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# A Longitudinal Case Study of Student's Metacognitive Regulation Strategies Use in an Undergraduate Civil Engineering Program

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## Abstract

The world is constantly changing, and the practice of engineering, therefore, requires that professionals and students continuously learn and critically think to persist in solving complex societal problems. For students, this requirement calls for an ability to use appropriate strategies to acquire and apply new knowledge as needed. However, undergraduate engineering curricula rarely directly develop students' ability to reflect - assess their skill/knowledge gaps and plan for their learning. In civil engineering core coursework, the use of theory-grounded reflection exercises that emphasize metacognitive regulation strategies (MRSs) may aid instructors in developing students' reflexivity and ability to be self-directed learners. The purpose of this single-case design research study was to examine a student's progression in their application of MRSs while engaged in structured reflections in four core courses in their civil engineering program. Data were collected between Fall 2023 and Fall 2025 at an R1 Midwestern US university. The participant used reflections to identify a difficulty encountered while completing an assignment, assess actions taken, and plan further actions to improve learning. Qualitative methods were used to analyze the participant's reflections for the use of MRSs. Results showed that the participant demonstrated increased ability to engage in multiple elements of MRSs. By increasing student's abilities with MRSs, critical thinking skills may be improved and that will be useful for solving new and unfamiliar problems in the future.


## Introduction

Societal issues require technological developments that are increasingly complex and rapidly and unpredictably changing. To remain valuable, one must "master the art of quickly learning complicated things" [1, p. 13]. Evidence of such complex problems can be found in recent crises relating to the built environment. These crises include the 2016 Millennium Tower tilting in San Francisco [2], [3], [4] and the 2017 Oroville Dam Spillway in California [5], [6]. Engineers had to learn and apply technologies to deal with these crises. Dealing with the Oroville Dam crisis involved deploying instruments for investigation and monitoring [5]. These solutions have ultimately led to the prevention of total failure and recovery. The recovery of the Millennium Tower also involved engineers learning and applying unfamiliar technology for advanced monitoring, in-situ remediations, and modeling to predict structural movements. These examples show that engineers are required to have the ability to critically think and acquire new knowledge to develop solutions to problems.

Beyond crisis situations, engineers are now exposed to complex problems in their daily activities. Students need to develop the capacity to engage with rapidly changing technology to solve these problems because, as Schön [7] noted, professionals are often faced with tasks in different contexts that require thinking critically during action. For instance, engineering professionals engaging in routine tasks like hazard mapping [8] and regulation of drinking water [9] must demonstrate capacity to engage with new technologies using critical thinking to ensure safety and compliance. This capacity relates to higher-order thinking [10]. For students, the scope of higher-order thinking has been translated to student outcomes 1 and 7 in ABET [11] criterion 3 which state that students should demonstrate “an ability to identify, formulate and solve complex engineering problems” and "an ability to acquire and apply new knowledge as needed, using appropriate learning strategies," respectively. While civil engineering students receive many opportunities to achieve student outcome 1, there are typically fewer formal instruction opportunities targeted to help students achieve student outcome 7.

Reflection is a technique that is useful for developing the capacity to process difficulties and solve problems. For students, reflection can help them think through an action to articulate what was done and what could be done differently to achieve desired results [12]. When handling a difficulty with learning some concepts in different fields of engineering, reflection on past action was found to be very useful for students to think about their “thinking process” [13], [14], [15]. The thinking about the “thinking process”, also known as metacognition, provides self-awareness for users of reflection, allowing them to identify an appropriate approach for dealing with known difficulties. With repeated use of reflection, students can become more self-aware and control their approaches when they encounter unfamiliar or unstructured problems which are common in engineering education [16]. Knowing that reflection is a way that practitioners or experts can deal with unique problems or uncertainties [7], it is important that engineering students are exposed to reflection as a technique to develop critical thinking and problem-solving capabilities.

Some studies have examined the use of reflection in developing metacognition among engineering students. However, only a few of the studies have implemented reflection in multiple courses [13] or with the same participants [14], while some others have been conducted without theoretical underpinnings. Effective use of metacognitive strategies is developed over time [15], [17], and their effective use can separate experts from novices [7]. Therefore, there is a need for conducting longitudinal studies that examine how the formal use of reflection can be valuable to instructors and institutions preparing civil engineering students for the level of critical thinking and lifelong learning required of professionals.

The purpose of this study was to explore how a civil engineering student developed in their use of metacognition regulation strategies over an extended period of time across multiple engineering courses in which theory-bound guided reflections were embedded. Embedding structured reflections is needed [18] because long-term critical thinking and lifelong-learning skills are not effectively developed through instruction outside the context of a discipline [19]. These skills are developed when challenging tasks in a specific discipline, requiring new or modified learning strategies, are coupled with the formal use of metacognitive regulation strategies [20].

**Background**

The theory of metacognition and model of learning strategies were to guide this study. The theory and model are both explained in the following sections. The integration of the theory and model is also provided.

### *Metacognition*

Metacognition may be described as an awareness and active consideration of everything relating to and leading to a cognitive process. Awareness by an individual entails having adequate knowledge of a cognitive process, while active consideration implies regulation of the cognitive process [21]. For instance, when an individual is aware of a task, their abilities for the task, and possible ways of carrying out the task, there is knowledge of the process or metacognitive knowledge (MK). The individual then needs to select or regulate appropriate strategies and actions for such tasks to be achieved [21], [22]. An example of regulation is students analyzing the root cause of their errors on an exam [13] and developing strategies for better performance in future assessments. Regulation often differentiates good problem solvers from poor problem solvers [22], [23]. Therefore, it is not enough for individuals to be aware of their abilities, tasks, and strategies [23]; they need to engage regulation.

The regulation of metacognition requires strategies (metacognitive regulation strategies [MRSs]) when engaging in cognitive processes. Basically, these MRSs involve monitoring, evaluating, and planning [24], [25]. Monitoring strategies are for scanning for the existence of any difficulty, evaluating strategies are for checking the outcome of actions against desired outcomes, and planning strategies are used for selecting and scheduling actions/tasks [24]. In the context of learning among college students, these types of MRSs were found to be applied at various levels (e.g., [14], [23], [26]). For instance, Ku and Ho [23] found that high performance college students who were familiar with high-level planning strategies provided detailed descriptions of actions to be taken. Low-performance students provided vague planning strategies.

The goal for the introduction of MRSs is the development of a self-regulated learner – a level where students are capable of transferring context-specific strategies into dynamic and new situations. The evidence of the goal is in Brown's [24] description that MRSs and MK are interrelated, feeding each other recursively as shown in Figure 1. When an individual reflects on a task or difficulty, the outcome of the regulation of cognition leads to an addition to MK. The revised knowledge provides a basis for the subsequent regulation of cognition in the next task or difficulty. The understanding of interdependence between MK and MRSs can provide instructors with the knowledge to design instructional resources for developing student ability for metacognitive regulation and subsequently, higher-order thinking skills.

### *Existing Study using Multiple Reflection Exposures*

Though there has been very limited implementation of reflection in multiple courses for the same students, some valuable insights have been drawn from previous studies. For instance, guided reflection can be used to help students in advanced coursework recover from poor performance [13]. Further, students in an advanced engineering course (Solid Mechanics) demonstrated more elaborate/detailed reflection as compared with Freshmen who were enrolled in an "Introduction to Engineering" [13]. To examine students' development in engagement with MRSs, Author [14] implemented reflection with two cohorts across two semesters, where students were first-year engineering students in the spring and sophomores in fall. Results from the multiple exposures to reflection showed that some students exhibited improved engagement with some MRS elements. This study led to implications for instructors' use of reflections to help students develop MRSs.

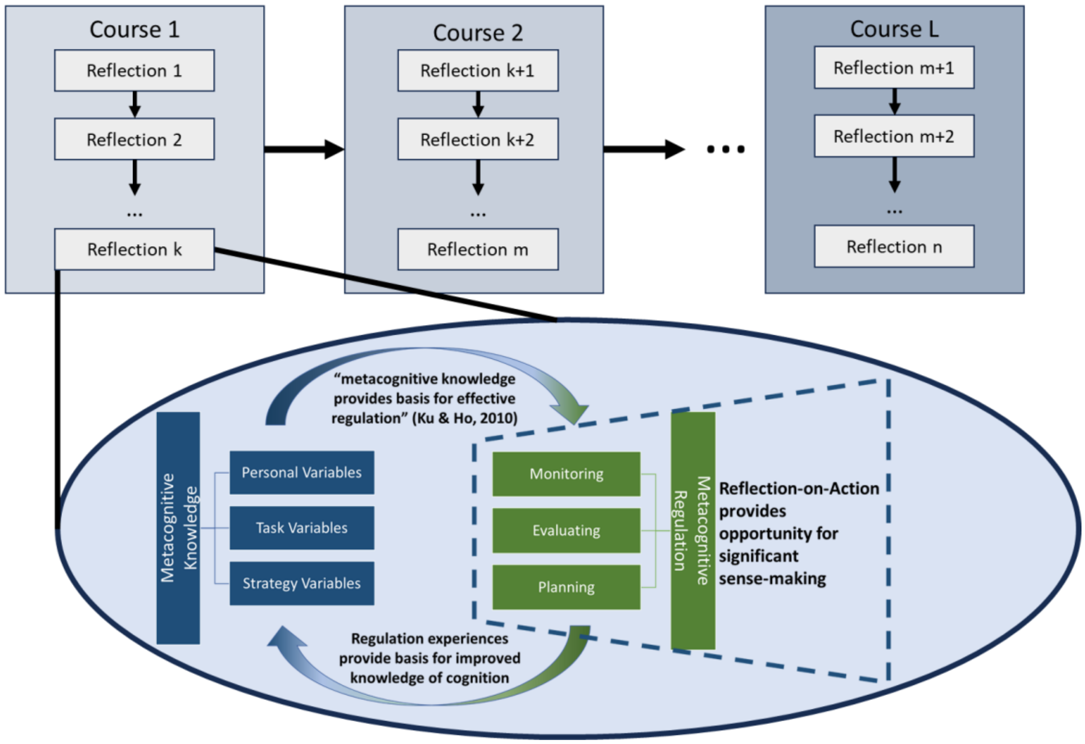


**Figure 1: Conceptual framework (informed by Cunningham et al. [22])**

## Research Question

How did a student develop in their use of metacognitive regulation strategies when engaged in structured reflections embedded in a civil engineering core curriculum?

## Methods

### *Setting and Participants*

This study was part of a larger study, which was conducted at a large, land grant, midwestern R1 university in the United States of America. This study was conducted in four separate engineering courses in an undergraduate civil engineering program from Fall 2023 to Spring 2025. These courses spanned first-year to junior levels. Each course (Course 1 to Course 4) is described in more detail below. Typically, undergraduate students in civil engineering enrolled in Course 1 to Course 4 sequentially. Course 1 and Course 4 were prerequisites to other courses in the program. However, none of the four courses was a prerequisite to any of the other four.

### *Course Backgrounds*

For Course 1, the goals of this first-year course were for students to obtain foundational understanding of civil engineering disciplines, ethics, concepts, and service to community and an understanding of knowledge and tools to be a successful engineering student while gaining exposure to practical applications in civil engineering disciplines. Topics included time management, use of Microsoft applications for word processing, spreadsheet, and presentations, sustainability, ethics and professionalism, and AutoCAD. Items that made up the student grade included homework, quizzes, group tasks, projects, reports, reflections, and attendance. Written reflections were 3% of course grade in Fall 2023. The reflections were assessed by the research team using a theory-informed rubric, which mirrored the a priori coding scheme used in this study (Table 5).

Course 2 was a sophomore level project-based course, with the goal of incorporating programming logic for spreadsheet solutions and integrating professional and management skills in authentic civil engineering projects. Topics ranged from importing data into Excel to using Power Query and Visual Basic Application (VBA). The course grade included assignments, a final project, attendance, and reflections. Written reflections were 5% of the course grade in Fall 2024. The reflections were graded by the course instructional team (teaching assistant) using the theory-informed rubric.

For Course 3, the goals of this junior level course were to introduce students to environmental topics and fundamental concepts such as material balances, water and air quality, waste management and treatment, risk assessment, and ethics. Items that made up the course grading included course engagement & participation, weekly homework, self-reflection, quizzes, mid-term examinations, and a final comprehensive examination. Reflections accounted for 10% of the final course grade in Spring 2025. The reflections were assessed by course instructional team (teaching assistant) using a theory-informed rubric.

In Course 4, the goal of the junior level course was to introduce students to the analyses of determinate and indeterminate trusses, beams, and frames in structural systems. Topics included determinacy and boundary conditions, trusses, beams and frames, deflections, flexibility methods, and slope-deflection methods. In Fall 2025, items that made up the final grade included homework, semester project, homework self-assessment, reflections, participation and engagement, two mid-term examinations, and the final examination. Reflections accounted for 3% of the final grade. The assessment of reflections was done by the instructional team (teaching assistant) and an AI tool; both applied the theory-informed rubric. Using researcher-assessed reflections, the AI tool was trained to grade and provide feedback on the monitoring and evaluating dimensions of MRS.

***Case Description***

A case was selected from among civil engineering students who consented to participation in the study. The case was unique due to exposure to four courses in the larger study. This single-case study typifies the uniqueness in extreme case sample studies. Using Creswell and Guetterman's [27] description of qualitative sampling strategies, this single case was unique in its characteristics. The uniqueness was in the combination of participant demography and number of courses completed in the longitudinal study. The uniqueness provided the basis for exploration and description [28] and extension of the repository of knowledge on reflection and learning strategies.

This case study was conducted during Miguel's (pseudonym) study as an undergraduate student in the civil engineering program. Miguel was a sophomore in Fall 2023, a junior in Fall 2024 and Spring 2025, and a senior in Fall 2025. By demographics, Miguel self-identified as belonging to the following demographic groups: first-generation college students (FGCS), ethnic/racial minority group (Hispanic/Latino), and micropolitan home/origin (as defined [29]). In Table 1, the demographic groups to which Miguel belonged are presented as the percentage of each course's enrollment. Except for FGCS in Course 3, Miguel's group demography was less than 20% of each class's enrollment.

**Table 1. The percentage of Miguel's demographics in Courses 1 to 4**

| | **Course 1 Fall 2023 (N=120)** | **Course 2 Fall 2024 (N=71)** | **Course 3 Spring 2025 (N=44)** | **Course 4 Fall 2025 (N=58)** |
|---|---|---|---|---|
| FGCS | 16.7% | 11.3% | 22.7% | 15.5% |
| Hispanic/Latino | 10.0% | 12.7% | 11.4% | 6.9% |
| Micropolitan | 10.8% | 15.5% | 11.4% | 13.8% |

***Reflection Implementation***

As shown in Table 2**,** reflections were linked to specific course tasks which were described as anchors. According to Authors [26], "anchoring" occurs when typical engineering assignments provide the context for reflection. Throughout the study, reflections were assigned and graded via Canvas. Canvas was the learning management system that was used for student coursework at the site of study. Students were assigned the prompts for reflection once the anchor task was due. Typically, students had four days to complete each written reflection across the study. With the exception of Reflections 1 and 2 in Fall 2024 (Course 2), students were always asked to respond to three MRS prompts (described below). In Course 2, each MRS was added one at a time so students could focus on reviewing instruction on each strategy and receive feedback before the next MRS was reintroduced.

**Table 2. Reflection implementation in Course 1 to Course 4**

| **Data** | **Course 1 (Fall 2023)** | **Course 2 (Fall 2024)** | **Course 3 (Spring 2025)** | **Course 4 (Fall 2025)** |
|---|---|---|---|---|
| Assignment Anchors | Assignment & Project | Assignments & Project | Homework | Homework |
| No. of Reflections Implemented | 3 | 4[a] | 4 | 3 |

[a] Monitoring prompt only in Reflection 1; Monitoring and Evaluating prompts only in Reflection 2.

Table 3 shows the prompts for Monitoring and Evaluating strategies were consistent, while the Planning prompt changed. In the larger study, students demonstrated difficulty in understanding what was expected from original Planning prompts [14] which led to the modification of Planning prompt. In Fall 2023, the "Application" element of planning was used as an alternative element for grading when students felt they had successfully addressed their difficulty. From Fall 2024 and onward, students' responses to Planning were to have the Goals, Steps, and Justification elements regardless of the Planning prompt students responded to [14].

**Table 3. MRS rubric elements and prompts used in Course 1 to Course 4**

| MRS Dimension | Rubric Elements | Prompt |
|---|---|---|
| Monitoring | Difficulty<br>Experience<br>Identification<br>Standard | "What is one difficulty you are (or were) most concerned about? Be specific. Include a description of how know (you knew) you are (or were) having this difficulty." |
| Evaluating | Actions<br>Assessment<br>Change/<br>Confirmation | "How have you tried to overcome this difficulty? Include a description of how your approaches have been successful or unsuccessful and what you learned." |
| Planning (Course 1) | Goal<br>Steps<br>Justification<br><br>**OR**<br>Application | "Respond to ONE of the prompts below, NOT BOTH:<br>If you are still having the difficulty: What is your plan to further address this difficulty? Include an explanation of why you believe your plan will help.<br><br>**OR**<br>If you were successful in addressing this difficulty: Discuss when and how you might use these approaches in the future." |
| Planning (Course 2 – 4) | Goal<br>Steps<br>Justification | "Respond to ONE of the prompts below, NOT BOTH:<br>If you are still having the difficulty: What is your plan (goal and steps) to further address this difficulty? Include an explanation of why you believe your plan will help.<br>**OR**<br>If you were successful in addressing this difficulty: Think beyond this course to future engineering problem-solving situations, projects, or career challenges. What is your plan (goal and steps) for improving or modifying your approach as described above or adding new learning strategies to address similar difficulties? Include an explanation of why you believe your plan will be effective." |

Resources were provided to students to clarify reflections expectations. Some of the additional resources were in the form of explanatory notes in the reflection instructions. For instance, reflection instructions had hints such as: "*The learning difficulty you are asked to identify needs to focus on the knowledge and skills being developed in this course (as opposed to more general study skills, such as time management or team issues, or difficulties in other courses)*". This hint addressed the area of reflection focus. Another hint was intended to differentiate terms: "*Goals are different than actions. A goal describes the result(s) you want to achieve with regards to the problem. A goal is an outcome of actions taken*". "*Actions are the step(s) that will be taken to achieve the goal. Actions are the process to get to the outcome*." Additional reflection resources included those listed in Table 4. The resources served as training materials and guidance to provide students with help in thinking about their difficulties and adequate understanding of reflection elements.

**Table 4. Additional resources provided during reflection implementation**

| Course (Term) | Reflection Resources and Artifacts |
|---|---|
| Course 1 (Fall 2023) | • Focus area<br>• Rubric<br>• Videos on metacognition and reflection, monitoring, and evaluating (participant granted access via Canvas before Reflection 2)<br>• Video on Planning (participant granted access via Canvas before Reflection 3) |
| Course 2 (Fall 2024) | • Focus area<br>• Rubric<br>• Deep dive document on learning strategies<br>• Videos on metacognition & reflection and monitoring<br>• Feedback on prior reflections |
| Course 3 (Spring 2025) | • Focus area<br>• Rubric<br>• Deep dive document on learning strategies<br>• Videos on metacognition & reflection, monitoring, evaluating, and planning<br>• Feedback on prior reflections<br>• Videos from peers about value of reflection |
| Course 4 (Fall 2025) | • Focus area<br>• Rubric<br>• Flowchart version of rubric<br>• Deep dive document on learning strategies<br>• Videos on metacognition & reflection, monitoring, evaluating, and planning<br>• Feedback on prior reflections<br>• Videos from peers about value of reflection |

### *Data Collection and Analysis*

To analyze the MRS dimensions (i.e., Monitoring, Evaluating, and Planning) in Miguel's reflections, the research team iteratively revised the codebook used in previous studies [14], [30] which was based on a set of *a priori* codes developed by Ku and Ho [23]. The short version of the codebook is shown in Table 5. The level of abstraction expected in a student's response is also noted. "Concrete" entails stating factual things, "Semi-abstract" requires some sense-making of concrete facts, and "Abstract" indicates a deeper level of sense-making. The level of student engagement with each element of an MRS was assigned using the revised codebook. "None" was assigned when there was no evidence of the description of an MRS element in the participant response. "Vague" was assigned when information relating to an MRS element was superficial. And "Sufficient Detailed" was assigned when participant had high engagement with an MRS element [14].

**Table 5. A priori coding scheme for metacognitive regulation strategies – short version [23], [30]**

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

An example of Miguel's response to the "Evaluating" prompt is provided below with labels indicating the elements found by the research team.

> [Action] *I reviewed lecture notes, watched tutorials, and practiced with smaller datasets*.
> [Assessment] *These steps helped me understand the basics better. Practicing on smaller problems was helpful, but I still struggled with more complex formulas.*
> [Change/confirmation] *I learned that breaking big problems into smaller steps works well, but I also need to ask for help sooner when I'm stuck. This approach has taught me a better way to handle challenges and balance self-study with seeking support.*

From the example above, Miguel's engagement with the "Action" element of Evaluating was coded as "Vague" because it was not reproducible. The engagement did not provide details on what topic was reviewed, or what was sought in the videos. Participant's engagement with the "Assessment" of their action was also coded as "Vague" because there was no evidence for *how* practicing with a smaller dataset helped. However, the participant's engagement with the "change/confirmation" of thinking was coded as "Sufficient Detail" because there was clear expression of belief.

Similar to a previous study [14], the levels of engagement in the elements of an MRS were translated to a score and then to a rating as shown in Table 6. To compute an MRS score, each None was assigned a zero, a Vague was assigned a one, and a Sufficient Detail assigned a two. For the example above, the participant received a rating of Developing (D) (for two Vagues and one Sufficient Detail; score = 4) for their use of Evaluating.

**Table 6. 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 (I) | 2 – 3 | 2 |
| No Attempt (N) | 0 – 1 | 0 – 1 |

To ensure the reliability of the study outcome, two novice coders (Coder A and Coder B) involved in the research underwent multiple rounds of coding training across the three MRSs and using data from the larger study. Specifically, Coder A underwent training on Monitoring with Coder C, the expert coder and principal investigator (PI). Coder B underwent training on Evaluating and Planning with Coder C. At the end of the training, the inter-rater reliability (IRR) for applying the codes ranged between 80% and 100%.

## Results

Reflection responses were coded for level of engagement in the MRSs. The results are presented in the order of MRS prompts (i.e., Monitoring, Evaluating, and Planning) as shown in Table 7 and Figures 2-4.

An overview of Miguel's ratings for each MRS are shown in Table 7. For each MRS, the participant's initial engagement at the beginning of the study was at the Insufficient Evidence (IE) rating. The results for each MRS are shown in detail in Figures 2-4. Overall, Miguel improved his engagement with Evaluating and Planning more than Monitoring.

**Table 7. Overview of Miguel's use of MRSs**

| Course (Term) | No. Reflections Implemented | Ratings [a] | | |
|---|---|---|---|---|
| | | Monitoring | Evaluating | Planning |
| Course 1 (Fall 2023) | 3 | IE, IE, NS[b] | IE, IE, NS | IE, IE, NS |
| Course 2 (Fall 2024) | 4 | IE, D, E, E | U[c], D, D, E | U, U, P, E |
| Course 3 (Spring 2025) | 4 | E, NA, E, D | E, IE, D, D | P, IE, D, D |
| Course 4 (Fall 2025) | 3 | E, E, E | D, E, D | D, E, E |

[a] See Table 6 for Ratings
[b] NS indicated Miguel did not submit a reflection
[c] U indicates that this part of the reflection was unassigned

### *Monitoring*

Miguel exhibited different ratings in engagement with Monitoring as a metacognitive regulation strategy. As shown in Figure 2, Miguel had a "not so significant" movement from ratings of

Insufficient Evidence to Emerging. Across the period of exposure to guided reflections and resources for support, about half (7 out of 13; 53%) of Miguel's engagements with Monitoring were rated Emerging . There was a very limited demonstration of higher proficiency ("Developing or Proficient).

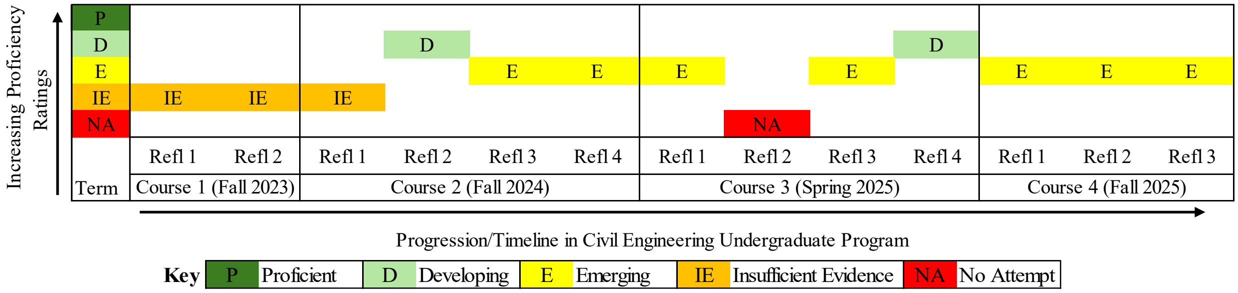


**Figure 2. Miguel's Ratings in the Use of Monitoring across Four Courses**

At the beginning of exposures to guided reflection during Course 1 (Fall 2023), Miguel's response was as shown below and coded:

> [Difficulty – Vague] *Misuse of time has to be the biggest thing I need to work on.* [Experience – Vague] *There are often times I put things off into a time where I often end up stressed and worried about completing it. This often interferes with my learning as I forget to do assignments, because I am preoccupied doing other assignments I put off."*

This reflection, like other early reflections, lacked some elements of Monitoring. For the elements that were present, Miguel's reflections were Vague. Except for Reflection 2 in Course 2, Miguel did not include the Standard element in his reflections.

For the most prominent rating for Miguel was Emerging (7 out of 13, Figure 2). An example of an Emerging rated reflection (Course 4, Reflection 3) is presented below.

> [Difficulty – Sufficient Detail] *One difficulty I was most concerned about in this Structures class was keeping the equations and steps straight during slope-deflection and moment calculations.* [Experience – Vague] *These comments showed me that I sometimes mixed up formulas or copied the wrong value when moving to the next step.* [Identification – Vague] *I knew I was having this problem because I often got the right idea at the beginning but lost accuracy in the middle of the long calculations. The mistakes usually showed up when signs flipped, when I carried values from a previous step, or when I rushed and skipped writing out a full equation.*

Miguel did not engage with all elements of the Monitoring strategy. This reflection, like many others, was missing the Standard element. Like other reflections rated as Emerging, Miguel often did not achieve Sufficient Detail in more than one element of Monitoring. For instance, Miguel rarely clearly described how his learning concerns were identified. However, Miguel demonstrated improved ability to identify a learning concern by providing sufficient detail for the Difficulty element of Monitoring (8 out of 10 reflections) from Reflection 2 Course 2 to Reflection 3 Course 4.

*Evaluating*

As shown in Figure 3, Miguel's initial reflections were rated Insufficient Evidence for the Evaluating MRS, but were more often rated as Developing across the remaining period of the study.

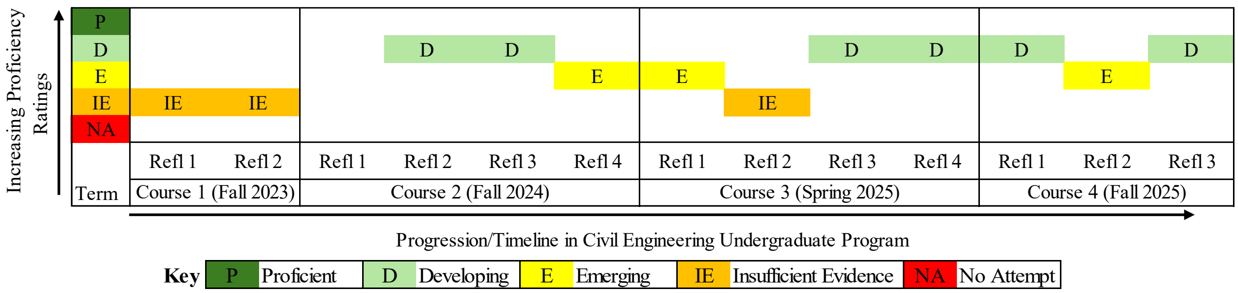


**Figure 3. Miguel's Rating in the Use of Evaluating across Four Courses**

In Reflection 2 of Course 1 (Fall 2023), Miguel's response was coded as follows:

> [Assessment – Vague] *I have managed to successfully solve this* [Actions – Vague] *by finding more time outside of class to be able to solve this adequately. I had tried to spend less time in regards to looking things up and trying to manually forcibly understand things,* [Assessment – Vague] *but this only delayed me worse and did not work.*

The reflection, like others at lower proficiency, lacked an element of the Evaluating, in this case Change/Confirmation. Other Evaluating elements that were present in Miguel's reflections were Vague.

An example (Course 4, Reflection 1) of a reflection rated as Developing for Evaluating is presented below.

> [Actions – Sufficient Detail] *I fixed it by doing a quick pre-check at the top of every problem. I write my sign rules (+x right, +y up, +M CCW). I list each support and its reactions (roller = V only, pin = H+V, fixed = H+V+M). I mark any internal hinge with M=0 and plan to split the body there. I ask three questions: can it move in x? in y? rotate? I also do a one-line count: r = external reactions, e = 3 + number of hinge conditions. For hinge cases I draw two FBDs with the action reaction pair.* [Assessment – Sufficient Detail] *When I follow this, I catch the three-roller beam as unstable, my Problem 2 sums balance, and I stop adding a fake horizontal at a pin on rollers. My time drops to roughly 10 min per problem. When I skip the pre-check, the old mistakes come back.* [Change/Confirmation – Vague] *What I learned: check stability first; a hinge gives M=0, not reactions; and a pin on rollers acts like a roller. Writing the signs first prevents moment sign mix-ups.*

The reflection had all of the Evaluating elements. However, the element of Change/Confirmation in belief did not indicate future use, hence the Vague code. Miguel may have had difficulty with conceptualizing a belief because all evaluating reflections were either vague or lacking a belief except for Reflection 2 in Course 2 (Fall 2024).

### *Planning*

As shown in Figure 4, and similar to Monitoring and Evaluating, Miguel's initial Planning reflections were rated as "Insufficient Evidence." While Miguel achieved ratings of Proficient and Developing on some reflections, others were intermittently rated lower.

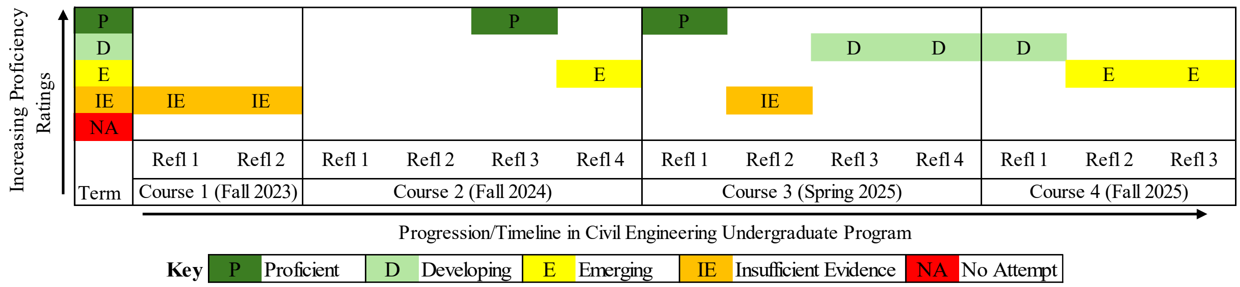

**Figure 4. Miguel's Ratings in the Use of Planning across Four Courses**

One common finding across the study was that Miguel did not define a Goal in each reflection rated as "Insufficient Evidence" (IE) or "Emerging" (E) for Planning. Another common finding was that Miguel attempted Justification of Steps across the study. Yet, most justifications were Vague, except for Reflection 3 Course 2 and Reflection 1 Course 3. The vagueness in Justification was largely due to the absence of the Goal element in Planning. An example from Reflection 2 in Course 4 is presented below.

> *I am still working on this difficulty.* [Steps – Sufficient Detail] *My plan is to slow down and spend at least 15 extra minutes on each problem checking my free body diagrams and equations. I will compare my steps with class notes and solution examples to make sure my work balances before moving forward. I believe* [Justification – Vague] *this plan will help because it forces me to catch mistakes early and build better habits for solving structural problems.*

The reflection above, just like similar submissions, showed that Miguel substituted Steps for the Goal. Except for reflections with Insufficient Evidence ratings with Planning, all other Planning reflections had Sufficiently Detail for Steps.

An example (Course 2, Reflection 3) of Miguel's Proficient engagement with the Planning dimension of MRS is presented below.

> *I learned the value of starting small and building up, but I also realized I need to ask for help sooner.* [Goal – Sufficient Detail] *By semester's end, I will confidently Group By to organize data by three columns and create accurate summaries.* [Steps – Sufficient Detail] *My next steps are: Meet with my instructor or peers for help. Practice grouping data for one hour weekly. Write a simple guide to remember the steps. …* [Justification – Sufficient Detail] *Asking for help clears confusion, while regular practice and a guide build confidence for future tasks.*

Here, Miguel provided Sufficient Detail for all elements of Planning. This proficiency indicated that Miguel's exposure to multiple reflections allowed him to attain a maximum level of engagement with elements of the Planning strategy.

### *Overall Engagement with Abstraction (Sensemaking)*

Overall, when the abstraction elements across various MRS are considered, Miguel did not show development in sense-making. Using the *a priori* coding scheme in Table 5, the elements that require a level of abstraction are Standard (Monitoring), Confirmation/change of belief (Evaluating), and Justification (Planning). Across the study, Miguel's reflections were predominantly coded as Vague or None for these abstract elements. An example of a Vague abstraction is as follows.

> [Standard – Vague] *The assignment focused on mastering tools like INDEX/MATCH to work with data effectively. Struggling with this affected my ability to meet this goal.*

Here, the participant made reference to working with data effectively but misses adding why that is important.

Another example of vague abstraction is as follows.

> *I think* [Justification – Vague] *this will help because these habits already worked during Homework 6. They helped me stay organized and spot mistakes before they caused wrong answers. Since real engineering problems are often even more complex, these strategies will help me stay accurate and confident when solving them.*

Here, the Justification should link specific Steps with the Goal. Rather, the Justification was focused on why the steps were good.

Resources were provided to support Miguel's understanding of reflection requirements for proficiency in MRSs. However, there was no evidence of Miguel's engagement with the resources beyond possibly the instructions for each reflection. Out of the four videos available (Table 4) to students during reflection implementation, Miguel had a single view of the Metacognition and Reflection video (30% playtime). The percentage of playtime across the remaining videos was cumulatively about 10%. This means that Miguel never received any formal instruction on the MRSs and may have relied on classroom instruction or instructor or AI feedback to guide improvement.

## Discussion

This study investigated how a student developed in his use of metacognitive regulation strategies when engaged in structured reflections embedded in a civil engineering core curriculum. The investigation was directed towards uncovering the development of the ability of a civil engineering student to self-regulate learning, a skill that will be useful for critical thinking and lifelong learning as required in engineering practice.

Regarding the research question, multiple exposures to guided reflections can lead to improved use of the MRSs. For instance, all Miguel's reflections in the Course 1 (Fall 2023) were lacking some elements across each MRS. However, Miguel being able to attain higher ratings with each MRSs at some point in the study may suggest that consistent engagement in formal reflection can help civil engineering students develop critical thinking skills. Miguel showed a slight improvement over the use of MRSs in Schwab et al. [14] where two cohorts were exposed to the same guided reflections embedded in courses over just two terms. Miguel's greater number of reflections across four courses may explain the greater improvement in the use of the MRSs.

Effective use of MRSs requires engineering students develop their ability with abstraction (sense-making). Each MRS has an abstract element – which implies that proficiency in the use of MRSs require that students develop the capability to abstract. Miguel's lack of development in abstraction was reflected in the rating of the MRSs. Miguels' poor abstraction was similar to the reflections by the majority of Cohort 1 participants in [14] and all participants in [30]. In Ku and Ho's [23] study that examined college students' use of MRSs, high performance students were found to demonstrate sensemaking through connecting with standards (monitoring), using procedural knowledge to conceptualize detailed action (planning), and self-evaluations that led to revision of thoughts (evaluating). Ku and Ho further noted that "skilled thinkers paid more attention to reviewing their reasoning and conclusions during on-going execution of tasks to make sure their performance met the task goals" [23, p. 262]. This level of thinking is what compounds over time to form critical thinking skills for professionals. Through reflection, experts use critical thinking to make sense of emerging challenges – a skill that further differentiates expert from novices in professional practice [7]. For this civil engineering student to develop critical thinking skills, there must be improvement in the ability to make sense of tasks, difficulties, and situations beyond the familiar and concrete.

Attainment of and sustained proficiency in the use of MRS requires student commitment. During the study, Miguel demonstrated engaging in higher ratings in MRSs. But the higher ratings were not sustained across the study. Miguel's proficiency regressed on two of the three MRSs. The regression may be linked to the lack of evidence that Miguel used instructional resources that could have helped his understanding of the MRS elements. The provision of resources, clarifications, and guidance were in alignment with Hattie and Donoghue's [31] and Pressley et al.'s [18] position that the development of skills relating to metacognition require guided and student-centered approaches. Zimmerman [32] noted that teachers must not allow their assistance to undermine the self-awareness and involvement that a student needs in developing the capability to self-regulate learning.

**Implications for Developing Student Use of MRS for Self-Regulated Learning**

There are a few implications from this study that can be useful for students, instructors, engineering education researchers, and administrative officers in higher education. The findings from this study suggested that for a student to self-regulate learning and develop critical thinking skills, there must be repeated and guided exposures to reflection. This study has shown that a student can attain proficiency in MRSs under repeated and guided exposure to reflections.

However, certain questions will need to be answered. When a student attains proficient engagement with MRSs, how can the development be sustained? What would a program-wide adoption of reflection look like for undergraduate students in civil engineering programs? What impact would a program-wide implementation of reflection have on sustaining proficiency in MRSs?

The key takeaway from this study is that a student must be guided to provide detailed writing that helps thinking through experiences, difficulties, what success looks like, and how to attain success. Such detailed writing will also be useful for becoming good communicators with all stakeholders in the field of engineering. In addition, an engineering student must develop the ability to abstract or conceptualize ideas beyond just describing concrete incidents, steps, or physical systems. A civil engineering student must become self-aware and critical by asking questions like, why are the learning expectations useful/valuable to me (standard)? What is new or reinforced from the outcome of my attempts to handle this difficulty (change/confirmation)? Why would potential actions help me attain my goals (justification)?

**Limitations**

This study investigated how a student developed in their use of MRSs when exposed to guided reflections in four courses in civil engineering undergraduate curriculum. However, there are limitations that should be considered regarding the generalization of findings from this study. These limitations relate to the methods, specifically the number of participants, setting of the study, and other data. First, a single case was useful in understanding how a student developed in the use of MRS. However, the findings cannot be generalized for all civil engineering students. Further studies (such as a multi-case study) will be required to understand how civil engineering students with different demographics develop in their use of the MRSs.

Second, the setting of the study was also a limitation. For instance, the course content and assignments that anchored reflections may have impacted students' engagement with reflection. Instructors varying level of experience with reflection and engagement with reflection in the classroom may also have considerable effect on students' engagement in reflection. Similar studies set in different courses with different instructors at different institutions may yield different results.

Finally, the data used in the study may not be sufficient to establish causality for the trends in Miguel's use of the MRSs. For instance, Miguel's knowledge and use of learning strategies were not considered in conjunction with the use of the MRSs. Instructors' perception of using reflection may also be useful context for the student's use of the MRSs. Additional data, such as student motivation for engaging in reflections may also be evidence of causality. The larger study will use more data to provide insight into the use of reflections to develop civil engineering students' capacity for engaging in metacognitive regulation.

**Conclusion**

The focus of this study was to understand how one civil engineering student developed in their use of metacognition regulation strategies over an extended period and multiple engineering courses in which theory-bound guided reflections were embedded. A qualitative analysis was used to explore the participant's engagement with the dimensions of MRS (i.e., monitoring, evaluating, and planning). The exploration revealed some improvement in the student's use of the MRSs in their reflections over an extended period of time. However, for the student to achieve effective use of MRSs, there must be improvement in abstraction ( sensemaking).

Future studies may examine a larger number of students' development in their use of MRS over extended exposure to guided reflections. Such longitudinal studies can uncover the impact of engagement with resources for guided reflections in undergraduate civil engineering program. The outcome may also be useful in informing instructors and program administrators on the direction to follow towards a program-wide implementation of guided reflections.

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