Metacognitive Development Through Structured Reflection: A Case Study in Biological and Agricultural Engineering

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Abstract

Developing students' metacognitive regulation and effective use of learning strategies is central to supporting adaptive learning in engineering education. This qualitative single-case study examined one undergraduate engineering student's metacognitive regulation and use of learning strategies across four semesters that incorporated structured written reflection. The student's 19 reflections were deductively coded at the element level of the three metacognitive regulation dimensions: Monitoring, Evaluating, and Planning. The students' texts for each element were classified for level of detail (None, Vague, or Sufficiently Detailed), and each dimension assigned an overall proficiency level. In parallel, the student's knowledge and use of learning strategies, as communicated through their reflections and pre-post surveys, were analyzed. Results indicated overall movement from Emerging toward Developing and, in some cases, Proficient engagement across the three dimensions, though growth was uneven across semesters. Improvements were most evident in elements that required concrete descriptions, while elements requiring abstract thinking remained more inconsistently articulated. The student's level of detail was lowest for Planning. Across semesters, growth in knowledge of learning strategies reflected increased frequency of Consolidating-Surface and Acquiring-Deep strategies. These findings suggest that sustained instructional support plays a critical role in developing metacognitive regulation. Instructors should continue supporting students with clear feedback and instructions from the reflection activities, especially for elements that require sensemaking.

Keywords: Self-Directed Learning, Metacognition, Reflection, Learning Strategies, Case Study

1. Introduction

Engineering graduates are expected to manage their learning independently, adapt to changing professional demands, and acquire new knowledge throughout their careers. This expectation is reflected in ABET Student Outcome 7, which emphasizes graduates' ability to acquire and apply new knowledge using appropriate learning strategies [1]. Developing this capability requires paying attention to social, motivational, and behavioral aspects, beyond content mastery. It calls for students to become aware of how they learn, regulate their thinking, and intentionally adapt their learning strategies over time [2], [3], [4].

One of the ways that students can develop this capability of acquiring and applying new knowledge is through structured reflection which formalizes students' thinking about their learning, otherwise known as their engagement in metacognition. This approach also provides a useful lens for understanding students' metacognitive development based on the processes they use to regulate their learning and their knowledge of learning strategies to improve their learning.

Metacognitive regulation involves planning, monitoring, and evaluating one's learning, while learning strategies are one form of metacognitive knowledge that facilitates regulation [5], [6]. Students who engage deeply in metacognitive regulation are more likely to select strategies, assess their progress, and respond productively to a difficulty. These behaviors support self-directed learning and lifelong learning outcomes that are central to engineering programs [7], [8].

Reflection has emerged as a common instructional strategy to support metacognitive development in engineering education [9], [10]. When reflection is anchored to authentic coursework, it can prompt students to articulate challenges, evaluate their approaches, and plan future actions in ways that strengthen metacognitive regulation (monitoring, evaluating, and planning) and learning strategies [11], [12], [13]. Recent studies have examined student reflections to characterize metacognitive growth, yet most investigate development within a single course or over a short time frame [14], [15], [16], [17]. As a result, the gap that this study addressed is a lack of longitudinal studies that use theoretical frameworks and multiple forms of evidence to examine students' metacognitive development across several engineering courses that embed reflection and over time.

The purpose of this qualitative single-case study was to explore how a Biological and Agricultural Engineering (BAE) student's reflections reveal changes in learning strategies and metacognitive regulation over time. The approach involved tracing the student's metacognitive development across four required courses over multiple semesters using written reflections coded for metacognitive regulation and self-reported learning strategies. The use of complementary data sources provided a richer picture of metacognitive development than any single method alone. The intention is to inform BAE instructors and curriculum developers on how structured reflection activities can be used across the curriculum to intentionally strengthen students' metacognitive skills and promote deeper learning in engineering courses.

2. Theoretical Framework

This study is guided by metacognition and self-regulated learning theories. Metacognitive theory distinguishes between metacognitive knowledge - what learners understand about themselves, tasks, and strategies - and metacognitive regulation, which includes the processes of planning, monitoring, and evaluating their work [5], [6]. These regulatory activities help students identify challenges, assess their progress, and make adjustments to their learning.

Zimmerman's model [18] conceptualizes self-regulated learning as a cyclical process involving forethought, performance, and self-reflection. In the forethought phase, learners set goals and select strategies (metacognitive regulation - planning). During performance, they apply those strategies while monitoring their understanding (metacognitive regulation - monitoring). In the self-reflection phase, learners evaluate outcomes and determine how their strategies contributed to success or difficulty (metacognitive regulation – evaluating). Zimmerman [18] argues that repeated engagement in these phases supports the development of metacognitive regulation skills over time, as learners refine their awareness of how they learn and strengthen their ability to plan, monitor, and evaluate their learning.

Reflection is an essential mechanism in this developmental process. Drawing on Schön's idea of reflection-on-action [19], structured reflection enables learners to revisit completed tasks, articulate difficulties, analyze strategy effectiveness, and identify future adjustments. Over time, these reflective experiences strengthen both metacognitive knowledge and metacognitive regulation, contributing to more intentional and effective learning behaviors.

Metacognitive and self-regulated learning theories guided the design of reflection prompts, data analysis using a rubric, and interpretation of student responses. The theories provided constructs used to identify evidence of the regulatory processes such as planning, monitoring, and evaluating, and the metacognitive knowledge variable regarding the students' awareness and use of learning strategies. These theories supported the examination of reflection as a mechanism through which students developed their metacognition over time.

3. Literature Review

Previous studies have documented important insights regarding the implementation and assessment of students' metacognitive development when reflection is embedded within a course. Research conducted among middle school students showed that learners with higher metacognitive skills were more likely to select appropriate strategies and solve problems correctly, while those with lower metacognitive skills struggled to understand the problem, choose strategies, and arrive at correct solutions [20]. Stephanou and Mpiontini [21] examined the role of metacognitive knowledge and metacognitive regulation of fifth and sixth grade students' self-regulated learning and performance. They found that students reported moderate use of metacognitive knowledge and regulation, with planning emerging as the most common regulatory strategy. Their results showed that metacognitive regulation played a stronger role than metacognitive knowledge in shaping students' self-regulated learning styles, particularly the intrinsic and identified types of behavioral regulation. Additional work showed that structured self-reflection on both how and what students learn can lead to improvements in academic performance, although the magnitude of these gains may be limited [22]. From an instructional perspective, Perry et al. [23] reported that faculty and teaching assistants observed benefits of reflective practices, including improved self-regulation, deeper learning, and enhanced critical thinking, while also identifying challenges such as limited instructional time, student resistance, off-topic responses, and limited familiarity with metacognition. These one-course studies demonstrate that embedding reflection within coursework can support students' metacognitive development, but that the effectiveness of reflection depends heavily on how it is designed, supported, and assessed. Understanding both the benefits and constraints identified in prior work provides important lessons for instructors seeking to use reflection as a mechanism for fostering metacognitive skills.

To examine metacognitive regulation in practice, some researchers have analyzed students' written reflections using structured coding schemes. In engineering education, the Monitoring-Evaluating-Planning (MEP) framework has been used to characterize students' levels of engagement in metacognitive regulation strategies [13], [24], [25]. This framework builds on earlier work by Ku and Ho [26] and has since been revised in subsequent studies to capture changes in students' metacognitive engagement over time [24], [25]. For example, a study by Singh and Diefes-Dux [13] found that students in a junior-level process engineering course with little prior experience in reflection often demonstrated low to moderate levels of planning and monitoring, while few comments were coded as actions, transfer, or evaluating. Similar patterns from Singh et al. [24] investigating change in students' level of engagement with metacognition within a third-year environmental engineering course showed mostly vague evidence of monitoring, evaluating, and planning across assignments, suggesting limited depth of metacognitive engagement. In contrast, Stratman and Diefes-Dux [25] showed that the way reflection prompts are worded matters. Prompts that emphasized using feedback to improve performance supported planning and evaluating, while prompts focused on the students' learning progress encouraged the use of monitoring strategies. Findings from these studies demonstrate that structured coding schemes make visible not only whether students engage in metacognitive regulation, but also the level and consistency of that engagement. As a result, such frameworks provide a useful methodological approach for examining how students' metacognitive regulation develops within and across courses.

Longitudinal studies in engineering suggest that growth in metacognitive regulation is gradual rather than immediate. Schwab et al. [16] conducted a two-year study examining students' use of metacognitive regulation strategies across sequential engineering courses. Despite repeated opportunities for reflection, the study found slight to no noticeable improvement in students' metacognitive regulation over time. This work employed a developmental rubric that assessed students' reflections along a continuum ranging from No Attempt to Proficient [26], [24] for each metacognitive regulation strategy. In another two-year study where students participated in think-aloud problem-solving tasks and interviews within a problem-based engineering curriculum, data showed one-half of the students demonstrated increased complexity in their understanding of self-directed learning and strategy use by the end of the program [8]. These findings highlight the need for longitudinal investigations and sustained instructional support, as students' ability to regulate their learning develops incrementally and requires continued practice and feedback. The findings also suggest that examining metacognitive development across multiple courses may provide a more complete picture than single-course studies alone.

Metacognitive regulation is connected to students' metacognitive knowledge, particularly their knowledge and use of learning strategies. Learning strategies are commonly described along a surface-deep continuum, a distinction originating in foundational work by Marton and Säljö [27] and later expanded by other researchers [28, [29], [30], [31]. The use of surface strategies typically emphasizes task completion and memorization, whereas deep strategies focus on conceptual understanding, integration, and meaning making [30]. Research shows that students' use of learning strategies varies based on instructional design, assessment practices, and task demands [32], [33], [34], [35]. While the surface-deep distinction is widely used in higher education, some scholars caution against treating these approaches as fixed learner types or a simple hierarchy. Howie and Bagnall [36] argue that Biggs's model has been widely adopted without enough critical examination, which has contributed to simplified uses of the framework, including an emphasis on promoting deep approaches without sufficient attention to context. They suggest that such interpretations risk overlooking the role of task demands, learning context, and students' purposes for engaging with particular strategies. From a metacognitive perspective, the focus is therefore not on promoting one approach over another, but on students' awareness of multiple learning strategies and their ability to select strategies that best align with a specific difficulty or learning gap [36], [37]. This ability to choose and adapt strategies reflects metacognitive knowledge and supports regulation by allowing students to respond appropriately to different learning situations rather than relying on a single approach.

This study addresses the need for longitudinal studies that use theoretical frameworks and multiple forms of evidence to examine students' metacognitive development across several engineering courses that embed reflection and over time.

4. Research Questions

This single case study addressed three research questions:

1. How does a student's metacognitive regulation (monitoring, evaluating, and planning) change across their reflections over multiple semesters?
2. How does a student's metacognitive knowledge of learning strategies change over time?
3. What is the interplay between a student's metacognitive knowledge and regulation?

5. Conceptual Framework

The conceptual framework guiding the study is informed by [38], as shown in Figure 1. It illustrates how students move through multiple reflections across several courses. Each reflection gives them a chance to draw on what they already know about themselves and their strategies, engage in monitoring, evaluating, and planning, and then carry that learning into future coursework. Over time, this repeated cycle helps students develop a clearer sense of themselves as learners and refine the strategies they use.

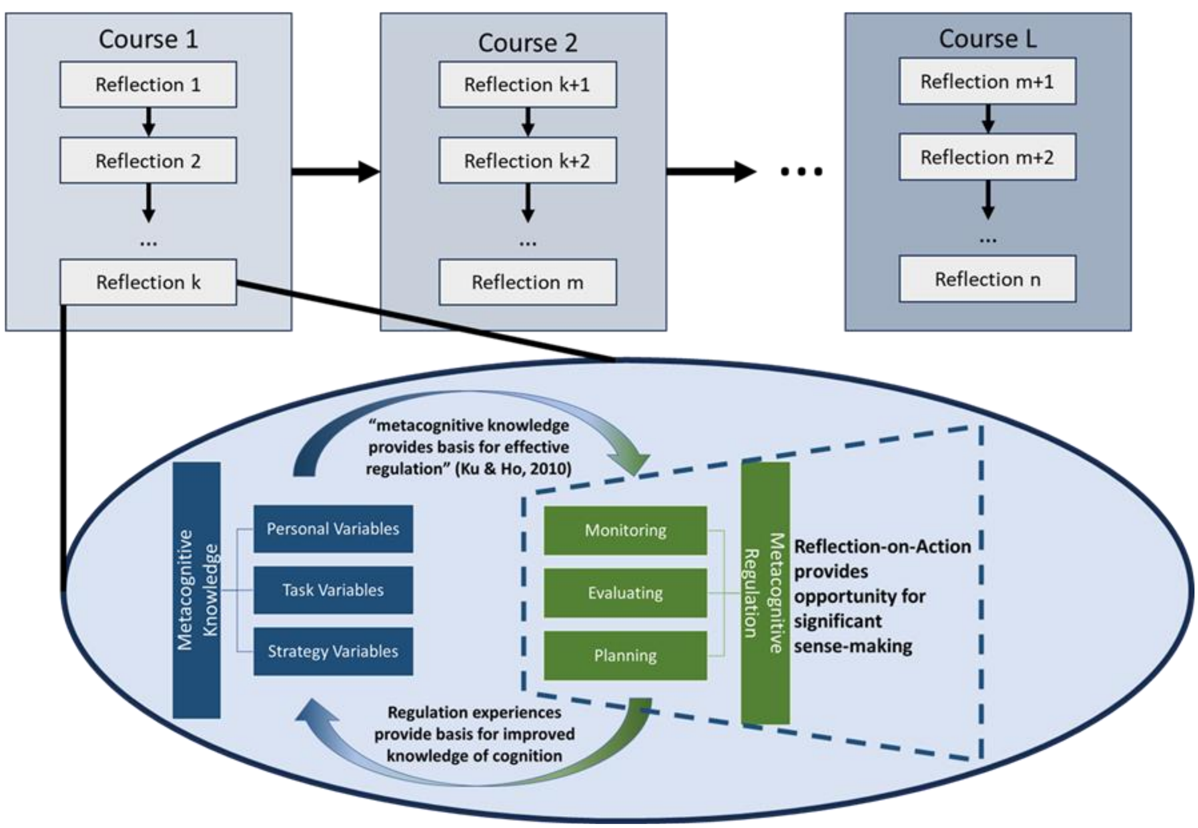

Figure 1. Conceptual framework for proposed work (informed by [38])

This framework highlights four key ideas. First, metacognitive knowledge (including personal, task, and strategy knowledge) informs how students approach their difficulties or gaps. Second, metacognitive regulation (planning, monitoring, and evaluating) is implemented through structured reflection tasks. Third, these reflection tasks are reflection-on-action [19] in nature, providing opportunities for sense-making, allowing learners to integrate past experiences in their learning to inform future decisions. To achieve reflection on action, guided reflection emphasizes components of self-regulation [18], through the cyclic process of forethought, performance, and self-reflection on their learning. The arrows in Figure 1 emphasize the reciprocal relationship between metacognitive knowledge and regulation. Knowledge provides a basis for effective regulation [26], and regulation experiences provide a basis for improved knowledge and cognition. For this single case study, the framework provides a useful approach to tracing how one student's metacognitive development unfolds over time across different courses in the biological and agricultural engineering program.

6. Methods

6.1 Setting and Participants

This qualitative single-case study was conducted at a midwestern R1 U.S. university in a BAE program. The case was randomly selected from a group of twelve consenting students with reflection experience in four consecutive courses. The case was a White, female student who was a first-year student in Spring 2023 and came from a metropolitan area. She completed 19 reflections across four courses spanning the student's first to junior years, over four semesters, from Spring 2023 through Spring 2025. These structured reflections were embedded within required program courses and were designed to strengthen self-directed learning and reflective practice. Instructors had decision making power over what assignments they anchored in reflection and the overall percentage of weighted reflection they assigned across the four courses as described below.

6.2 Course Design and Reflection Implementation

Reflection activities were embedded into four courses spanning an introductory computational problem-solving to a junior-level systems analysis, where the latter course was often taken by seniors. Across these courses, reflections were intentionally linked to ongoing coursework, a structure that researchers have referred to as anchoring, where reflection assignments are directly tied to an engineering task [24]. With this approach, students completed a typical engineering assignment (e.g., homework, project milestone) and then responded to reflection prompts that asked them to describe a challenging or meaningful aspect of that task. In the current study, each reflection prompt encouraged the student to articulate how they monitored progress, evaluated understanding, and planned for improvement in their learning. Students responded to the following reflection prompts across the monitoring, evaluating, and planning dimensions.

- *What is one difficulty you are (or were) most concerned about? Be specific. Include a description of how you know (or knew) you are (or were) having this difficulty.* [Monitoring]

- *How have you tried to overcome this difficulty? Include a description of how your approaches have been successful or unsuccessful and what you learned.* [Evaluating]

- *If you are still having the difficulty: What is your plan to further address this difficulty?* [Planning]

The implementation details, instructional focus, and demographic context for each course are summarized below.

Course 1: Spring 2023 (First-Year Level)

The first course was a foundational engineering class focused on problem-solving techniques and procedures using Excel, graphical methods, and MATLAB. It emphasized clear communication of engineering problems and solutions within the context of agricultural and biological systems of engineering. Major topics included introduction to engineering concepts, engineering design and problem-solving, and computational tools for data analysis and modeling.

Students completed five reflections with the first focused on MATLAB basics, followed by four reflections aligned with project milestones that progressed from the problem statement and objectives to background and sampling methods, and finally to methods and results. These reflections contributed approximately 2% of the course grade and were graded by the research team (graduate research assistants) using a theory-grounded rubric that was shared with the students. Brief written feedback aligned to the rubric was provided. As this was the first semester, reflections were introduced in the curriculum; no video or supplemental materials were available to the students.

The course enrolled 74 students, of whom 77% were first-year, 43% male, 51% female, 6% unknown, and 68% identified as White. Additionally, 14% were first-generation college students, and about 47% came from metropolitan areas, with others distributed across micropolitan areas (22%) and other less populated regions (31%), as defined by the 2010 Rural-Urban Commuting Area (RUCA) Codes, ZIP codes [39] (USDA, 2020).

Course 2: Fall 2023 (Sophomore Level)

The second course was a laboratory-based class focused on the physical and mechanical properties of biological materials. Across the semester, students completed six reflections, each corresponding to a laboratory activity, such as Physical Properties: Size and Shape, Hydraulic Conductivity, and Mechanical Properties (Compression, Shear, Flexure, and Tension). The reflection assignments encouraged students to connect technical understanding with their professional and teamwork experiences. These reflections accounted for 10% of the course grade and were graded by the instructor using the theory-bound rubric; written feedback was provided.

In Fall 2023, four short videos were released: Metacognition & Reflection, Monitoring, Evaluating, and Planning. This course introduced short video content explaining key aspects of reflection, including student examples from previous semesters and guidance for improving the monitoring and evaluation dimensions. The instructor did not release the Metacognition &

Reflection video to the students. The other three were released. The Monitoring and Evaluating videos were assigned in the course's weekly task lists, but the Planning video was not.

The class enrolled 65 students, of whom 83% were sophomores, 51% male, 41% female, and 66% identified as White. In addition, 14% were first-generation students, and about 48% were from metropolitan areas, with smaller proportions from micropolitan (19%) and other regions (33%).

Course 3: Fall 2024 (Junior Level)

The third course was a junior-level introduction to biomedical engineering; it introduced students to engineering principles and system design as applied to biological and human systems. Key topics included biomechanics, bioelectricity, and tissue engineering, among others. Students engaged in assignments that required concept mapping, literature review, and project communication, linking engineering concepts to reflection on learning processes.

Students completed four reflections corresponding to major course components: a bioelectricity concept map exercise, a literature search and product selection for the term project, a biomechanics concept map exercise, and a project communication assignment. Reflections contributed about 1.7% of the overall course grade and were graded by the instructor using the theory-bound rubric with limited written feedback.

To support reflective learning, students had access to a Canvas module containing all four videos, a peer reflection video (former student's perspectives on the value of reflection), a Deep Dive Learning Strategies PDF (for reference when considering strategies they might use to improve their learning), and the rubric. Students were encouraged to (re)view the videos before completing each reflection.

The class enrolled 33 students, primarily juniors (97%) and one senior (3%). About 70% were female, 27% male, and 64% identified as White. Three students (9.1%) were first-generation college students, and 63% came from metropolitan areas with smaller numbers from micropolitan (6%) and other regions (31%).

Course 4: Spring 2025 (Junior Level)

The fourth course was a junior-level systems and transport class emphasizing energy and mass transfer processes relevant to biological and environmental engineering. Major topics included modes of heat and mass transfer with a semester-long team project that required integrating theoretical and design analysis.

Students completed four reflections associated with project parts 1-4, corresponding to problem definition, two rounds of engineering analysis, and then a final project presentation and report. Reflections represented 7.8% of the course grade and were graded by the instructor using the theory-bound rubric without written comments. To guide reflection, students had access to a Canvas module with the four videos, the peer reflection video, the Deep Dive Learning Strategies PDF, the rubric, and flowcharts illustrating the detail required in reflections for each of the monitoring, evaluating, and planning dimensions. Students were encouraged to (re)view the videos before completing the reflections.

The class enrolled 40 students, of whom 57% were juniors, 25% seniors, and 15% fifth-year seniors. Approximately 50% were female, 47% male, and 75% identified as White. About 12% were first-generation college students, and 62% came from metropolitan areas, with smaller proportions from micropolitan (12%) and other regions (26%).

6.3 Data Collection

Data for this study consisted of 19 written reflections completed by one student across four required engineering courses between Spring 2023 and Spring 2025. Each reflection was designed to elicit evidence of student employment of metacognitive regulation strategies (MRS), specifically monitoring, evaluating, and planning, and metacognitive knowledge (i.e., learning strategies obtained through the open-ended prompts), as part of ongoing curricular efforts to support self-regulated learning. For this single case study, this data provided insight into how the student's use of learning strategies complemented her metacognitive regulation across the courses taken.

To capture students' knowledge, use, and evaluation of learning strategies, pre- and post-surveys were administered. These surveys collected qualitative, self-reported data on the learning strategies students used in their coursework and how they perceived the effectiveness of those strategies in specific learning situations. The pre-survey additionally gathered information about strategies students were not using regularly but believed could be beneficial for supporting their learning.

On pre and post surveys, students were asked to "*list and describe three learning strategies that you currently use most frequently in your engineering coursework to help you learn.*"… "*State your first learning strategy.*" and *"For your first learning strategy, how does this one work for you? Provide example(s) of when it is used and how it is and is not successful.*" The prompts for the second and third learning strategy followed the same format. On the pre-survey only, students were asked to *"propose and describe three learning strategies that you are currently NOT using (or NOT using very frequently) in your engineering coursework to help you learn but have potential to be helpful." …"State your first proposed learning strategy," and "for your first proposed learning strategy, why do you think this one will help you? Be specific about when and how,"* and the prompts for the second and third learning strategy followed the same format.

6.4 Data Analysis

Qualitative Coding and Reliability Procedures

The student's reflections were analyzed qualitatively using an *a priori* coding scheme that assessed the student's level of engagement in the three metacognitive regulation dimensions (planning, monitoring, and evaluating). Deductive coding was guided by an adapted version of the Metacognitive Regulation Strategies (MRS) codebook used in prior work [24] and developed by [26] (Table 1 for short version). The analysis focused on identifying textual evidence of the level of monitoring, evaluating, and planning behaviors in the student's responses.

The level of detail supplied by the student for each element was classified as either None, Vague, or Sufficiently Detailed. None indicated that no evidence describing the MRS element was mentioned, Vague reflected brief or general statements that lacked clear detail, whereas Sufficiently Detailed indicated evidence of clear, specific descriptions in the student's responses that directly addressed the MRS element. Counts for levels of detail for each element in the student's reflections were then used to determine an overall proficiency for each metacognitive regulation dimension (MEP), classified as Insufficient Evidence (IE), Emerging (E), Developing (D), or Proficient (P) as summarized in prior work [16] with exemplars of students' reflections using the same rubric.

Table 1. ***A priori*** **coding scheme for metacognitive regulation strategies – short version [26], [24]**

Dimension	Elements	Abstraction	Description	Detail Levels
Monitoring	Difficulty	SA	Clearly identify a learning concern	None (0), Vague (1), or Sufficiently Detailed (2)
	Experience	C	Clearly describe experience in which learning concern arose	
	Identification	SA	Describe how the learning concern was identified (the evidence)	
	Standard	A	Make explicit tie to learning expectations or other standard	
Evaluating	Action	C	Clearly describe actions taken or not taken to address the learning concern	
	Assessment	SA	Assess actions taken to improve learning	
	Change/ Confirmation	A	Express change in or confirmation of one's thinking (about learning strategies or learning concern) as a result	
Planning-	Goal	SA	Describe a clear goal	
	Steps	C	Articulate action(s) to be taken	
	Justification	A	Explains/justifies choices being made to move forward	

To get an overarching sense of quality and trends in student engagement in a given MRS dimension, the number of Sufficiently Detailed (SD) and Vague (V) classifications were converted to a Proficiency scale (Table 2). From this quantitative look at the trends, a more detailed look at the elements was conducted to understand which elements were strong or weak. To this end, as shown in Table 1, the nature of each element was categorized as either Abstract (A) – requires sense-making, Semi-abstract (SA) – needs some sense-making of concrete facts, or Concrete (C) – stating very factual things. Note that each MRS dimension includes an element that requires abstract thinking.

The coding team consisted of two novice coders and an expert coder, who also served as the principal investigator (PI) of the broader project. Each novice coder was trained using the MRS framework before coding independently. Inter-rater reliability was sought through multiple rounds of coding to achieve a minimum 80% simple match for each subdimension. For each coding round, the coders independently analyzed ten reflections, after which consensus discussions were held to refine the codebook used in previous studies [24], [16] and to clarify operational definitions. The codebook was updated iteratively after each round to strengthen coding precision, conceptual alignment, and analytic rigor.

Table 2. MRS Element Score to Rating Conversion

Rating	Monitoring Range of Scores	Evaluating and Planning Range of Scores
Proficient (P)	8	6
Developing (D)	6 – 7	4 – 5
Emerging (E)	4 – 5	3
Insufficient Evidence (IE)	2 – 3	2
No Attempt (N)	0 – 1	0 – 1

Both novice coders' initial work on the planning dimension, and interrater reliability with the expert coder was achieved at 80-100% for each subdimension on either the second or third round of coding. Next, one novice coder focused on the monitoring dimension, achieving 90-100% reliability on the subdimension with the expert coder on the second round, while the second novice coder focused on the evaluating dimension and achieved 80-90% reliability on the subdimensions on the second round.

Evidence of student's metacognitive knowledge, specifically their learning strategies, came from two sources: their reflections and their responses to the open-ended prompts concerning the top three learning strategies they use and plan to use. Text segments about learning strategies were deductively coded using five themes based on [40]: Acquiring-Surface, Consolidating-Surface, Acquiring-Deep, Consolidating-Deep, Transfer (Table 3).

Table 3. Learning strategies (LS) coding scheme

Learning Strategies	Description	Specific Examples
Acquiring-Surface	Basic comprehension and rote memorization of information. Emphasizes initial exposure and reproduction of knowledge rather than deep processing.	Flashcards, Notetaking, Textbook Reading
Consolidating–Surface	Encoding knowledge such that it can be retrieved at later times. Strengthen recall and retention of information through structured review and repetition. Organization, scheduling, and short-term reinforcement.	Reviewing Notes, Repetition, Study Time Management
Acquiring–Deep	Developing meaningful understanding and higher-order thinking by connecting, interpreting, and applying knowledge beyond surface recall. High levels of awareness, control or strategic choice of multiple strategies	Concept Mapping, Use of External Resources, Elaboration
Consolidating–Deep	Promote internalization and long-term mastery of concepts through interactive, problem-solving, and application-based learning.	Group Study, Peer Teaching, Revising Work
Transfer	Extend learning beyond the immediate course by applying it to other contexts or disciplines.	Connecting to Other Subjects or Real-World

The student's self-reported use of learning strategies was determined in two ways: (1) those qualitatively identified in her reflections using the established coding scheme for surface and deep learning strategies, and (2) her written self-reported strategies captured in a pre-post reflection survey in each course. After establishing coding reliability, the reflections were analyzed to examine the depth, consistency, and evolution of the student's metacognitive behaviors across semesters. The analysis focused on how the student planned, monitored, and evaluated her learning in different engineering contexts and how these regulatory behaviors changed over time.

Learning strategies extracted from reflections and those self-reported in surveys were then compared with the MRS patterns to explore the interplay between the student's metacognitive knowledge and metacognitive regulation. These comparisons provided insight into the extent to which the student demonstrated surface or deep learning approaches and how those approaches related to her monitoring, evaluating, and planning behaviors. The frequencies and code labels obtained from the student's level of engagement in the three metacognitive regulation dimensions were used descriptively to illustrate developmental patterns.

7. Results

The results are presented in a two-fold manner to address the three research questions. First, for each reflection, the student's engagement in the MRSs was coded at the element level. These results are presented descriptively using counts and patterns across reflections and semesters organized by Monitoring, Evaluating, and Planning. Second, the student's knowledge and use of learning strategies are presented by semester, drawing on strategies identified in written reflections and, where available, self-reported survey responses. Together, these results provide a descriptive account of changes in the student's metacognitive regulation and use of learning strategies over time. Tables 4, 5, and 6 summarize the elements' levels of detail and Overall Proficiency across each semester's total number of reflections completed by the student. Refer to [16] for the summarized version of the rubric describing the Overall Proficiency levels and Table 1 for descriptions of each element of the Monitoring, Evaluation and Planning dimensions, respectively.

7.1 Monitoring

Table 4 summarizes the level of detail (None, Vague, Sufficiently Detailed) and Overall Proficiency observed for each Monitoring element (Difficulty, Experience, Identification, and Standard) across the student's 19 reflections, organized by semester for the four courses. The student's level of engagement in the first course (Spring 2023) was at Emerging; the level jumped to Proficient by the second course and then leveled off at Emerging and Developing in her third and fourth courses with embedded reflection. Across all reflections, descriptions of her Experience had the highest level of detail (14 SD, 5 V) followed by Difficulty, which showed moderate variation across reflections (11 SD, 8 V). The student provided the lowest level of detail for Identification and Standard, and these were the only Monitoring elements in which responses were coded as None (N), but only in the first course. To demonstrate the drop in detail, and thus overall proficiency with Monitoring, after Fall 2023, a Proficient and an Emerging example from the student's sophomore and junior-level courses in Fall 2023 and Spring 2025, respectively, are described below.

Table 4. Level of Detail and Proficiency for Monitoring Elements Across Reflections

Semester (No. Reflections)	Detail Levels[a]				Overall Proficiency
	Difficulty	Experience	Identification	Standard	
Spring 2023 (5)	2 SD, 3V	3 SD, 2 V	3 V, 2 N	3 V, 2 N	IE, E, E, E, E
Fall 2023 (6)	6 SD	6 SD	6 SD	6 SD	P, P, P, P, P, P
Fall 2024 (4)	1 SD, 3 V	1 SD, 3 V	2 SD, 2 V	1 SD, 3 V	E, D, D, E
Spring 2025 (4)	2 SD, 2 V	4 SD	1 SD, 3 V	2 SD, 2 V	E, E, P, D
Total (19)	**11 SD, 8 V**	**14 SD, 5V**	**9 SD, 8 V, 2 N**	**9 SD, 8 V, 2 N**	**7 P, 8 E, 3 D, 1 IE**

[a] SD = Sufficiently Detailed, V = Vague, N = None

For both examples within the Monitoring dimension, the student responded to the following prompt: *What is one difficulty you are (or were) most concerned about? Be specific. Include a description of how you know (or knew) you are (or were) having this difficulty.*

Proficient Example Fall 2023 (Reflection 10)

> *One difficulty that I was most concerned about when completing the lab memo for the shear and compression lab, was my ability to produce results when given a set of data that was very large numerically* [Difficulty]. *This difficulty arose due to my lack of ability to deduce the reasoning for the data when it is such a large amount of unlabeled data. During lab we were given data sets that we collected from the compression and shear tests of both the pellet and corn, however, these data sheets we massive columns of over 3000 data points without any labels on them. I felt overwhelmed when I was trying to decipher these data sheets due to their size and length, specifically when I was trying to determine what data each column was providing and what I was supposed to do with this data. I felt that I didn't have enough understanding of what the memo was asking of me and what properties I was trying to determine from the data to determine how to use the data provided to me* [Experience]. *I became aware of this concern when I was trying to create my stress-strain graphs from the data I was provided. To create these graphs, I had to determine what variable each column of data was representative of* [Identification]. *Being able to understand the data provided is a very important aspect of engineering that I will have to continue to use not only for future memos but also in my future career. The point of this class is to learn how to make connections from the data provided to the issue that you are trying to fix* [Standard].

Difficulty (red color) was coded Sufficiently Detailed because the student provided specific details regarding the technical learning concern of handling a large set of data when completing the lab memo for the shear and compression lab. *Experience* (orange color) was coded Sufficiently Detailed because she provided enough detail regarding the state of things at the time of experiencing the difficulty and expressed feeling overwhelmed when trying to decipher the data sheets. *Identification* (blue color) was coded Sufficiently Detailed because she mentioned realizing she had the difficulty while creating stress-strain graphs from the data and determining what variable each column represented. *Standard* (green color) was coded Sufficiently Detailed because the student, made a connection of the learning concern to a class learning expectation and its relevance to her future career in engineering.

A drop in the level of detail was observed from Reflection 10 in a sophomore-level course, where all Monitoring elements were coded as Sufficiently Detailed, to some elements marked Vague in Reflection 17 from a junior-level course as presented in the Emerging example below. This Emerging example shows that the elements that required some form of abstract thinking –

Difficulty, Identification, and Standard – were marked as Vague, while Experience that required stating factual things (concrete) remained marked as Sufficiently Detailed.

Emerging Example Spring 2025 (Reflection 17)

> *One learning difficulty in which I was most concerned about when completing the second part of the team project was my ability to assign relevant engineering principles to the design that my team and I had come up with* [Difficulty]. *This learning difficulty arose while I was working on the assignment Project Part 2- Engineering Analysis, where my team and I had to analyze and provide engineering topics for the designs we chose* [Experience]. *I was able to identify this learning difficulty while I was trying to assign engineering principles to the first design of our project, a box cooled by chilled water running through pipes. I was able to identify some engineering principles using my knowledge of thermodynamics and fluid dynamics,* [Identification] *but there were still many concepts about the cooling process that I wasn't able to explain using engineering concepts, because I have not learned about these concepts yet. This made it difficult to assign the designs a complete engineering analysis* [Experience]. *This challenge is especially important when looking at the learning expectations of this class* [Standard]. *This class is called heat and mass transfer, and we will cover topics regarding the heat and mass transfer of environmental and biological elements* [Experience]. *However, we have not covered all the course material at this time. By the end of the semester, I should have a full understanding of these concepts and be able to provide a compete engineering analysis to the designs chosen* [Standard].

Difficulty (red color) was coded Vague because the description lacked specific details about the project topic she and her team were working on and what engineering principles were being referred to. The timeline for achieving this goal and how success would be measured were not explicit as well. *Experience* (orange color) was coded Sufficiently Detailed because she provided enough detail describing that this was from a heat and mass transfer class and an assignment on engineering analysis in project part-2. However, the Experience described is scattered throughout her reflection, and part of the feedback was around organizing her thoughts to separate Experience from Identification. *Identification* (blue color) was coded Vague because it remained unclear in her description how she was assigning these engineering principles and what the outcome was that brought her to the realization of having the difficulty she mentioned experiencing. *Standard* (green color) was coded Vague because the student simply mentioned meeting an expectation from class of completing the assignment but lacked a link to why it is important to have a complete engineering analysis of the project designs. Perhaps a reference to how this knowledge/ability of assigning engineering principles to a design tie to future engineering work would have made this element clearer.

7.2. Evaluating

Table 5 summarizes the level of detail (None, Vague, Sufficiently Detailed) and Overall Proficiency observed for each Evaluating element (Actions, Assessment, Change/Confirmation) across the student's reflections, organized by semester for the four courses. The student's level of engagement in the first course (Spring 2023) which was at Emerging and Developing, shifted to entirely Developing by the second course and remained at Developing for the third and fourth course, except for one Proficient (Reflection 15) in the third course. Assessment (Semi-Abstract) showed the highest level of detail as Vague, while the highest level of detail as Sufficiently Detailed was from Actions (Concrete). Change/Confirmation (Abstract) had a mix of SD and

Vague (10 SD, 7V). The three descriptions coded as None were from the elements – Assessment and Change/Confirmation – in the first course. The student's level of detail was predominantly at Developing for the Evaluating dimension and an example from Reflection 18 in her junior level course is presented below.

Table 5. Level of Detail and Proficiency for Evaluating Elements Across Reflections

Semester (No. Reflections)	Detail Levels[a]			Overall Proficiency
	Actions	Assessment	Change/Confirmation	
Spring 2023 (5)	3 SD, 2 V	4 V, 1 N	2 SD, 1 V, 2 N	IE, E, E, D, D
Fall 2023 (6)	6 SD	6 V	2 SD, 4 V	D, D, D, D, D, D
Fall 2024 (4)	4 SD	2 SD, 2 V	3 SD, 1 V	D, D, D, P
Spring 2025 (4)	2 SD, 2 V	4 V	3 SD, 1 V	D, D, D, D
Total (19)	**15 SD, 4 V**	**2 SD, 16 V, 1 N**	**10 SD, 7 V, 2 N**	**1P, 15 D, 2 E, 1 IE**

[a] SD = Sufficiently Detailed, V = Vague, N = None

The student responded to the following prompt within the Evaluating dimension: *How have you tried to overcome this difficulty? Include a description of how your approaches have been successful or unsuccessful and what you learned.*

Developing Example Spring 2025 (Reflection 18)

> *To overcome this difficulty, I used my resources, specifically my professor. I had asked him what assumptions we should use to make our calculations* [Actions]. *While helpful, he was a bit vague in his answer and told us to assume the worst weather conditions in the summer, which we interpreted to mean to assume the hottest day, no wind, direct sunlight, and extremely humid conditions. This provided us a starting point, but did not provide any concrete numerical values to include for the assumptions* [Assessment]. *This is where I then used online resources. I looked up information online: what's the hottest average day in Lincoln during summer, what's a safe fridge temp for food, and all of the other variables that I needed to assume to be able to complete my calculations. I used all of these values to build my set of assumptions* [Actions] *and finally got the calculations done. Even though I got through the assignment, I'm still not 100% sure if the assumptions I used were the best choices for the project* [Assessment]. *These actions did, however, confirm my thinking about learning strategies and how asking for help, specifically from your professor, is a great way to help overcome any learning difficulties you may have, or at least set you in the right direction to overcome it yourself* [Change/Confirmation].

The *Actions* element (red color) was coded Sufficiently Detailed because the descriptions of the actions taken were detailed and clear. For example, it was clear that she was looking for weather-related information online. *Assessment* (blue color) was coded Vague because the student simply stated that the actions taken were partially helpful but lacked a clear expression of why she thought that was the outcome. In addition, her description was scattered, and she was advised to pull the pieces together and provide a clear declaration of success or not, with reasoning regarding the actions taken. However, the element *Change/Confirmation* (green color) was coded Sufficiently Detailed because the student described a change in thinking when she mentioned realizing how helpful it was to seek help from her professor as a way to overcome a learning difficulty.

Similar to the Monitoring dimension, this example showed that the student's level of detail was marked Sufficiently Detailed for the Actions element, which required stating factual things, and Vague for Assessment, which required some abstract thinking. However, the Change/Confirmation element, which required abstract thinking, was marked Sufficiently Detailed.

7.3 Planning

Table 6 summarizes the level of detail (None, Vague, Sufficiently Detailed) and Overall Proficiency observed for each Planning element (Goal, Steps, Justification) across the student's reflections, organized by semester for the four courses. The student's level of engagement in the first course (Spring 2023) was at Emerging and Insufficient Evidence. In the second and third course, her level of engagement showed Emerging and Developing, with some at Proficient in the third course. The fourth course showed only Developing. The highest level of detail at Sufficiently Detailed was seen in the Steps (Concrete) while the Goal (Semi-Abstract) and Justification (Abstract) showed a mix of Vague and None levels of detail. To demonstrate an increment in the student's level of detail with Planning (for some elements), after Fall 2023, an Emerging and Developing example from the student's sophomore and junior-level courses in Fall 2023 and Spring 2025 are described below.

Table 6. Level of Detail and Proficiency for Planning Elements Across Reflections

Semester (No. Reflections)	Detail Levels[a]			Overall Proficiency
	Goal	Steps	Justification	
Spring 2023 (5)	2 V, 3 N	1 SD, 4 V	5 V	E, E, E, IE, IE
Fall 2023 (6)	1 SD, 5 V	3 SD, 3 V	2 SD, 1 V, 3 N	E, E, E, D, D, E
Fall 2024 (4)	3 SD, 1 N	3 SD, 1 V	2 SD, 2 V	P, P, D, E
Spring 2025 (4)	3 SD, 1 V	3 SD, 1 V	1 SD, 1 V, 2 N	D, D, D, D
Total (19)	**7 SD, 6V, 4 N**	**10 SD, 9 V**	**5 SD, 9 V, 5 N**	**2 P, 7 D, 8 E, 2 IE**

[a] SD = Sufficiently Detailed, V = Vague, N = None

For both examples within the Planning dimension, the student responded to the following prompt: *If you are still having the difficulty: What is your plan to further address this difficulty?*

Emerging Example Fall 2023 (Reflection 8)

> *I feel that I sufficiently addressed this difficulty to a degree that allowed me to complete my lab memo and produce a recommendation, however, I feel that I am still struggling to understand how to use the data produced and apply it to the standards provided. To address this difficulty I am going to watch videos that can help teach me strategies to better understand how to use the standards* [Steps]. *I am setting this goal to help me understand how to apply the standards, and standard equations, to the data produced in the lab to help me achieve proficiency in analyzing data and using standards* [Goal]. *Becoming proficient in this skill will help me better prepare for future labs as well as my future career* [Justification]. *To reach this goal I am going to read the standards and look at multiple examples of how data produced is used within standards as well as watch videos that will provide me strategies to better analyze these numbers* [Steps]. *This will help me ensure that I have the best understanding of the standards I can have before trying to use equations from the standard in my own work* [Justification].

Goal (red color) was coded Vague because it lacked specific details about the type of standard equations, the timeline for achieving the goal and how success would be measured. *Steps* element (blue color) was coded Sufficiently Detailed. The approaches mentioned were specific and reproducible. However, *Justification* (green color) was coded as None because it wasn't clear why the student believed the steps she proposed would help her achieve the goal. Part of what was stated as justification was a reiteration of the goal when she mentioned gaining a better understanding of the standards.

Developing Example Spring 2025 (Reflection 18)

> *I believe that I was sufficient in using my resources to overcome this learning difficulty for what i needed to complete the project part 3, however, I still need to come up with better assumptions that I can use for my final rendition on my project that better asses the engineering aspects of each design. I will do this by setting a smart goal for myself. Over the next two weeks, I'm going to make a reference sheet with typical environmental engineering assumption values* [Goal] *by looking through our notes, reliable online sources, and a couple of textbooks. Then I'll set up a quick check-in with my professor or TA to make sure the assumptions I plan to use are on track for our project. I'll use that info to redo my calculations and be able to clearly explain why I used each number* [Steps]. *This plan will help me to come up with assumptions that are relevant to the project and will allow me to come up with the best outcomes* [Justification].

Goal (red color) was coded Sufficiently Detailed. The specific details about the goal, such as the time-bound aspect (two weeks) and how success would be measured (making a reference sheet) were described. However, the student received feedback regarding pulling the pieces of the goal together since they were scattered throughout her description. *Steps* element (blue color) was also coded Sufficiently Detailed because the actions she described taking such as checking-in with her professor or TA to make sure the assumptions she planned to use were on track for the project, clear and reproducible. However, *Justification* (green color) was coded as None because it was framed as a reiteration of the goal. She simply mentioned that the plan would work but missed explaining why she thought or believed the steps she suggested would help her achieve the goal.

Just like the Evaluating dimension, a similar trend was seen in the Planning dimension, with the student's level of detail remaining Vague or even None for elements such as Goal and Justification, which required some form of abstraction. In contrast, the Steps element which required stating factual information, remained Sufficiently Detailed. For Planning, the Justification element, which primarily required abstract thinking, was coded as None for both reflection examples.

7.4 The Student's Knowledge of Learning Strategies

The student's knowledge of learning strategies (Table 7) was examined using two complementary data sources: strategies identified within written reflections and strategies self-reported through the open-ended survey prompts.

Self-reported learning strategies were collected only in Fall 2024 and Spring 2025; no pre- or post-surveys were administered in Spring 2023 or Fall 2023. Therefore, learning strategy outcomes reported for Spring 2023 and Fall 2023 reflect strategies extracted from the student's written reflections only, whereas Fall 2024 and Spring 2025 include both reflection-based and self-reported strategies (italicized in Table 7). These learning strategy outcomes (Table 7) are reported as: *Worked* – was successfully used, *Did not work* – wasn't successful, *Mixed* – had elements of success and no success and *Unknown* – no evidence of use present.

Spring 2023

The student completed five reflections in Spring 2023 as part of a foundational engineering course focused on problem-solving procedures using Excel, graphical methods, and MATLAB. Learning strategies identified from the reflections were primarily within the Consolidating-Surface (CS) and Acquiring-Deep (AD) categories. The only evidence of the Acquiring-Surface (AS) strategy used was attending to physical or mental health, and no Consolidating-Deep (CD) strategies were identified.

Across reflections, reported outcomes varied by learning strategy category. Within the Acquiring-Deep (AD) category, elaboration was reported as effective in Reflection 1. In that reflection, the student described how revisiting course materials helped clarify expectations for the assignment. Peer learning, also categorized as AD, was reported as effective in later reflections (Reflections 4 and 5), particularly after the student sought clarification on problem requirements through interaction with others.

AD strategies were also described as having mixed outcomes in earlier reflections. For example, in Reflection 3, the student described uncertainty about task expectations despite engaging in peer learning and elaboration. In addition, learning strategies within the Consolidating-Surface (CS) category, such as practicing problems, were similarly reported as a mixed outcome when the student was unsure about how to apply tools such as Excel or MATLAB. She stated:

"*I was unsure what answer I was trying to find and what tools I was supposed to use to find them. For example, in Homework 5 problem 2, I found myself wondering what my overall answer was supposed to be and if I was supposed to use MATLAB and Excel or just one or the other."*

In contrast, the Acquiring-Surface (AS) strategy of attending to physical or mental health was reported as not effective in addressing the identified learning concern. In Reflection One, the student noted that attempts to overcome procrastination were unsuccessful, explaining:

"I have tried to overcome procrastinating many times, and every time I have eventually reverted to my old ways."

In some reflections, evidence of whether some learning strategies worked was missing (unknown). These strategies were mostly from the Consolidating-Surface category – reviewing/revising notes, study time management, seeking help from Professor/TA and only one from the Acquiring-Deep category – self-tutoring.

Table 7. Student's Learning Strategies by Category

Semester	Learning Strategy (LS) By Category	Reported LS Outcomes
Spring 2023	**AS:** attend to physical/mental health **CS:** early study, goal setting, reviewing/revising notes, study time management, seeking help from Professor/TA, practicing problems **AD:** peer learning, elaboration, self-tutoring	**Worked:** elaboration (Refl-1), seeking help from Professor/TA (Refl-4), Peer learning (Refl-4 & 5) **Mixed:** elaboration (Refl-3), practicing problems **Did not work:** attend to physical/mental health **Unknown**: reviewing/revising notes, study time management, seeking help from Professor/TA, self-tutoring
Fall 2023	**CS:** early study, reviewing/revising notes, practicing problems, goal setting **AD:** peer learning, watching tutorials, elaboration, concept/mind mapping	**Worked:** reviewing/revising notes, elaboration, peer learning, concept/mind mapping **Mixed:** early study, concept/mind mapping**,** peer learning, reviewing/revising notes (Refl-7 & 10)
Fall 2024	**AS:** self-isolation, reading research papers, annotating **CS:** reviewing/revising notes, goal setting, spaced study, study time management **AD:** concept/mind mapping, elaboration, reflection, watching class videos **Used:** reflection, watching online tutorials, self -isolation, watching class videos, reviewing/revising notes, group study (CD) **Proposed:** textbook reading before and after, reviewing/revising notes	**Worked:** self-isolation, reviewing/revising notes, reading research papers, elaboration, annotating, concept/mind mapping, g*roup study, watching class videos* **Mixed:** *watching online tutorials, self-isolation, reviewing/revising notes* **Did not work:** *reflection*
Spring 2025	**AS:** annotating, textbook reading, reading class materials **CS:** goal setting, study time management, early study, practicing problems, seeking help from professor/TA **AD:** reflection, elaboration, watching online tutorials **CD:** group study **Used:** reviewing/revising notes, seeking tutoring, group study, active engagement in/outside class concept/mind mapping, elaboration **Proposed:** self-isolation, watching online tutorials	**Worked:** *reviewing/revising notes, group study, concept/mind mapping,* seeking help from professor/TA **Mixed:** textbook reading, watching online tutorials, seeking help from professor/TA **Did not work:** annotating, practicing problems **Unknown:** *seeking tutoring, active engagement in/outside class, elaboration*

Fall 2023

The student completed six reflections in Fall 2023 as part of a laboratory-based course focused on the physical and mechanical properties of biological materials. Compared to the previous semester, similar learning strategies were identified from the reflections, primarily within the Consolidating-Surface (CS) and a broader range for the Acquiring-Deep (AD) categories. Peer learning (AD) appeared across reflections, particularly when the student described asking classmates how to calculate the percentage of corn in a mixture or interpret lab procedures.

Across the six reflections, reviewing/revising notes (CS) was reported as effective, particularly in later reflections (Refl-6), while elaboration, peer learning and concept/mind mapping (AD) were also described as effective in specific instances. For example, the student noted:

"I reread and looked over the slides provided that explained the lab, which provided helpful hints about what properties need to be determined and what variables are used to determine them."

At different instances within the same semester, strategies, including early study and reviewing/revising notes for Reflections 7 and 10 (CS), concept or mind mapping and peer learning (AD), were described as having mixed outcomes, as the student continued to refine her understanding of lab expectations. Unlike Spring 2023, no strategies were explicitly described as not working.

Fall 2024

Four reflections completed in Fall 2024 were drawn from a junior-level biomedical engineering course. Learning strategies identified from the written reflections spanned three categories: Acquiring-Surface (AS), Consolidating-Surface (CS), and Acquiring-Deep (AD).

AS strategies included self-isolation, reading research papers, and annotating course materials. Self-isolation was described as studying in a quiet environment to reduce distractions. In one reflection, the student noted:

"I started studying and completing assignments in areas with little outside distraction to allow myself to lock in on what I was studying and nothing else. The action I took to improve my learning has worked for me."

CS strategies included reviewing/revising notes, goal setting, spaced study, and study time management. AD strategies included concept or mind mapping, elaboration, reflection, and watching class videos. For example, when describing elaboration and concept mapping, the student stated:

"I would use Google to research the topics and determine similarities and differences between the BME topics… then review what I had written to see if I could deduce if it was always true of the topics."

Across the reflections, several strategies were reported as having worked, including self-isolation (AS), reviewing or revising notes, reading research papers, annotating, elaboration and concept/mind mapping. From the student's self-reported learning strategies, group study (pre-survey) and watching videos (post-survey) were also reported as having worked. For example, regarding using the group study learning strategy she stated:

"This is very successful for me because I am able to ask them questions and we can teach each other things we understand."

From the same self-reported learning strategies, she reported that using reflection as a learning strategy did not work.

"Reflections do not work for me. They do not help me learn any material or help myself understand why I need to change my learning strategies or if they were successful."

On the other hand, from the post survey, the student reported self-isolation (AS), reviewing or revising notes (CS) and watching online tutorials (AD) as having mixed outcomes. For instance, self-isolation was reported as effective for individual assignments but not for collaborative learning.

"This works for me when I need to complete individual assignment such as this one. This does not work for me when I need other people to help me learn such as studying for exams."

Spring 2025

Four of the five learning strategy categories present across the four reflections were part of a junior-level systems and transport course completed in Spring 2025. Strategies within the Acquiring-Surface (AS) category included annotating, textbook reading, and reading class materials. Similar learning strategies to Fall 2024, such as self-isolation (AS) and study time (CS) were reported. Textbook reading (AS), seeking help from the professor/TA and watching online tutorials (AD) were reported as having mixed outcomes while annotating (AS) and practicing problems (CS) were described as not effective. The student mentioned that annotating supported short-term organization but did not extend to broader understanding.

"While this approach helped me manage my thoughts for this specific assignment, I realized that it only provided a short-term solution."

The self-reported strategies from the pre-survey that worked were reviewing/revising notes (CS), concept/mind mapping (AD), group study (CD) from the post-survey and seeking help from professor/TA was extracted from the student's reflections. The only Consolidating-Deep strategy (group study) emerged when the student encountered difficulty selecting appropriate heat and mass transfer concepts for final design calculations. She mentioned:

"*I turned to my group members to review why we selected certain values and whether we had consistent assumptions across all calculations. This helped clarify some of the discrepancies across design calculations."*

All the three self-reported learning strategies from the post-survey marked as unknown were from the Acquiring-Deep category: seeking tutoring, active engagement in/outside class and elaboration.

8. Discussion

8.1 RQ1: Development of Metacognitive Regulation Across Dimensions

The student demonstrated an overall shift from Emerging toward Developing and, in some instances, Proficient engagement across the Monitoring, Evaluating, and Planning dimensions. However, this growth was uneven across semesters and appeared closely tied to the unique contexts in each course such as consistency and explicitness of instructional feedback, decision making power of each instructor regarding the weighted percentage they assigned to reflection, and how long the student had been exposed to reflection in the classroom.

Findings showed lower levels of detail in the student's responses during Spring 2023, with elements requiring abstract thinking marked as None for the first three reflections. This pattern could be attributed to differences in grading by graduate research assistants, despite the use of the same rubric. It may also reflect the student's adjustment in thinking during her early exposure to structured reflection, since she self-reported having had no prior exposure to reflective practice before college. In addition, these elements marked as None could suggest that the student was not reading prior feedback or had difficulty interpreting the feedback during the early stages of reflection. Prior research suggests that students' initial engagement with reflection activities often results in responses that remain descriptive or limited in depth, particularly when interpreting instructional expectations and feedback [41], [13]. In addition, Zimmerman [3],[4] highlights that self-regulated learning evolves gradually through iterative cycles of planning, monitoring, and evaluation which may explain the observed progression over time in the student's level of engagement.

In Fall 2023, the student's level of engagement was strongest and most consistent, coinciding with a semester that had the highest weighted percentage assigned to reflection and in which the instructor provided written feedback and instructional videos aligned with each metacognitive dimension. Prior research shows that explicit instructional support and feedback help students engage more deeply with metacognitive regulation strategies [8], [16]. In later semesters, when written feedback was reduced or absent, the student's level of detail across elements requiring abstract thinking such as Identification, Standard, Assessment, and Justification dropped. This pattern highlights the importance of continued instructional support rather than reliance on repeated opportunities for reflection alone in supporting the development of metacognitive regulation abilities [16].

8.2 RQ2: Growth in Learning Strategies

Growth in the student's use of learning strategies was reflected by an increased number and repeated use of similar learning strategies rather than a shift toward new or deeper categories. Across semesters, the student relied primarily on Consolidating-Surface and Acquiring-Deep strategies, with only one Consolidating-Deep strategy (i.e. group study) emerging in the student's junior-level courses. One plausible interpretation regarding the student's selection of similar learning strategies may be due to her reliance on strategies that felt familiar and had previously received feedback as acceptable. When feedback doesn't challenge strategy selection or prompt comparison across alternatives, students may miss an opportunity of becoming critical thinkers and lifelong learners who engage in deeper sense-making as reflected through the use of deep learning approaches [26], [35].

8.3 RQ3: Interplay Between Learning Strategies and Metacognitive Regulation

Beyond the number of strategies used, growth was evident in how the student articulated and evaluated learning strategies across metacognitive regulation dimensions. The highest levels of sufficiently detailed elements were observed in the student's articulation of concrete elements, which included Actions in Evaluating (15 SD) and Steps in Planning (10 SD), indicating increased clarity in describing what was tried and how the learning concern was addressed. Evidence of more sufficiently detailed descriptions was observed in the third and fourth junior-level courses for the Change/Confirmation element, suggesting a pattern of growth in abstraction (sense-making) regarding her thinking about the use of learning strategies and learning concerns. This pattern of improvement in her thinking and use of appropriate learning strategies, aligns with prior studies that reported enhanced critical thinking [26] and problem-solving [20], [35] among students that selected higher-level metacognitive strategies. However, there were also occurrences of vague or absent (none) descriptions for Change/Confirmation within Evaluating, as well as for Goal Setting and Justification, within Planning. Across the three dimensions, the highest level of detail coded as None was seen in the Planning dimension. These occurrences reflect persistent difficulty with abstraction (sense-making), which prior studies identify as essential to development of metacognitive regulation skills [24], [16].

9. Limitations

This qualitative case study focused on a single student, which limits the transferability of the findings to other learners or instructional contexts. Variations in course structure, reflection prompts, and instructor/graduate research assistant feedback across semesters may have influenced how the student articulated her use of metacognitive regulation and learning strategies. Differences in who provided feedback (instructor versus teaching assistants) may have shaped the consistency and depth of the student's thinking for subsequent reflection exercises. In addition, the missing self-reported learning strategy data in Spring 2023 and Fall 2023 may have limited insight into the student's use of learning strategies during those semesters, affecting interpretation of development over time.

10. Implications for the Study

This study shows that repeated opportunities for reflection alone may not be sufficient to support sustained development in students' metacognitive regulation without consistent and explicit instructional guidance. There is a need to carefully examine the factors that may have contributed to the lack of sustained detail in the student's reflections across courses. Further, supports need to be identified to help students engage in elements requiring some form of abstract thinking. Instructors should be intentional about emphasizing the benefits of reflection and ensure students are using available resources to support their learning.

In addition, students' reliance on familiar learning strategies within the consolidating-surface and acquiring-deep levels across semesters highlights the need for instructors to think deeply about approaches they could use to help students explore other learning strategies or better map task difficulty to appropriate learning strategies. Generally speaking, instructors need to expose students to a broader spectrum of learning strategies in the classroom, which could include introducing students to more deep learning strategies. Additionally, instructors should consider the learning strategies students report using in their reflections and provide feedback that suggests alternative approaches students could consider. Such engagement from instructors around what students are trying to do with learning strategies can help students become more aware of their learning processes. These intentional efforts to continuously show students the importance of expanding their learning strategies toolbox can support students' ability to develop adaptive learning practices that will be useful when faced with changing work demands in engineering practice.

Further, with the current rise of student use of generative AI, instructors are faced with challenges of students using generative AI to do their reflection assignments. Instructors will have to develop strategies to instill in students a desire to develop metacognitive skills for a work force that increasingly demands that employees engage in abstract thinking to perform tasks AI can and should not do.

11. Conclusion

This study examined a single engineering student's metacognitive regulation and use of learning strategies across four courses using written reflections. Findings showed growth across the Monitoring, Evaluating, and Planning dimensions from early Emerging levels toward Developing and, at times, Proficient engagement. This growth was uneven across semesters and appeared strongest when feedback was explicit and aligned with the rubric. Changes in the use of learning strategies reflected a tendency towards repeated use of similar Consolidating-Surface and Acquiring-Deep strategies rather than a shift toward using Consolidating-Deep strategies. Overall, the need to continuously encourage and support students towards becoming critical thinkers and lifelong learners by providing clear and timely feedback can't be over-emphasized. In the future, a longitudinal study of multiple students' metacognitive development across different courses and instructional contexts will explore whether similar patterns emerge. Including additional cases and collecting self-reported learning strategy data would allow for comparative analysis and support stronger analytic insights into how feedback, course context, and implementation of reflection influence development of metacognitive regulation over time.

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