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Pairing Self-Evaluation Activities with Self-Reflection to Engage Students Deeply in Multiple Metacognition Strategies

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Abstract

Self-directed learning requires students engage deeply in all three metacognitive dimensions: Planning, Monitoring, and Evaluating. While instructors may currently integrate different activities in courses that provide the opportunity for students' metacognitive engagement, they might not draw students into thinking deeply. For new engineering educators, it might be challenging to select activities that could provide opportunity for sufficient student engagement in metacognition. The purpose of the study was to investigate pairing self-evaluation and self-reflection activities by classifying students' use of the metacognitive strategies and the highest levels to which students enacted these strategies. Data collection took place in a junior-level process engineering course in Spring 2021 at a large Midwest University. The present work used students' self-evaluations of their computational work and reflections on their learning for four assignments associated with the second unit of the course. A simple text analysis of the self-evaluation and reflection responses revealed that students wrote more text for the self-evaluations than for the reflections. A revised a priori coding scheme was used to code students' self-evaluation comments and reflection responses for the different metacognitive strategies and levels. Results showed that across all four assignments, students were predominantly engaged in the Evaluating strategy during self-evaluation, whereas they predominantly engaged in Planning and Monitoring in the reflection activity. Student engagement was at the low and medium levels of the three metacognitive strategies.

***Keywords**:* junior, reflection, metacognition, qualitative

I. Introduction

Lifelong learning is one of the desired employability skills in today's job market. For instance, consider the technologies with which engineering work. The continuous evolution of technology that results in the replacement of existing devices with new devices poses new challenges and opportunities for engineers [1]. Working with new devices requires new knowledge and skillsets. To keep pace with changing technologies, engineers need to adapt quickly by taking responsibility for their learning and engaging in continuous learning processes to acquire knowledge, skill, and values for their own improvement, i.e., lifelong learning [2]. Through an understanding of the importance of lifelong learning in today's job market requirements, ABET also emphasizes students' acquisition of new knowledge and its application by including the use of learning strategies as one of the student outcomes [3].

Students can develop lifelong learning skills through self-regulated learning (SRL) processes. In higher education, engaging students in SRL activities prepares students for their future work life and assists in the development of traits and skills of lifelong learners [4], [5]. For a student to be a self-regulated learner, they must develop an understanding and awareness of their learning and should be able to use that awareness to control their learning process [6]. Self-regulation in students can be achieved through development of three metacognitive strategies: Planning, Monitoring, and Evaluating [7].

Instructors can use a variety of activities to promote students' metacognitive engagement, such as think-alouds, guided mastery, Socratic questioning, narratives (dialogue and storytelling), concept mapping, and reflective writing. Including activities that provide an opportunity for reflection enhances students' self-regulation abilities [8]. Self-evaluation and reflection are two activities that support students' engagement in their own learning by allowing them to take a step back and consider what and how they learn [9]. Self-evaluation is defined as the activity wherein students critically evaluate their work against a set of reference standards [10], whereas, during reflection, students develop strategies that are required to perform a task effectively [11].

Reflection is often used to engage students metacognitively in engineering courses [12], [13], but the implementation of a combination of different activities, such as self-evaluation with reflection, is limited in engineering. Including only the reflection activity may not provide sufficient opportunity for students to engage in all three dimensions of metacognition: Planning, Monitoring, and Evaluating [14], which limits their preparation as self-regulated learners. Hence, self-evaluation and reflection could be used in combination by instructors in their courses to engage students in all dimensions of metacognition and better support them to be self-regulated learners.

The purpose of this qualitative study was to identify the dimensions and levels of metacognitive strategies used by engineering students during self-evaluation and reflection on weekly assignments in a process engineering course. The study serves a twofold purpose. First, this work highlights a strategy that allows students to engage in all dimensions of metacognition, which could assist them in becoming self-regulated learners. Second, it demonstrates how engineering instructors could use students' self-evaluation and reflection artifacts to identify the types of metacognitive strategies students need to improve upon and to consider additional instruction to better prepare students as self-regulated learners.

II. Theoretical Background

For the development of students' self-regulation skills, it is necessary for instructors to understand the role of students' metacognitive engagement in developing self-regulated learners. Also, instructors must know the importance of student engagement in all three dimensions of metacognition: Planning, Monitoring, and Evaluating.

Metacognition is commonly considered to be "thinking about thinking". The two components of metacognition are knowledge and regulation [15]. The first component, knowledge of cognition, is about knowing one's own cognitive processes and consists of three kinds of knowledge: declarative, procedural, and conditional. In essence, knowledge of cognition is knowing about learning strategies and when and why to use them [16]. The second component, regulation of cognition, refers to controlling one's thinking and learning using three regulatory strategies: Planning, Monitoring, and Evaluating. Along with the important role of metacognition in self-regulation, it is one of the most powerful predictors of students' learning capacity [17].

Self-regulation refers to self-generated thoughts, feelings, and behaviors that are oriented towards attaining goals [18]. In self-regulated learning, students take responsibility for their learning and actively engage themselves in the learning process [18]. Self-regulation is a cyclic process and consists of three phases: Forethought (Planning), Performance (Monitoring), and Self-reflection (Evaluation). The forethought phase includes goal setting and motivational beliefs; the performance phase includes self-observation and control; and the self-reflection phase is self-evaluation of one's performance. Self-reflection then leads to new goal setting. Each phase of the SRL process requires students' awareness of their learning, and a lack of awareness may disrupt the SRL cycle [19]. As a result, the role of metacognition is important in SRL because "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" [20, p. 116].

Self-regulation involves all three dimensions of metacognitive regulation: Planning strategies, Monitoring progress, and Evaluating the usefulness of strategies employed. Hence, integrating activities, such as self-evaluation and reflection, that provide opportunities for students to engage in broader and deeper metacognition, could help develop self-regulated learners.

Background

Studies have been conducted to develop self-regulated learners by engaging them in metacognition through different activities. A few such studies are described below.

Ugulino and Ferreira [21] used self-assessment and feedback strategies to improve the performance of business information technology students and help them to become independent learners. Each week, a list of challenges based on the topic covered in that week's lecture were provided to students for self-assessment of their proficiency with the topics using a rubric with three levels of proficiency (entry, intermediate, and target). Student were asked to submit their completed work using online grading system, which was also accessible to mentors for inline feedback on students work, and to check accuracy of students' self-assessment of the topic. Results of analysis of students' perception of approach of self-assessment of their proficiency with feedback from mentors, and high pass rate of the course showed that low-performance students favored the approach. The overall result showed that providing self-assessment activities with feedback from mentors created awareness for learning in students.

Zarestky et al. [22] designed a qualitative study to uncover students' critical thinking and problem-solving skills from their reflection and survey responses in a graduate-level computing course. Thematic analysis of students' reflection writings indicated that reflection assisted in the development of students' metacognitive awareness, self-regulated learning behavior, and problem-solving and critical thinking skills.

Jaiswal et al. [23] designed a sequential explanatory mixed-method study to investigate students' reflective process in undergraduate engineering courses. Three open-ended reflection prompts, each representing one of the three dimensions of metacognitive strategies (Planning, Monitoring, and Evaluating), were given to students. Results of the cluster analysis on quantified students' performance on reflection assignment revealed two group with similar reflection patterns: Active and Inactive. The qualitative analysis of students' reflection responses compared the characteristics of active and inactive reflectors.

A type of guided reflection called Exam Analysis and Reflection (EAR) was implemented in mechanical, electric, and microelectronic courses [12], [24] to investigate the effectiveness of students' reflections on their performance. Benson and Zhu's [12] work reported uncertainty on the effectiveness of reflection on improving students learning. Similarly, Claussen and

Dave [24] found no statistically significant improvement in students' performances on the final examination who were engaged in the EAR, but they recommended integrating reflection throughout the course to improve the benefits from the reflection activity.

The studies above did not provide explicit information on the dimensions and levels of metacognitive (regulatory) strategies used by students while working on integrated metacognitive activities in their courses. Due to the lack of information on metacognitive strategies used by students, instructors may face difficulties in recognizing areas that need additional support so that students can efficiently engage in metacognition and hence becomes self-regulated learners. Below are a few works that explicitly focus on dimensions and levels of students' metacognitive engagement.

Singh and Diefes-Dux's [14] work explored students' use of metacognitive strategies in their reflection responses. Students' reflection responses were analysed using an *a priori* coding scheme based on Ku and Ho's [25] work with dimensions aligned to the metacognitive strategies. The result of the work showed that students were engaged in low or medium-level Planning and Monitoring and low-level Evaluation.

In another study, Stratman and Diefes-Dux [26] examined the effect of differently worded reflection prompts on the dimensions and level of students' metacognition strategies using an *a priori* coding scheme based on Ku and Ho work [25]. Students used different metacognitive strategies depending on the working of the reflection prompt. Planning, Actions (taken), and Evaluating were used more when the reflection prompt focused on using feedback to evaluate and improve performance, while Monitoring predominated for the reflection prompt focused on using one's proficiency with the learning objectives to reflect on what is going well or what is difficult.

The studies above indicate that metacognitive strategies can be identified in students' reflections and using one metacognitive engagement activity or reflection prompt type is not sufficient to prompt all metacognitive dimensions. As a result, the present work combined self-evaluation and reflection to prompt students to engage in the full set of metacognitive strategies and each at a deep level. The present work aims to identify the metacognitive strategies students used and the levels at which they used these strategies during self-evaluation and reflection activities in a course.

III. Research Questions:

Research questions addressed in this study are:

1. What dimensions and level of metacognitive strategies do students use in their self-evaluation of weekly problem-solving assignments?
2. What dimensions and level of metacognitive strategies do students use while responding to a follow-on reflection prompt?

IV. Methods

Setting and Participants

The study was set in a junior-level introductory process engineering course offered by a department of agricultural and biological engineering in Spring 2021 at the midwestern US research-intensive (R1) university. A total of N=28 students enrolled in the course, with 75% male and 25% female. Both juniors and seniors took the course. The course was required or elective for students depending on their degree program and area of emphasis. In Spring 2021, the course was required for graduation for 50% of the enrolled students. The course met twice each week for 75 minutes per session throughout the semester. Due to the COVID-19 pandemic, the course was delivered in synchronous mode with class time spent in web conferencing. Also, the university reduced the course instruction time from 15 to 14 weeks due to the COVID-19 pandemic. Canvas, the learning management system, was used to communicate with students for assignment submission, reflection submission, self-rating quizzes completion, and to share course material (e.g., syllabus, list of learning objectives, self-evaluation excel template, content videos, readings, solution keys).

The course outcomes emphasized both technical and professional skills development. The four technical content modules in the course were: 1) conservation of mass, 2) fluid flow (pipes, fittings, and pumps for Newtonian and non-Newtonian fluids), 3) fan selection, and 4) thermal preservation while developing. Problem-solving skills development was a cross-cutting outcoming. The course also strongly emphasized students' professional skill development. This emphasis complemented the development of students' process engineering knowledge and skills. In the course, students were assigned the role of associate engineers for a consulting group. The associates were responsible for providing engineering expertise to rural communities to assist in developing local small agricultural and food manufacturing businesses and start-ups. Students were informed and familiarized with the course design, their roles, and activities in the early weeks of the semester. In class, limited time was allotted for lectures on technical content and more on engaging students in workplace-like activities such as discussions, training problems, and projects. Students were expected to complete traditional course lecture material outside of class so that class time could be efficiently utilized to answer questions and engage in training. For professional skills, the focus was on preparing students to be effective team members and reflective practitioners.

There were four graded components in the course: weekly training assignments (Training A and Training B), teamwork assignments, projects (two team projects), and examinations (four individual written exams). Standard-based grading was implemented across all elements of the course. In this grading method, learning objectives were used as the basis for grading and a five-point grading scale, i.e., Proficient (100%), Developing (80%), Emerging (50%), Insufficient Evidence (1%-5%), and No Attempt (0%) was used in the assessment of each learning objective. To support this grading system, a detailed list of learning objectives (LOs) was provided to students. Each training unit consisted of a detailed list of LOs available to students through Canvas. The LOs were divided into different categories: Problem-Solving Methods and Computational tool use (PS), Self-regulation strategies (R), Teamwork (TM), and Technical content (Conservation of Mass, Fluid Flow (FF), Fans (FA), and Thermal Processing (TP)). The present study used students' self-evaluations and reflections on assignments in the course's second unit, i.e., Fluid Flow. Sample LOs for this unit are shown in Table 1.

Table 1. Sample learning objectives with proficiency indicators for fluid flow unit.

Fluid Flow		
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	Discuss the impact of changing system characteristics and fluid properties on the Reynolds number	Discuss the impact of changing: • Pipe diameter • Velocity • Fluid density • Fluid viscosity
Problem Solving		
PS 01.00	**Employ a robust problem-solving process that clearly documents engineering work**	
PS 01.08	Check solutions using one or more quantitative or qualitative methods	• Quantitative checks are completed when possible • Qualitative checks (e.g., relative magnitude of results, units, comparison to other sources, personal experience) are completed when quantitative checks cannot or are not supplied
PS 02.00	**Present results in a form suitable for technical presentation**	
PS 02.03	Format tables for technical presentation	• Title (above the table) must provide sufficient context tounderstand the table • Column or row headings are clear and units are supplied • Contents must have managed significant figures
PS 03.00	**Employ computational tool standards when solving engineering problems**	
PS 03.01	Employ standards for problems solving specific to Excel	• Template for Excel is used • Filename is appropriate • Headers are complete • Sections are used as intended • No knowns or constants are hardcoded in equations
R 01.00	**Employ self-regulation strategies to guide personal learning and professional growth**	
R 01.01	Critically review computational work	• Identify errors • Note needed corrections • Identify opportunities for improvement • Note potential changes
R 01.02	Use learning objectives as basis for self-accessing personal performance and past actions to learn and planning for improved learning	• Make explicit reference to specific learning objectives andproficiency evidence • Make explicit reference to personal performance and pastactions to learn • Make explicit plans to improve learning as needed

Training Modules and Assignments

The four technical content modules of the course were named training modules (TR), and each TR consisted of three to four weekly training assignments (TR.X). Each of the training assignments was divided into two parts: Training A and B. Training B was further divided into two parts, i.e., B.1 and B.2. Each Training A consisted problems in which students practiced applying the technical content concepts they were learning in an authentic agricultural and biological engineering context. Training B followed with an opportunity for self-evaluation of work done on the computational problem (Training B.1) and reflection on learning (Training B.2). Each component of the training is described more fully below.

Practice (Training A): Training A consisted of one or two practice computational problems designed in the consulting group context based on assigned reading material. Before Training A was assigned, relevant reading and video content were provided to students through Canvas. Based on the learning material, students were expected to work on these computational problems. All problems were to be completed in a specified format in Excel. A template with specific sections that followed a standard problem-solving method was provided.

Self-Evaluation (Training B.1): To prepare students for workplace learning, the instructor did not assess students' computational work on Training A for technical detail. Instead, the instructor assessed students' abilities with problem-solving, self-evaluation, and reflection. In Training B.1, the instructor released the solution key for Training A. The solution key was in the required problem-solving format in Excel. Students were asked to self-evaluate and reflect on their learning using the provided solution key. A detailed pdf file was shared with students explaining the problem-solving process and how to annotate one's work. Students were instructed to annotate their work by providing comments in their Excel work file. They were instructed to: 1) identify errors, 2) note needed correction, 3) identify opportunities for improvement, and 4) note potential change. The point of Training B.1 was to provide ideas for the reflection.

Reflection (Training B.2): Part B.2 was conducted as a "Quiz" (of type Graded Survey) via Canvas. Students were asked to complete two activities: (1) self-rate their abilities and (2) respond to three reflection prompts. First, students rated their abilities with each of the week's learning objectives. For each learning objective, five text descriptors were given to students indicating their ability to demonstrate a learning objective *without referring to any resource* to *I am not sure what this means*. (For more detail see [27]). Second, students were made to look back and reflect on (1) their learning and plans to improve, (2) what helped them in the course, and (3) what hindered their learning. The intention of the written reflection was to bring together students' observations of their learning, garnered through the self-evaluation and LO (Learning Objective) self-ratings, and make a plan to overcome identified deficiencies.

For the current work, students' responses to only the first open-ended reflection prompt were analyzed. The exact wording of this prompt was:

> *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 what that skill being useful in your work as an engineer?*

Prior to the first reflection, the instructor informed students about the reflection prompts, and sample responses to these prompts were shared with students to set expectations for student engagement in reflection at a deeper level.

Data Collection

For the present study, students' self-evaluations of their computational work and their responses to the first open-ended reflection prompt were collected from the second training module (i.e., Fluid Flow). This module had four training assignments (TR 2.1- TR 2.4). Training 2.1 and 2.2 each included one authentic problem. Training 2.3 and 2.4 each included two authentic problems.

Students' self-evaluations of their computational work explaining what they learned, what they missed, and what they need to work on were extracted from students' submitted training Excel assignment files and compiled in a single Excel data file for coding. Students' reflection responses were downloaded from Canvas "Quiz" assignments and compiled in Excel.

Data Analysis

First, an overview of the students' responses was garnered. Descriptive statistics (mean, standard deviation, and interquartile range) of the total word count in students' self-evaluations and reflections were computed for each training.

Second, a revised *a priori* coding scheme [25] was used to qualitatively analyze students' self-evaluation comments and their responses to the first reflection prompt. The original coding scheme [25] was developed to code students' thinking comments during a think-aloud activity. The coding scheme consisted of three dimensions that map to the three metacognitive regulation strategies (Planning, Monitoring, and Evaluation), each with two levels (low and high). This coding scheme was used for reflection-in-action (during a task, e.g., think-aloud activity). This coding scheme was modified by clarifying the dimensions, introducing a third level (medium), and clarifying the levels to make it useful for reflection-on-action (after completion of the task and preparation for future tasks). The modified coding scheme was used to identify students' metacognitive strategies from their reflection responses [14], [26]. To capture a greater depth of reflection, a few adjustments were made in the coding scheme by further clarifying the dimensions, adding a fourth level (very high), and clarifying all levels. The current coding scheme, shown in Table 2, used in this study consisted of three dimensions: Planning, Monitoring, and Evaluating. Each of the three dimensions of the coding scheme were broken into four levels: Low, Medium, High, and Very High. The order of the dimensions presented in the coding scheme has been adjusted to Evaluating, Monitoring, and Planning to better indicate the reflective process instigated by the reflection-on-action activities that were implemented in this study.

When using the current modified coding scheme to code students' reflective comments, the Evaluating dimension was applied to students' comments indicating the analysis of thoughts, learning of content, and differences between the standard problem solution and their own work. The Monitoring dimension was applied to comments showing students' perceptions of their knowledge, skills, or abilities with regard to the learning objectives or topics and their experience with the topic. The Planning dimension was applied to comments that indicated goal setting, actions planned to improve on their learning, and rationales for the selection of action(s) to achieve the goal. Within a dimension, levels were applied to indicated students' engagement in thinking, from a surface level (e.g., awareness) to a deep level (e.g., sense-making).

Table 2. Metacognitive regulation dimension coding scheme [25], [28]

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 [25].	
Low (EL)	Identifies a problem without any indication of trying to solve the problem [25]. 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 [25].
Very High (EVH)	Provides an assessment of the action(s) taken or describes obstacles overcome [28]
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 [25]; 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 [25]	
Low (PL)	Indicates an awareness of the need for planning [25]
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 [28]

To ensure the trustworthiness and generalizability of the developed coding scheme, the new coding scheme was used to code multiple reflection responses. Two coders, one with coding experience on a dataset collected in the Process Engineering course and the other coder working on a dataset collected from a first-year engineering course, coded ten reflection responses from the first-year engineering course. The similarity percentage was calculated based on the similarity of dimensions and level of metacognitive strategies identified by coders. In the first round of coding, 60% similarity was obtained. In the first round, both coders agreed on the same dimension for students' comments, but differences existed in the coding of the level of dimensions. This difference in coding of levels of dimensions was due to a lack of content knowledge of first-year engineering course on the part of one coder. Later with discussion, the difference was resolved, and the similarity percentage for the second coding round improved to 80%.

Students' comments were qualitatively analyzed using a color-coding scheme. A specific color was assigned for each metacognitive strategy: for Planning comments, it was gold, Monitoring was in red, and Evaluating was in purple. After color coding of comments, the level was decided for the dimension. Levels for each dimension were marked in numbers from 0 to 4, where 0 was for the Low level and 4 for the Very High level. Students' reflection text was parsed based on the learning issues addressed by the student. For example, if a student mentioned two different topics in their response, the text for these two issues was separated and coded separately. If a student's comments on a single issue included multiple codable phrases associated with a dimension, but these phrases were at different levels, only the highest level for the dimension was recorded.

Below are the examples from a student's self-evaluation and reflection response to demonstrate the coding process of all four assignments of training set 2. Just a few of the 15 self-evaluation comments of a student from TR 2.3 are shown.

> *"Friction factors clearly marked on moody diagram page"*
> *"Title with clearly displayed results and an explanation about what is changing"*
> *"Should've indicated non-Newtonian"*
> *"In solution there is a very long length that I have no idea where it came from"*
> *"All conversions and primary steps are on the top row, what we're looking for is in the bottom row"*
> *"Clearly labelled what calculations are used for which fluid"*

In the above comments (purple), the student only mentioned problems and acknowledged differences between their work and the standard solution key. This surface-level reflection was coded as Evaluating Low (EL).

In the example below, the same student's reflection response from TR 2.3 includes Planning and Monitoring metacognitive strategies:

> *"The only thing that I feel that really needs improvement is my calculation organization. I need to organize my work in a more linear fashion that could be easier to interpret and read. I can do this by having each step follow right behind each other or add some arrows."*

In the first comment (red), the student indicated a level of understanding (Monitoring) for a specific topic, but the student did not provide evidence for their feeling that something needed to be improved. This dimension was coded as Monitoring Low (ML). The second sentence (gold) indicates that the student was engaged in the Planning dimension of metacognitive strategies. The student mentioned a vague goal, "easier to interpret and read", and vague action "adding some arrows" in the reflection response. The presence of vague goal and action was coded as Planning low (PL).

Finally, following all coding of the self-evaluations and reflections, visualizations of the results were created. Stacked-bar charts were constructed to show (1) the distribution of the three metacognitive strategies appearing in students' comments and (2) the distribution of the highest level to which students reflected for each of the metacognitive strategies.

V. Results

Three types of results are presented here. First, an overview of the word counts in students' self-evaluations and reflections are provided. Next, the distribution of the metacognitive strategies (Planning, Monitoring and Evaluation) ascribed to comments appearing the self-evaluations and reflections are summarized. Finally, the levels of each metacognitive strategy appearing in the self-evaluations and reflections are shown.

To get a sense of the length of students' self-evaluations and reflections, the mean, standard deviation, and interquartile range of the word counts for students' total comments were determined (Table 3). The results reveal that students wrote more during the self-evaluation process than in the reflection. The standard deviation and interquartile range indicate wide variation in the word counts for both the self-evaluation and reflection.

Table 3**.** Descriptive statistics of word counts for students' self-evaluations and reflections

Training	**Self-Evaluation**			**Reflection**		
	M	***SD***	**IQR**	***M***	***SD***	**IQR**
2.1	217	165	207	74	64	55
2.2	254	209	272	86	87	84
2.3	314	207	286	92	71	89
2.4	251	180	251	76	58	65

Students' responses to the self-evaluation and reflection activities were broken into distinct topics and coded for the highest level of each metacognitive strategy used by students. Figure 1 shows the percentage of comments coded as Planning, Monitoring, or Evaluating in students' self-evaluations and reflections for each of the four assignments associated with the fluid flow unit.

Overall, the Evaluating strategy dominated students' self-evaluation comments, while Planning and Monitoring were more prevalent in the students' reflections.

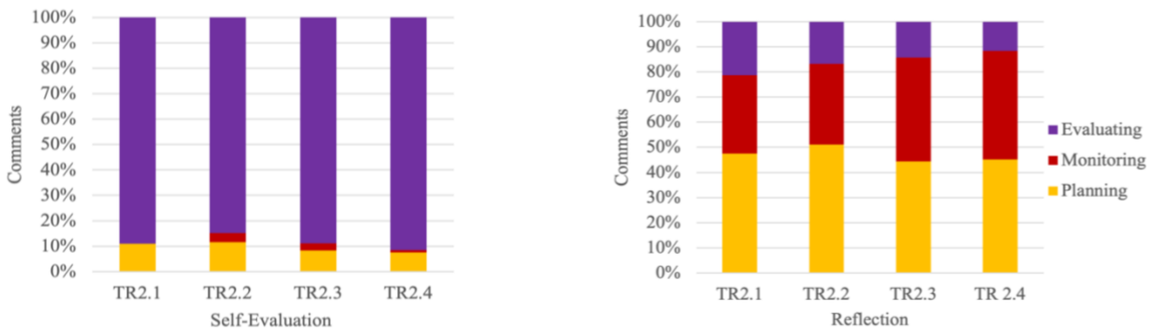

Figure 1. Metacognitive strategies used in self-evaluation and reflection

Figures 2 to 4 show the distribution of metacognitive levels expressed for each metacognitive strategy (Planning, Monitoring, and Evaluating) for the students. What is displayed indicates the highest level students demonstrated in their self-evaluations and reflections for the three strategies: "None" captures the number of students who submitted a self-evaluation or a reflection but did not demonstrate a given metacognitive strategy.

The highest level of Evaluating that appeared in students' self-evaluations and reflections is shown in Figure 2. Again, Evaluating comments appeared more frequently in the self-evaluations than the reflections. During the TR 2.1 self-evaluation, all students provided at least one comment coded as Evaluating. Except for the TR 2.2 self-evaluation, students' highest level Evaluation was predominately at the Medium level. For the reflection, the number of students that engaged in Evaluating was highest in TR 2.1. Low level comments were common. Across both assignments, there was a decrease in the number of students engaging in the Evaluating.

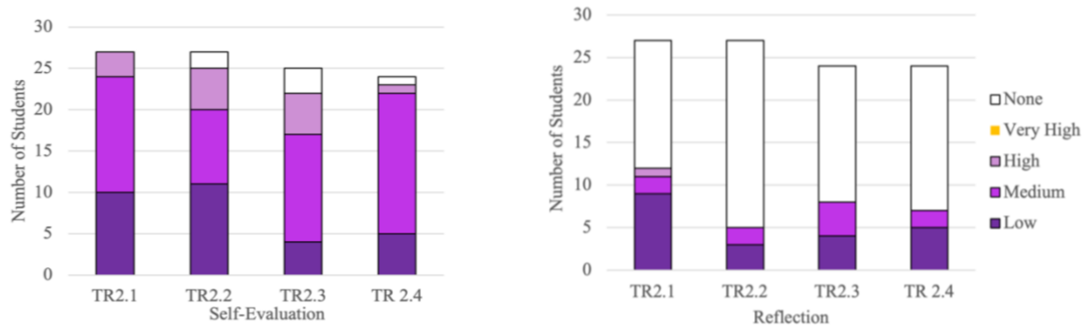

Figure 2. Highest level of Evaluation in students' self-evaluations and reflections

Figure 3 shows the highest level of Monitoring coded in students' self-evaluations and reflections. Students very rarely engaged in Monitoring in the self-evaluations. Responses in reflections showed more Monitoring, though monitoring comments were consistently at the Low and Medium levels. The number of students that engage in Monitoring increased from TR2.1 to TR 2.4. For TR 2.4, the number of Low level responses dropped, and Medium level responses increased.

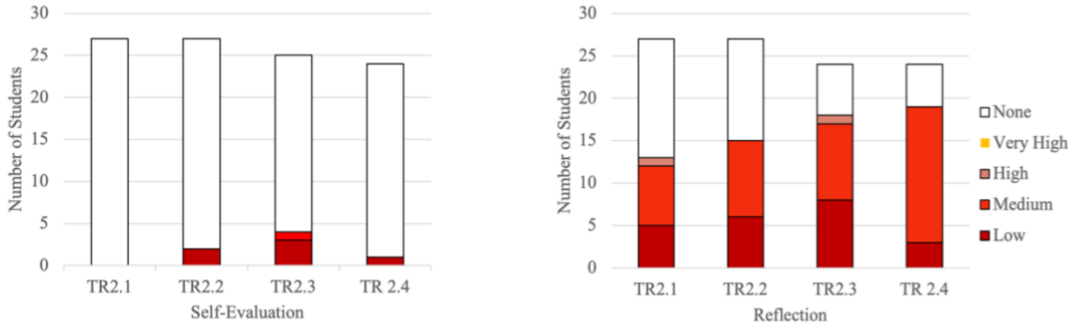

Figure 3. Highest level of Monitoring in students' self-evaluations and reflections

Figure 4 indicates the highest level of Planning demonstrated by students. Planning was employed less in the self-evaluations than in the reflections. Across the self-evaluation and reflection responses, the students provided Low and Medium levels of Planning. For the TR 2.2 reflection, one student employed a Very High level of Planning. This was the only Very High level demonstration of a metacognitive strategy.

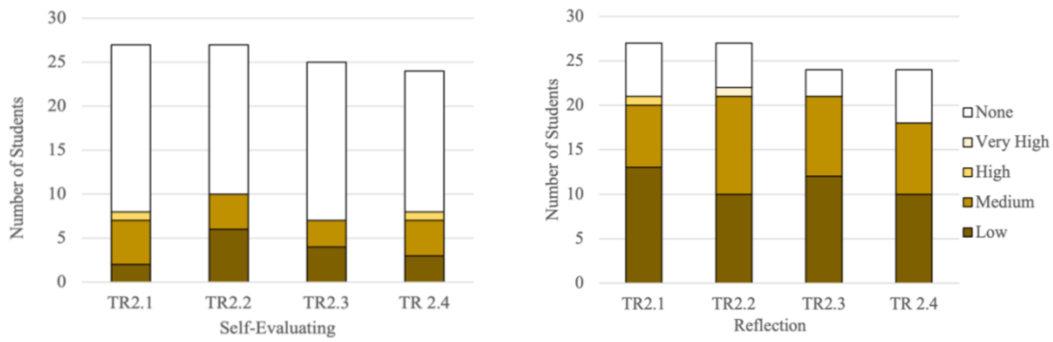

Figure 4. Highest level of Planning in students' self-evaluations and reflections

VI. Discussion

The metacognitive activities of self-evaluation and reflection were designed to provide an opportunity for students to engage in a broader and deeper level of metacognition to prepare them as self-regulated learners. The study investigated the metacognitive strategies used by students and the levels at which they were employed during self-evaluation and follow-up reflection activities in the second module of the course. Overall, students' use of metacognitive strategies was different for the self-evaluation and reflection activities. This difference highlights the need for pairing these reflective activities.

Regarding the first research question, analysis of students' self-evaluation comments revealed that students were predominantly engaged in Low to Medium levels of Evaluating. Only a limited number of students engaged in Low to Medium Monitoring. This balance of metacognitive strategy employment during self-evaluations may be expected due to the nature of the assignment. Finding errors and needs for improvement is an evaluative task.

Students' engagement in Low Evaluating showed a lack of reasoning in their comments, indicating superficial engagement in this strategy. The lack of reasoning or meaning-making may be attributed to the assignment itself. Within Excel, students tagged their comments to locations in their spreadsheets with identified errors or needs for improvement. Students may have viewed the location of the tags as providing their reasoning. The assignment prompts themselves did not indicate that students should make meaning of their actions around the identified errors or needs for improvement. That said, in a study of students' self-evaluations, Yerushalmi et al. [29] reported that for a given problem, most students were able to correct their mistakes, but only a few students were able to describe the reason for their mistake. So, it is possible, that in the present study, students were also unable to articulate reasons for their errors or needs for improvement. Combining this past finding with the present study results provides strong support for including instruction on metacognitive strategies early in the semester that could assist students in making greater meaning of their actions so as to engage in higher levels of Evaluating. A few such instructional strategies could be providing detailed feedback or making students aware of self-prompting questions that could help them engage in higher levels of metacognition.

For the second research question, students' reflection responses showed their predominant engagement was at the low to medium levels of Planning and Monitoring, with a few students engaging in low to medium Evaluating. Students may have done little or no Evaluating because so much was done in the self-evaluation. The students' Monitoring and Planning comments generally lacked detail in terms of their learning / problem-solving experiences (Monitoring) or goals and actions (Planning). A similar lack of detail in students' reflections has been noted in other studies [e.g., 23]. The relatively low levels and lack of Planning and Monitoring again highlight again a great need for instruction and feedback on students' metacognitive skills.

Ku and Ho [25] associated high-level Planning and Evaluating with skilled thinking, whereas low-level engagement represents unskilled thinking. Overall, the combined analyses of students' comments in the self-evaluations and reflections showed that students' Planning and Evaluating levels were a bit above unskilled thinking. Across both activities, students' engagement in Monitoring is comparatively low. In self-evaluation, students' engagement in Monitoring was nearly non-existent, whereas, in the reflection activity, it was lower than for Planning but more than for Evaluating. Studies show that accurate metacognitive monitoring is essential for students' academic achievement and self-regulation [30], [31]. Instructors could use a strategy training approach to improve students' monitoring [32].

VII. Limitations

The generalizability of the study results is limited in two ways: First, the sample size is small and focused on junior and senior engineering students in a particular engineering course. Second, the data was collected during COVID-19 when student engagement in coursework was potentially different than in a non-COVID-19 impacted semester. Similar results might not be found in a different engineering education setting or at a different time.

VIII. Implications for Practice

To prepare students to be self-regulated learners, sufficient opportunities should be provided to engage them in each of the metacognition strategies and at deep levels. Instruction is needed early in the semester to give students insights into the importance of metacognitive engagement in students' learning process and its role in developing them as self-regulated learners. To elevate the level of students' metacognitive engagement in a course, instructors can include sample responses to self-evaluation and reflection activities for all levels and dimensions of metacognitive strategies [33]. Making students aware of metacognition might not be sufficient, but detailed personalized feedback on each student's responses might help improve their metacognitive strategies.

IX. Conclusion

The importance of the work is grounded in the need to develop self-regulated learners by providing opportunities for students to engage in a broader and deeper levels of metacognition by integrating more than one activity in a course. In a junior-level process engineering course, students' responses to self-evaluation and follow-up reflection prompts were analysed for the metacognitive strategies students employed and the levels to which they did so in four assignments of the second unit of the course. Results showed that most students used low-Evaluating dimensions during the self-evaluation activity, and the use of Planning and Monitoring was limited. Students' responses to the follow-up reflection prompt showed a low to medium engagement in Planning and Monitoring. Only a few students engaged in the low-level Evaluating. Overall, including self-evaluation and follow-up reflection activities in the course allows students to engage in multiple metacognitive strategies. However, their engagement level could not be classified as deep. Instructional strategies need to be devised to better assist students in becoming self-regulated learners.

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