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Students' Metacognitive Strategies Revealed Through Reflections on Their Learning of Process Engineering Concepts and Skills

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Abstract

Workplace learning requires one to be a self-directed learner. Self-reflection provides one with opportunities to assess their own learning processes. If engineering students were to develop self-reflection skills in parallel with their domain knowledge and skills acquisition, the transition from highly structured, instructor-led learning to more self-directed learning might be eased. However, there is little integration of reflection in engineering coursework though a few studies have emerged in recent years. The purpose of this work was to classify the different metacognitive strategies students employed in their reflections so that an assessment for the need for formal instruction on reflection could be made. This work was also intended as a starting point for helping instructors understand the quality of student reflections. Students in a junior-level introduction to process engineering course with little to no prior reflection experience responded to reflection prompts anchored in their weekly assignments and the course learning objectives. Reflections associated with the initial three assignments of the semester were coded for dimension and level of metacognitive strategies employed. Visual representations of the frequency of each code across the assignments showed that students predominately used low and medium levels of planning and monitoring. Few reflective comments were coded as actions, transfer, or evaluating.

I. Introduction

In this era of fast changing technologies and interdisciplinary work culture, engineers need to be well equipped with a wide variety of skills that will enable them to be creative, effective communicators, proficient at performing analytical tasks, and lifelong learners. Along these lines, ABET defined student outcome 7 as "an ability to acquire and apply new knowledge as needed, using appropriate learning strategies" [1]. Self-reflection is one such appropriate learning strategy wherein individuals assess their own knowledge, skills, and learning processes. Self-reflection provides opportunities to recognize areas for improvement in one's own learning, to consider ways to pursue improvement, and to monitor one's progress in the attainment of learning goals. An ability to self-reflect undergirds one's ability to be a self-directed learner.

Kember et al. [2] emphasized the importance of reflective practices in a professional degree by stating that the use of reflective practices while dealing with complex problems differentiates "experts" in the profession from "novices." According to Siewiorek et al. [3], undergraduate engineers learn to work on their problem-solving skills in preparation to work effectively on real-world problems, and in this process, reflection is extremely important for novices as reflection causes a shift in the individual thinking from self-centeredness to self-awareness. Having enhanced self-awareness takes students a step closer to being self-directed learners.

While the benefits of reflection for students' development of lifelong learning skills are well recognized, reflection is rarely included in engineering curricula [4]. One reason is instructors' perceptions of limited course time for such activity [4]. Yet, the integration of reflective exercises in students' engineering curricula could not only strengthen their ability to reflect and other lifelong learning skills but could also ease students' transition from highly structured school instruction to more self-directed workplace-like learning.

In our work, we aim to develop students' reflection abilities in agricultural and biological engineering students so that they begin to make the shift towards more self-directed learning. Our contention is that a junior level course should promote the transition of students from instructor-led learning to self-directed learning and a first step in this direction could be achieved through the habitual use of self-reflection. The question is, to what extent do students at this academic level engage in deep reflection on their learning? The purpose of this study was to determine the metacognitive strategies student in a junior level introduction to process engineering course employ when they have had little to no prior formal experience with reflection on their learning in their engineering coursework. Knowledge of students' metacognitive strategies could help instructors identify the need for formal instruction on reflection.

II. Background

A. Theoretical Framework

Self-directed learning (SDL) is defined as "a process in which individuals take the initiative, with or without the help of others, in diagnosing their learning needs, formulating learning goals, identifying human and material resources for learning, choosing and implementing appropriate learning strategies, and evaluating learning outcomes" [5, p. 18]. Self-regulated learning (SRL) is a process in which one can directs their own learning processes, and self-regulated learners are those "who are metacognitively, motivationally and behaviourally active participants in their own learning process" [6 p. 329]. "SDL is an umbrella term that covers aspects like interest in learning, formulation of long-term objectives, identifying resources/requirements and decision for independent learning, whereas SRL is related to cognitive, metacognitive, and motivational aspects that occur before, during and after accomplishment of task" [7, p. 36]. Self-regulation is necessary to motivate improvement [8], making self-regulation a necessary skill for success in one's academic and professional life.

Metacognition is commonly referred to as "thinking about thinking." Flavell [9] described two components of metacognition: knowledge and regulation. The knowledge component is about both knowing one's cognitive processes and having knowledge of strategies which are required to effectively perform tasks. The regulation component is concerned with the actual strategies (planning, monitoring, evaluating) implemented to control cognitive processes. These regulation strategies can be achieved through reflection.

Reflection is a technique that contributes to students' skills with higher-order thinking and deep-learning by allowing them to learn from their experience through their use of their cognitive (reasoning and knowledge) and metacognitive (intuition and self-awareness) skills [10]. This development of high order thinking skills will then contribute to students' preparation for and success in the workplace where one needs to be a reflective practitioner, one who manages their own learning based on task needs [11]. While reflection as "a way of thinking […] is complex, rigorous, intellectual, emotional and time consuming" [12, p. 844], metacognitive skills can be taught by providing suitable opportunities for development across the curriculum. Such skill development that could help students move beyond the novice level in their profession [13].

B. Reflection Practices in STEM Courses

Wegner et.al [10] described reflection as a new and unfamiliar practice for most engineering students because the heavy workload of engineering curricula does not leave space to develop reflective practices. That said, reflection is beginning to formally appear in STEM coursework. Of particular interest to the current study are studies in which student reflection was anchored in their coursework. A few such studies are described below.

Benson and Zhu [14] used a guided reflection exercise called Exam Analysis and Reflection (EAR) in two mechanical engineering courses, Introduction to Engineering and Solids Mechanics. In both courses, students were asked to review their exam answers and compare their solutions to the sample solutions. Students were then asked to respond to three guided reflection prompts: "How is my solution different from the solution provided? What went wrong with my solution? How can I use this information (i.e., what strategy can I use) to improve my performance on a similar problem in the future?" [14, p. 5]. They analyzed students' responses for the types of math, problem solving, and engineering errors the students detected in their work. While the authors detected greater elaboration on the part of more advanced students, they were unsure of the effectiveness of these reflections in improving students' learning.

Claussen & Dave [15] used EAR (by [14]) in an introductory electrical circuits course for non-majors to study the impact of including an incentivized post midterm-exam reflection on student's final exam performance. Study students were divided into control and intervention (EAR) groups; extra credit was provided on two mid-terms for working extra problems (control) or completing reflections (EAR group). The authors found no statistically significant improvement in performance on the final exam for either group or difference between groups.

Clark and Dickerson [16] studied the impact of using an adapted EAR exercise that incorporated SPICE (Simulation Program with Integrated Circuit Emphasis) simulation tools in a microelectronic course. Students compared their exam answers to the SPICE simulation results to identify their mistakes. Students' reflections were assessed based on depth (1: non reflection to 4: critical reflection) and content (actions - iteration, asking others, reviewing, assuming; assessing magnitude of differences; realization of differences between hand-calculations and simulations). Results showed evidence that exam problem type generated differences in reflection depth and content.

In a similar fashion, Andaya et al. [17] used a post-exam review activity (reflection) in a lower-division biology course. In part one of the activity, students corrected their mistakes and identified reasons for their mistakes. In part two, they reported their exam study strategies by selecting actions from a list. In part three, the students were asked to explain whether their grade was a reflection of their knowledge and time spent studying and what they and the instructor could do to improve the learning experience. The authors differentiated high and low quality reflection on errors, where quality was assessed based on scientific-accuracy and relevancy as well as appropriate reasoning. They found that the quality of reflections correlated with the original scores but did not correlate with improvement in exam performance from one exam to the next.

Across the studies described above, the researchers all came to a similar conclusion – their reflection interventions were limited in scope. They often recommended more reflective practice and formal instruction on reflection. A notable example of reflection integration across a course was Burden and Steghöfer's [18] effort to link reflection across a software engineering project course. Reflection-in-action (during an activity) and reflection-on-activity (after the activity) were paired with both learning activities and assessments on a weekly basis and included instruction on reflection. The aim of these researchers was not focused on the students' reflections themselves but on the demonstration of a model of reflective practice that others might use.

Diefes-Dux and colleagues [19] integrated weekly structured reflection in a first-year engineering course. The driver for using reflection was to improve students' interactions with the learning-objective based grading system that was intended to provide rich feedback. The structured reflection prompts intentionally guided students through cycles of Zimmerman's [6] self-regulated learning phases of planning, monitoring, and evaluating by having students attend to their thinking about their abilities with the course learning objectives and their feedback. The researchers found that reflections' that directed students' attention to their feedback, as opposed to a wider selection of learning strategies, led students to view their feedback more often [19]. They also considered the actions students discussed taking based on their feedback [20] and found that students most often cited reviewing course materials and checking their work or better managing their study habits.

In the current study, weekly reflection was implemented in an upper-division agricultural and biological engineering course. The reflections were anchored in students' evaluation of their weekly assignments as compared to a sample solution, in much the same way EAR focused on exam errors. That evaluation was also linked to students' perceptions of their abilities with the course learning objectives, similar to [19].

III. Research Questions

This study addressed two research questions:

1. What dimension and level of metacognitive strategies do students employ in their responses to reflection prompts anchored in weekly assignments?
2. What is the nature of students' responses for each metacognitive strategy dimension and level?

IV. Methods

A. Setting and Participants

This study was set in the introductory process engineering course offered in Spring 2021 by a department of agricultural and biologicalengineering at a midwestern research intensive (R1) university in the United States. The course enrollment (N=28) was 75% male and 25% female. This course was required or elective depending on which program students were enrolled in and was typically taken by juniors and seniors. In Spring 2021, for 50% of the students, the course was required for graduation. The course met twice a week for 75 minutes per session throughout the semester. Due to the COVID-19 pandemic, the university had reduced the course instruction time from 15 to 14 weeks and the course delivery mode was synchronous remote with class time spent web-conferencing. Canvas, the learning management system, was used to share the syllabus and all course materials (e.g., videos, class slides, readings, solution keys) and manage all assignments.

The design of this course incorporated some elements of practice-based education [21] or cognitive-apprenticeship (e.g., [22]) with the aim of immersing agricultural and biological engineering students in workplace-like activity within the bounds of classroom-based instruction [23]. The elements included authentic tasks, learning driven by tasks, teamwork, and reflection. The students were put in the role of associates in a consulting group whose mission was to *provide robust conceptual and practical engineering support for small businesses and start-ups in rural communities*. All assigned problems linked to varying degree to this mission. In keeping with the course design, class time was mostly devoid of lecture on technical content. Instead, class time was spent on professional skills development and problem-solving in teams.

The technical learning outcomes for the course were aimed at developing students' abilities to: (1) use law of conservation of mass to find stream mass flow rate and composition, (2) size and select pumps and fans for food and agriculture applications, and (3) use of thermal processing for improving food safety. Professional learning outcomes focused on building students' abilities to document their work, consider the ethical implications of their work, be reflective practitioners, and enact effective team behaviors. A complete set of learning objectives was provided to students to use as a reference to guide their learning and reflection. Examples of learning objectives relevant to this study are shown in Table 2. For each learning objective, a description of proficiency was provided.

Standards-based grading was employed across all elements of the course, meaning student performance on assignments was assessed using the learning objectives as items in criterion-referenced rubrics [24]. A five-point scale (i.e., Proficient (100%), Developing (80%), Emerging (50%), Insufficient Evidence (1%-5%) and No Attempt (0%)) was used to assess each learning objective. There were four graded components: training, teamwork assignments, a project with multiple milestones, and four written exams.

B. Training and Reflections

Training (TR). The course included weekly training (TR) assignments and each training module consisted of the following elements:

- Well defined learning objectives (examples in Table 2)
- Learning materials in the form of video content and readings
- An opportunity to learn and practice applying relevant engineering science concepts in authentic agricultural and biological engineering contexts (TR Part A)
- An opportunity to individually reflect on learning (TR Parts B.1 and B.2)

Prior to each TR Part A, students were provided with video content covering the engineering science concepts. The video content was occasionally supplemented with reading material. TR Part A consisted of one or two computational practice problems set in the consulting group context. In TR Part B.1, students were asked to evaluate their computational work using a solution key. In this self-evaluation process students were asked to annotate their work with comments on things they learned, missed, or need to work on. Once they submitted their commented work, TR Part B.2 became available for students to reflect on their abilities with relevant learning objectives (e.g., FF 02.00 items in Table 2).

Table 1. Sample learning objectives with proficiency indicators for conservation of mass unit.

Conservation of Mass		
FF 02.00	**Use the law of conservation of mass to find stream mass flow rates and compositions**	
FF 02.01	Given a process description, draw and fully label a flow diagram	• Units are shown with boxes and labels • Arrows are used to represent streams and direction of flow • Streams are given symbolic labels for mass flowrates using the $\dot{m}_i$ format • Streams are given symbolic labels for compositions using the $x_{i,L}$ format • Values are noted for all knowns associates with mass flowrates and compositions • System(s) are identified with boxes with dashed lines
FF 02.04	Perform material balances on a multi-unit process **<u>without</u>** recycle and bypass streams	• Write the overall mass balance for the entire system • Write a full set of component mass balances for the entire system • Write the overall mass balance for each unit in the system • Write a full set of component mass balances for each unit in the system • Identify whether the problem is solvable (degree-of-freedom analysis) • Select, with rationale, the independent equations needed to solve the problem • Complete the problem using standard problem solving method (PS 01.06-01.08)
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 to understand 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 and proficiency evidence • Make explicit reference to personal performance and past actions to learn • Make explicit plans to improve learning as needed

In keeping with the workplace-like learning philosophy of the course, students' TR Part A computational work was not graded in detail by instructor, rather the instructor focused on students' abilities to apply a robust problem-solving process (PS 01.00 series), communicate results (PS 02.00 series), and use the computational tool (PS 03.01). Students' work on TR Part B was assessed for employment of self-regulation strategies (R 01.00 series). There were 12 TR assignments across the semester. TRs accounted for 15% of the course grade.

Reflections. TR Part B.2 consisted of two parts. In the first part, students rated their abilities with each relevant learning objective given a list of five text descriptors that ranged from *I can do this on my own without referring to resources* to *I am not sure what this means (I am very lost)* (these are described in detail in [19]). In the second part, students were asked to respond to three reflection prompts. The first prompt asked:

> *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?*

The two remaining prompts asked what was helping and what was hindering their learning.

In the first class of the semester, the instructor explained the importance of writing reflections to students' development as reflective practitioners. In the second class, the instructor described the reflective process used in the course including the review of the sample solution and their thinking about their abilities with the learning objectives as anchors for reflection. A few shallow reflection comments were discussed to set expectations for deeper reflection.

C. Data Collection & Analysis

Data Collection. Students' reflections on the topic first topic of the Spring 2021 semester, conservation of mass, were used as the source of data. Specifically, the data of interest in answering the research questions were drawn from students' open-ended responses to the first reflection prompt for each of the first three trainings (TR 1.1, 1.2 and 1.3).

Analysis. A five-category coding scheme (Table 3) was used to classify the different metacognitive strategies used by students when responding to the reflection prompt (Table 3). This coding scheme was based on work of Ku and Ho [25], which classified three metacognitive strategies: Planning, Monitoring and Evaluating and described Low and High levels associated with each category. While Ku and Ho's work was concerned with reflection-in-action (reflection while in the middle of working on a task), the classifications appeared to have utility for making sense of reflection-on-action (reflection done after a task is complete). This coding scheme was refined in [26] for coding first-year engineering students' responses to similar reflection prompts. The resulting coding scheme used in this study differed from that of [25] in two ways. First, two new dimensions were added: Action and Transfer. Second, a medium level was introduced to the Planning, Monitoring and Evaluating strategies to provide more nuance in the levels.

Table 2. Metacognitive dimensions coding scheme [25], [26].

Dimension	Description
Planning (P)	Student comments on preparation for task execution, identifies procedures and requirements for a task [25]
Low (PL)	Indicates an awareness of the need for planning [25]
Medium (PM)	Specifies an action a student plans to take or a goal they hope to achieve, but not both
High (PH)	Specifies both actions and a goal; how an action will help achieve a goal
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 understanding or known/unknown information [25].
Low (ML)	Indicates an awareness of level of understanding, with no reference to a topic or just a reference to the topic.
Medium (MM)	Indicates an awareness of level of understanding with reference to a specific learning objective in number or text.
High (MH)	Indicates an awareness of level of understanding with reference to specifics on the proficiency list for a learning objective.
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.
Medium (EM)	Identifies a problem and a solution.
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; understanding of why the correct solution is right/their solution was wrong [25].
Action (A)	Student comments on actions they have/have not taken
Transfer (T)	Student comments connect past, concurrent, and future experiences; comments connect knowledge from the current course to knowledge from other courses
Low (TL)	Connects information/concepts learned in different courses
High (TH)	Connections made between concepts learned in other courses and how they apply to this course or helped their understanding of concepts learned in this course, or indicating past experience with a topic
Non-codable	Student comments that do not fit into any of the definitions above, reflection questions that had no answer

The qualitative analysis method for coding students' responses to the reflection prompt was similar to that employed by [27] in that the reflective comments were color-coded. A specific colour was assigned to each metacognitive strategy; Planning statements were marked gold, Monitoring red, Evaluating purple, Action blue, and Transfer green. Once comments were color-coded, the level was determined. Color-coding increased ease in understanding, comparing, and analysing multiple reflection prompts. Two coders reviewed all codes assigned to students' responses. Ultimately, if more than one statement of a given classification was codable, the highest-level metacognitive strategy employed in a given student's reflection was recorded.

The following two examples demonstrate the coding process. The text below is a student's reflection on TR 1.3. Here the student included three metacognitive strategies (i.e., Monitoring, Evaluating and Transfer).

> *"I believe that I really improved on my skills during Training 1.3A. Before this I struggled with setting up mass balances and solving a problem symbolically on my own. Although it is not a LO, I was also told that my assumptions were not clearly applicable to solving problem. I did much better this week at clearly identifying all components of the problem and making sure all of the mass balances matched my process flow diagram. My assumption also were clearly*

used to identify my problem solving process as a real engineer would do. You could clearly see all steps of my process and my technical presentation looked professional. All of these skills can translate to my engineering career in the real world."

In first and third statements of this text (in red), the student described their experience and status with topics associated with problem solving and mass balances, indicating Monitoring. This student also mentioned specific proficiency items from the learning objective list in their musings, leading to a code of Monitoring High (MH). In the second statement (in purple), the student mentioned the feedback they received on their work, which indicates a problem. But the student failed to describe how to the problem was resolved. It was therefore coded Evaluating Low (EL). In the last statement (in green), the student established a connection between their present and future. This statement was coded Transfer High (TH).

In this next example, the student's reflection on TR 1.3 included Planning, Monitoring, and Action metacognitive strategies.

"I have been struggling, but improving, with identifying all knowns and unknowns in the problem. I usually mistakenly define a variable as an incorrect value and then the remainder of my work is wrong because of a wrong assumption I made initially. By studying my mistakes in past training I have vastly improved on this. Instead of not being able to solve the problem, I only mistake one or two values. Continuing this method will help me improve further and eventually be fully proficient at this."

In the first comment (in red), the student expressed a level of understanding (Monitoring) at only the specific topic, leading to an overall code of Monitoring Medium (MM). In second statement (in blue), student mentions a step (Action) taken to make improvements, i.e., reviewing their mistakes on a past training. Finally, in the last statement, the student planned to perform an action "studying mistakes" but failed to indicate a goal for this action. This statement was therefore coded Planning Medium (PM).

V. Results

The results of the study are shown below in Figures 1 to 3, where each figure presents the frequency of the highest level metacognitive strategy employed for Planning, Monitoring, and Evaluating, respectively. These figures show results for the first three assignments (TR1.1, TR1.2 and TR1.3) associated with the topic of conservation of mass. Detailed explanations of these results are provided below.

Planning. Figure 1 indicates the proportion of students who engaged in the Planning dimension at various levels (High, Medium, and Low) and those who did not included a Planning strategy in their reflections. The maximum number of students who included comments on Planning occurred in association with TR1.2, but these reflections also included the greatest percentage of low-level Planning. When coding for Planning, the researchers also noted a difference in the way Planning comments were written. Some expressed more commitment, typically indicated with a strong verb "I will." Uncommitted responses tended to use phrases like "I need to." The use of uncommitted language increased from 13% to 40% to 50% across three assignments.

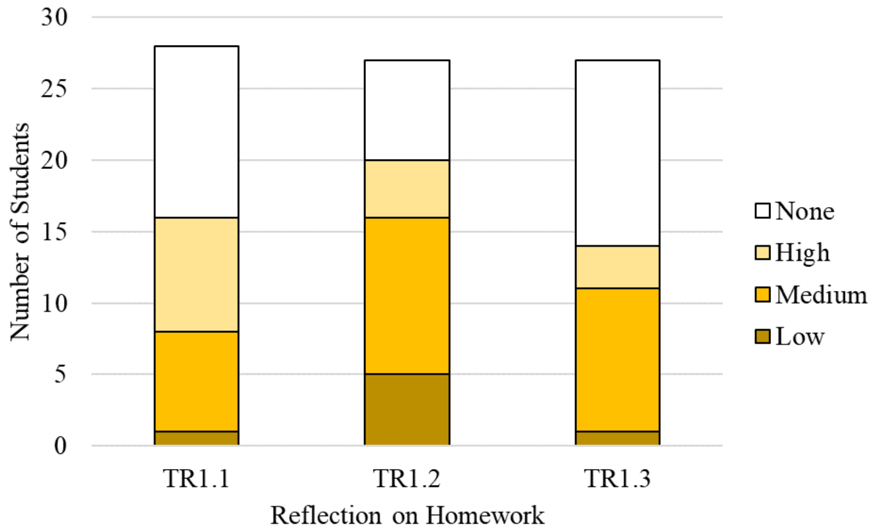

Figure 1: Highest level Planning comments included in reflections

Monitoring. Figure 2 shows the highest level of Monitoring that students included in their reflective writings. Reflections associated withTR1.1 had highest percentage of students engaged in Monitoring but also had the greatest percentage of low-level Monitoring. It is interesting to note that there was a continuous increase in the number of students engaged in medium-level Monitoring and a concomitant decrease in both low and high level Monitoring from TR1.1 to TR1.3.

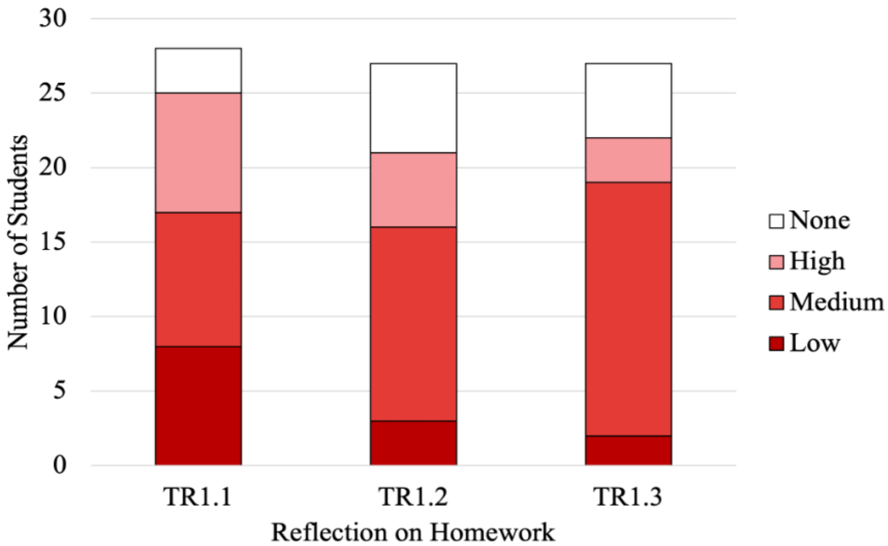

Figure 2: Highest level Monitoring comments included in reflections

Evaluating. The highest level of students' employment of Evaluating is shown in Figure 3. Compared to the other metacognitive strategy dimensions, fewer students included Evaluating in their reflections. Among the three assignments, TR1.1 had the lowest percentage (14%) of students who were engaged in Evaluating, whereas TR1.2 had the highest percentage (37%). Also, there was a continuous increase in the number of students engaged in low level Evaluating (EL) across the assignments.

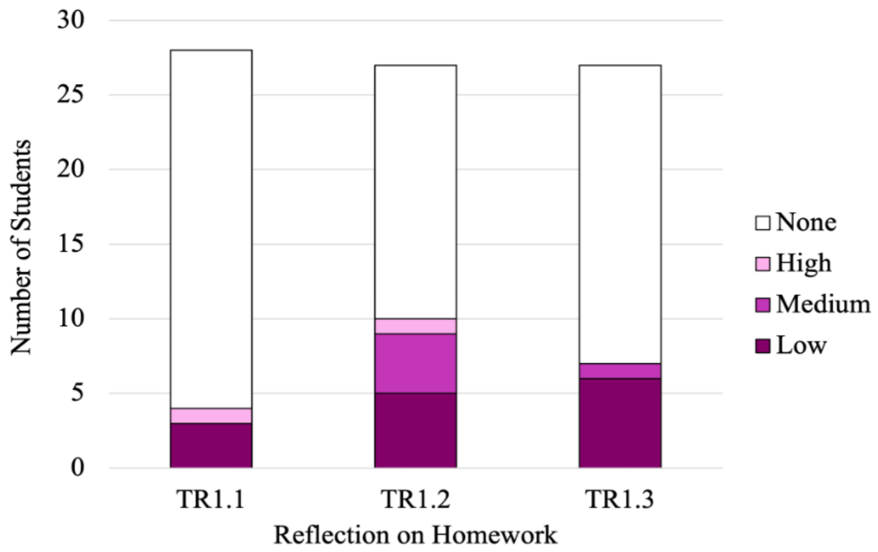

Figure 3: Highest level Evaluating comments included in reflections

Action &Transfer. Only a few students included Action comments in their reflection writings across all assignments (TR1.1, TR1.2 and TR1.3). Similarly for the Transfer dimension, only a few students were engaged in this metacognitive strategy, with a few more engaged in low level transfer (TL) than high level transfer (TH).

VI. Discussion

The purpose of this study was to investigate the metacognitive strategies that students employed while reflecting on their learning in the earliest part of a semester. As the students had no significant formal experience with reflection, the aim was to capture the dimension (i.e., Planning, Monitoring, Evaluating, Action, and Transfer) and level (i.e., High, Medium Low) of the strategies they employed and the nature of their statements to inform future instruction with reflection both in the course and potentially across the curriculum.

With regards to the strategies employed, the students in this study predominantly engaged in Planning and Monitoring. Similar findings were found for first-year engineering students who had no prior reflection experiences [26]. Ku and Ho [25] discussed how skilled thinkers engage in high level planning (PH) and evaluating (EH), while unskilled thinkers engage in metacognitive strategies only at the lowest level, indicating only an awareness of a need for planning, their understanding (of the topic), and task progress. Students in the present study predominantly employed Planning and Monitoring at low and medium levels. Few engaged in Evaluating in their written reflections, and those that did tended to do so at a low level. Finally, only a small number of students engaged in the action and transfer dimensions of metacognition. This profile of metacognitive strategy use indicates that the students on average are only somewhat better than unskilled thinkers.

To be fair, the infrequency and low level of Evaluating may be an artifact of TR Part B.1. As students evaluated their computational work and made comparisons to the sample solution, they were asked to comment on their errors and opportunities for improvement in their work documents. It is possible that students did not integrate those ideas into their written responses to the reflection prompt analyzed in this study. Future work will merge students' commenting in their work documents with their reflections to provide a more complete picture of their metacognitive strategies.

A more detailed look at the nature of students' reflective responses is demonstrated in the discussion of sample student comments below. Differences between levels are highlighted.

Planning. The Planning metacognitive strategy involved thinking about ways to improve proficiency. At the lowest planning level, statements like, *"In the future, I will take action to solve the problem in the most efficient manner,"* showed that the student was aware of a need to do something differently but were vague in defining an action or goal. Medium level Planning statements typically included actions but not goals; for instance, *"My future plan of actions is to watch lecture videos at least twice before I try to solve the problem. One time watching isn't enough, I also plan to pause the video and digest the information as often as possible."* While the action is clear in this example, the point of the action is not.

The highest level of Planning includes an explanation of how the student's action is going to help them to achieve a goal. For example,

> *"For solving a problem symbolically to completion and in a manner that facilitates subsequent computational tool use, I will make sure that I have all the unknowns, knowns, and my sketch clearly organized with all appropriate information present. I will make sure to order my equations so that each step is clear and makes sense to me. For performing material balances on single unit without recycle and bypass streams, I will study and practice mass balance problems in order to get more comfortable with recognizing and solving these types of problems. I will also make sure to reference the standard problem-solving method"*.

While this Planning statement met the minimum requirements for a PH code (it had actions and goals), much of the text consisted of rephrased learning objectives. As was often the case with PH coded statements, the student did not overly connect their goals to the LO proficiency indicators.

Monitoring. The Monitoring metacognitive strategy is about comprehension of the course material. Monitoring statements indicated a level of understanding or lack of understanding of a course topic. Responses like *"Towards the end of the [reflection], I started admitting that I need more help in some areas. I have always been good about attending office hours and it has helped me out tremendously."* indicated low-level Monitoring. Many ML statements were general statements about struggling with no reference to a topic. A medium-level Monitoring strategy not only acknowledges an awareness of one' understanding but includes specifics on the understanding, for instance, "*I need to improve upon completely understanding what the knowns/unknowns are in each problem. When I assume that something is known and it is actually unknown, it drastically alters the problem."* This statement specified the topic (i.e., finding knowns/unknowns) but failed to connect to anything specific about the topic. When that level of detail was provided, the student tapped into the proficiency indicators. Such a high-level monitoring (MH) reflective statement example is,

> *"However, I was confident in my skills to set up and solve the problem using the correct problem-solving technique. I would describe the skills I learned through this training to my future employer as a thorough problem-solving technique. I now have the ability to digest a client's request and understand the context of the*

> *problem and how the desired outcomes factor into the problem mathematically. I also have learned how to document my work so that other engineers can follow along and check for accuracy. Additionally, the formatting techniques I learned are useful for explaining the outcome of the analysis to the client so they can interpret the data and move forward with their decision making".*

Evaluating. For the Evaluating metacognitive strategy, reflective comments indicated one's assessment of their own performance with reference to feedback. Within this course structure, feedback was gained from the comparison of one's work to the sample solution and the instructor's assessment of their problem-solving processes, documentation, and computational tool use. At the lowest level, students often described their reactions to looking at the sample solution to a training. For example, "*After looking at the solution guide and referring back to course resources I feel like I can successfully create a table."* At a medium level, students expressed a solution to a problem they identified when evaluating their work,

> *"Identify and declare all knowns with units is a learning objective that I still need to work on. I noticed that in this last homework I missed a couple given values that I should have wrote down to help with my equations. They weren't directly the exact values but I should have adjusted them a little and then they would have been extremely useful. So I need more practice noticing those types of things."*

When engaging in a high-level evaluating monitoring strategy, student comments indicated a problem raised from feedback, provided a solution to the problem going forward, and described how their thinking or skills have changed. In the following example, the student came to the conclusion that their documentation is not just for them but for "another person."

> *"For me, my past assignment feedback has shown me that I am horrible at formatting my output in a way that clearly organizes my solution results. Technical presentation with excel is definitely my weak point. I think I need to take more time in the sheer formatting aspect of the excel solutions. I also noticed that some of my sketches might make sense to me in how I label them, but it doesn't always show enough detail for another person. I need to put more time into my layout of the problem".*

Action. Reflective statements that expressed an Action indicated the use of particular learning strategies. It included comments where students described an action they did or did not take. Learning strategies included using study resources (e.g., help within Excel, Google, course video content, LO list, sample solutions (not for evaluation but as resource), readings); asking the teaching assistant, instructor, or peers; or reworking problems completed in past or working on extra problems. A typical comment was *"I had to re-watch the video in order to understand it."* This code may have captured a different aspect of Monitoring, wherein one thinks about one did to learn and whether or not that was effective. The lack of Action comments across the training seem to indicate that students did not know that think about their learning strategies might be useful. Further, the prompt does not point towards this sort of thinking about one's learning.

Transfer. Transfer comments connected current learning to past, concurrent, or future experiences. Low Transfer comments acknowledged only a connection. *"These skills will be useful to me as an engineer because it helps me practice looking at a problem from multiple* *perspectives."* High level Transfer responses indicated that some concepts in TR 1.1-1.3 had connections to other learning experiences and explained how that learning applied in the current context. For instance, *"I need to shake off the rust with my Excel use and relearn some of its functions. I still have my textbook from my Computer-Aided Problem Solving course, which has detailed information on how to perform some Excel functions such as sorting, cell merging, and cell formatting."* Here the student described past experiences with Excel and what related resources they still had at their disposal.

In this study, the point of engaging students in reflection was to prepare them for self-directed learning - to habitually be able to identify gaps in their knowledge, consider means for closing those gaps, and assess their improvement attempts. In this vein, the first step was to allow students to identify their mistakes and opportunities for improvement by examining their work and comparing it to a sample solution. To facilitate students' work on the trainings and subsequent evaluation of their work, the course learning objectives for each of training were made accessible to students. It was anticipated that the LOs and the proficiency indicators would assist students in writing their reflections. It is interesting to observe that despite accessibility of the detailed LOs, students rarely made explicit reference to the proficiency indicators. Across the metacognitive strategies, this omission led to a limited number of high-level strategies being employed.

VII. Limitations

This study was only focused on the first few weeks of the semester. The metacognitive strategies employed might evolve over the remainder of the semester or be different for other topics. The data were collected during a COVID-impacted semester, perhaps limiting generalizability to a non-COVID-impacted semester. The specific course content may limit generalizability of results to other settings where other course content might naturally inspire more reflection even among reflection-novices.

VIII. Implications for Practice

In a junior-senior level course, it should be expected that students are in the process of transitioning to self-directed learning behaviours in preparation for being a reflective practitioner in the workplace. Such behaviours should include an ability to employ metacognitive strategies at a medium to high level when reflecting. Based on the initial indicators provided in this study, instruction is needed at the start of a course in which students have little to no prior reflection experience. While ongoing practice with reflection with feedback may improve students' depth of reflection, a discussion of high and low level student examples [17] and peer assessment of reflections may help raise the expectations for reflection [18]. Such instructional practices should provide insight on the basic idea of metacognition and different metacognitive strategies. Further, instructors could use the metacognitive strategies dimensions and levels as a framework for giving feedback on student's reflective responses.

IX. Conclusion

The dimension and level of students' metacognitive strategies employed while reflecting on their coursework were analysed in an upper-division agricultural and biological engineering course. Results showed that most students used planning and monitoring when writing self-reflections. Within these strategies, students' reflective comments were at the low to medium level as few students drew on the course's documented learning objective proficiency indicators to clearly articulate struggles with the course content or focus their improvement goals. Few students processed the actions they took to learn or what the results of those actions were. Very few students engaged in evaluation, though the authors acknowledge that evidence of this strategy may lie elsewhere in students' work and was not brought forward into their written reflections. Finally, few students employed transfer, meaning they did not make connections between their learning in the course and their other past, concurrent, or envisioned future experiences. Overall, evidence suggests that formal and ongoing instruction on reflection is necessary to prepare students for self-directed learning in the workplace.

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