt with the belief that upper-division students would be able to self-prompt themselves into making more meaning of their learning. However, this assumption proved false, as there is little evidence that students engaged in such self-prompting. Hence, this underscores the need for instruction on reflection and detailed feedback to direct students to improve their reflection abilities.

The second reason for the planning and monitoring emphasis could be that students may have felt they had completed their evaluation of their work during self-evaluation task. Students' limited use of the three metacognitive strategies aligns with the findings of Lew and Schmidt (2011) who described self-reflection as a complex process; students are poor at it, and instructors' guidance and supervision are needed to improve students' reflection abilities.

The few students who linked the anchors to their reflection employed low to medium levels of the three metacognitive. Studies have indicated that learners' self-evaluation skills influence their metacognitive engagement (Nisly et al., 2020; Steuber et al., 2017). Therefore, poor self-evaluation skills may be one of the reasons that students use low or medium level metacognitive strategies. To assist students in self-evaluation, external standards (solution key) were provided. However, offering external standards does not ensure that students will be able to think critically (Rawson & Dunlosky, 2007). A lack of critical thinking is demonstrated through low metacognitive engagement wherein students commonly describe what occurred but lacked evidence (Dewey, 1931) and depth of information. That is, students' engagement is limited to mere identification of their problems and not engagement in metacognition. Therefore, there is need to educate engineering students about the purpose of reflection and reflection writing (Csavina et al., 2016) to elevate the level of use of the metacognitive strategies.

The second reason for low metacognitive engagement could be the task value, which influences students' use of metacognitive strategies and the effort they expend on a given task (Buehl & Alexander, 2001). When students perceive a task as high value, they are motivated to use metacognitive skills (Bae & Kwon, 2021). This suggests that students may not have considered the anchor activities to be high-value tasks, highlighting their limited understanding of the importance of anchors in reflection.

Overall, metacognitive skills are difficult to develop over a short time or course (Nisly et al., 2020) but can be taught (Wedelin & Adawi, 2014) over an extended time. To ease the process of developing students' metacognitive strategies in a limited time, instructors can provide multiple opportunities in a course for students' metacognitive engagement and reflection writing (Jaiswal et al., 2021). Furthermore, instructors can improve students' level of use of metacognitive strategies by providing them sample responses for both desired and poor work for all dimensions and levels of metacognitive strategies (Zarestky et al., 2022).

VIII. IMPLICATIONS

This work has implications for both researchers and instructors. For researchers, the revised coding scheme allows for identification of both the metacognitive strategies and their levels of employment by students. Further, the detailed list of LOs provided a means for identifying whether or not students related their self-evaluations and LO self-ratings to their reflections. Without the LOs list, the relationships would have been more difficult to track.

For instructors, based on the lack of students' linking of the anchors to their reflection, instruction is needed at the start of the course that highlights the importance of the anchors and how anchors can be used effectively to improve engagement in reflection. Instructors should also provide reflection prompts for each of the three metacognitive strategies to engage students in all three dimensions of metacognition. Further, to improve students' level of metacognitive engagement, instructors can provide sample responses for each metacognitive dimension and level to highlight the differences among them. Finally, providing detailed feedback on students' reflection response can help students to work on points where their responses are insufficiently deep.

IX. CONCLUSION

This work focused on preparing students enrolled in a junior-level process engineering course as self-regulated learners. Students were provided with anchors with the aim of providing a means to sort out their learning difficulties so they could engage effectively in reflection. It was shown that students' ability to link the anchors to their reflections was limited and students employed the metacognitive strategies at only low to medium levels. Students' metacognitive engagement during self-evaluation and reflection were separately examined. Results showed that students mainly used low to medium levels of Evaluating in the self-evaluating activity, while the use of low to medium level of Planning and Monitoring dominated in their reflections. Overall, students' use of the three metacognitive strategies was at the superficial level.

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