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Reflection for Development of Metacognitive Regulation Strategies: A Two-Year Implementation Study

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Abstract

Engineering students need to develop lifelong learning skills (ABET 7) so that they can be self-directed learners who employ metacognitive regulation strategies (MRSs, i.e., monitoring, evaluating, planning). A way to develop MRSs is open-ended reflection that encourages students' critical thinking of their learning processes. Embedding reflection in engineering coursework is challenging. This study had two purposes, to examine (1) changes in the MRSs that students used in reflections across two semesters and (2) differences in students' MRSs when instructors were new to versus their second year of reflection implementation. At a large midwestern university, this study took place in two sequential courses with two cohorts of students who participated in written reflections alongside engineering coursework. Cohort 1 was taught by two instructors new to implementation, while Cohort 2 was taught by the same instructors in their second year of implementation. Two reflections from each course offering were qualitatively analyzed using an *a priori* coding scheme for assessing students' engagement in the MRSs. Comparisons were made (1) within cohorts to detect changes across two semesters, and (2) between cohorts to detect differences that can be related to changes in instruction. For some MRS elements, students' engagement slightly increased across semesters for both cohorts. There were some element differences across Cohorts. Recommendations for reflection implementation are shared.

Keywords: Reflection, Metacognition, Qualitative, Undergraduate

I. Introduction

One of the main goals of higher education is to help students develop autonomy regarding learning and thinking. Students who achieve this goal develop skills that can be translated to future environments such as the workplace, academia, and other situations requiring problem-solving. Students who achieve this goal are prepared to be lifelong learners; graduates capable of engaging in the continuous process of learning on one's own while increasing one's understanding of their thinking processes. In engineering, the development of students' lifelong learning skills is promoted through accreditation by ABET Criterion 3 Student Outcome 7 which requires graduates develop an "ability to acquire and apply new knowledge as needed, using appropriate learning strategies" [1].

A way students grow as lifelong learners is through development of their metacognitive abilities, which has been generally defined as "thinking about thinking." By developing their metacognition, students gain critical thinking skills while completing tasks, plans, actions, and challenges. In the classroom, studies have found students with higher metacognitive skills have greater success when problem solving [2]. Even when the problem was unfamiliar and non-routine, those with lifelong learning traits were able to translate their previous experiences in problem solving to that new problem.

One instructional strategy used to develop students' metacognitive abilities is reflection. Reflective activities have been implemented in numerous engineering classrooms (e.g., [3]). Despite a noted uptick in attention to reflection in engineering in recent years [4], it is also noted that instructors find implementation challenging in terms of time, knowledge of reflection and metacognition, and student perceptions of reflection [5], though instructors also recognize benefits for student learning.

Prior research by the authors [6], [7] have shown that students' metacognitive skills are generally low during the first semester students are exposed to reflection. Little research has been done to track students' metacognitive skill development across more than one semester. Further, little research has been done to investigate whether metacognitive skill development in a course changes with instructor experience with implementing reflection.

This study had two purposes. The first purpose of this study was to observe and analyze how students' levels of engagement in metacognitive regulation strategies (MRSs) change over two semesters. The second purpose was to gain insight concerning differences across students' levels of employment of MRSs when instructors were new to reflection compared to when instructors were in their second year of reflection implementation. From this insight, better resources can be developed and provided to new engineering instructors to implement reflections and help students develop MRSs.

II. Literature Review

Metacognitive regulation strategies (MRSs) entail monitoring, evaluating, and planning [8] and include the effective selection and use of various learning strategies. Students' development of MRSs can explain the differences in their performance when solving an unfamiliar problem [6]. In one study, when given an opportunity to apply problem-solving strategies, middle-school students with higher metacognitive skills found multiple appropriate strategies and were more successful at problem solving than their peers with lower metacognitive skills. Those with lower metacognitive skills experienced greater difficulty in understanding the problem as well as identifying appropriate problem-solving strategies. In another study, university students who self-reported engagement in MRSs improved their learning outcomes, especially in assessments [8]. In [8], the researchers discussed the importance of informing students of the benefits of applying metacognitive strategies during their learning, as half of the participants were focused on cognitive understanding. This supports the need to increase support for students' awareness and understanding of their learning through the development of their metacognition regulation strategies.

Students who can regulate their learning are more proactive, engaged, and resourceful [9]. By being proactive and actively engaging in the use of various learning strategies, students become prepared to transfer MRSs into the workplace and additional learning environments. For workplaces, these MRSs provide a smooth transition of learning on the job when learning new processes and roles. Within the workplace, it has been observed that the transition from dependent to independent learning has been more successful for students who have greater reflective and metacognitive skills [10]. Another example can be found in [11], where students collaborated on semester-long projects with local industry partners. In this course-based study, students wrote both post-project reflections and memos focused on how they problem-solved during the projects. Researchers found an increase in students' understanding of their learning and the strategies they can use to work through problems. Similarly, in the current study, coursework provided the anchor for reflections.

The three main strategies of metacognitive regulation, Monitoring, Evaluating, and Planning, can be observed, as demonstrated by Ku and Ho [9] who developed a coding scheme for determining low- and high-level engagement in each of MRS during think-alouds focused on problem-solving scenarios. Low levels across the MRSs translated to an awareness or recognition of a difficulty or need to check for understanding or plan. High-level use of the MRSs were indicated with the supply of further details, a description of the difficulty (Monitoring), thoughts on progress (Evaluating), and an identification of actions (Planning). Ku & Ho's coding scheme [9] has been adapted to investigate students' level of use of MRSs when writing reflections on coursework [10], [11]. The levels of detail were clarified and the scale expanded to low, medium, and high usage of MRSs in [7]. The coding scheme was again revised to distinguish the elements of each MRS [6]. For example, planning elements include goal setting, actions to achieve the goal and justification for choices made. These elements could then each be evaluated for detail (i.e., "none", "vague", and "sufficiently detailed"). The resulting coding scheme was used both as a research tool and a rubric guide for giving specific feedback to students to increase their levels of detail and engagement in the MRSs [11]. This study showed small improvements in students' use of the MRSs while reflecting on their third- and tenth-week assignments. The coding scheme enabled pinpointing of the elements that did and did not change. Still, the students' responses were still found to be "vague", or at the low engagement level. The current study uses the coding scheme.

Evidence across students' development of MRSs has been surmised to be a slow process. Many studies have found little to no gains in metacognitive skills as a result of single intervention or multiple interventions within a single course [11]. To gain an understanding of changes in students' levels of engagement over time, a longitudinal cohort study of students MRSs while engaged in written reflection on coursework was deployed in this study.

Another perspective of reflection assignments is the context in which reflection instruction and implementation is done and how that may affect students' understanding of the reflections. There has been previous work on the instructors' point of view of the implementation as well as reflecting on the reflections [12], [13]. In other cases, the importance of instructor follow-up [14] and purposeful, guiding intervention has been discussed [15], as simply giving students resources isn't enough. For students in another study, the frame of rating the effectiveness of the reflections was in the lens of students improving their weaknesses to 'master' specific topics of the course, where students with reflection assignments based on their feedback tended to have higher quality final projects compared to their peers with no reflection [16]. Specific courses previously studied in relation to the implementation of reflections in the engineering classroom include capstone design [17], heat transfer [18], and engineering service-learning [19], [20], [21]. Though each of these studies provides a different perspective on reflection in the classroom, there is limited literature on the impact of engineering instructors' experience with reflection implementation on students' metacognitive development. This study examines two cohorts of students with the same instructors to examine the impact of experience with reflection on students' use of MRSs.

III. Research Questions

This study addressed the following research questions:

1. Did engineering students' levels of engagement in metacognitive regulation strategies change over two semesters?
2. Were there differences in students' employment of the MRSs when the instructors were new to reflection and in their second year of reflection implementation?

IV. Methods

A. Setting and Participants

This specific study was conducted as part of a larger IRB approved research project at a large midwestern R1 university in two separate engineering courses offered sequentially in the spring (16 weeks) and fall (16 weeks), Course 1 and Course 2, respectively. Course 1 was a first-year course offered in Spring. Course 2 was a sophomore level course offered in Fall. Both courses were required for students within two different degree programs within the same department. While Course 1 is not a prerequisite for Course 2, the Course 1 to Course 2 sequence is typical for most students.

Course Backgrounds

The main objectives for Course 1 were to use knowledge, skills, and modern tools to solve science and engineering-related problems. Main topics included using graphical methods, Excel functions and spreadsheets, MATLAB commands and functions, and the engineering problem-solving process. Course 1 also emphasized effective technical communication of processes and solutions. In this course, students' course grades depended on eight components: attendance/participation, homework (including reflection), pre-class quizzes, project milestones, project poster, project report, performance as team member, and a class survey. The written reflection comprised 2.2% of the course grade in Spring 2023 and 3% in Spring 2024. In Spring 2023, the research team assessed students' reflections. In Spring 2024, the instructor, supported by two undergraduate teaching assistants, assessed students' reflections.

Course 2's main objective was to identify, describe, analyze, and interpret various engineering properties of biological materials. Course topics were units, dimensions, aspects' effect on material function, and experiment development and conduction. In this course, students expanded on physical properties to design various systems (e.g. harvesting, storage, processing) and measurement techniques (e.g. frictional effects, strength, moisture content, and thermal conductivity). In this course, the assignments that comprised the course grade in Fall 2023 and 2024 were lab memos, homework, class activities, individual projects, final project, and reflections. The written reflections comprised 10% of the course grade in Fall 2023 and 7% in Fall 2024. The instructor assessed students' reflections in both years.

In Spring 2023 Course 1 made no explicit reference to reflections on the syllabus. While in Fall 2023, Course 2 stated on the course syllabus a specific objective for students to develop and engage in reflective practices in monitoring, evaluating, and planning. The reflective piece was further elaborated in the syllabus under a section named 'REFLECTIONS' where the instructor explained how reflective practices develop thinking and abilities. In Spring 2024, in its syllabus, Course 1 adopted a similar "REFLECTIONS" description and made explicit reference to reflections in the grading scheme. In Fall 2024, Course 2 maintained its reflection learning objective and "REFLECTIONS" text.

Cohort Participants

Student enrollments in the courses are shown in Table 1. To make comparisons across semesters, cohorts were established from the enrolled and research-study consenting students. A cohort consisted of students who completed the two written reflections in each course that were analyzed in this study. Cohort 1 had 19 students while Cohort 2 had 22 students. Student self-reported demographics are shown for students retained in the study only; demographic information for non-consenting students were often incomplete, particularly in regard to first-year status and race/ethnicity. As was expected for a required first-year to second-year course sequence, study Cohort 1 had a majority (84%) of first-year students in Spring 2023 who were then second-year students in Fall 2023. Similarly, study Cohort 2 had a majority (82%) of first-year students in Spring 2024 who were then second-year students in Fall 2024. The male to female ratio was representative of the program enrollments which included a program emphasis area with a high percentage of females. Those retained in the study may have over-represented the white demographic group.

Table 1. Cohort Demographics

	Cohort 1		**Cohort 2**	
Course & Semester	Course 1 Spring 2023	Course 2 Fall 2023	Course 1 Spring 2024	Course 2 Fall 2024
No. Students Enrolled	77	65	48	49
No. Students Enrolled	56		38	
No. Students Consenting	30		24	
No. Students in Study	19		22	
No. First-Year in Course 1	16 (84%)		18 (82%)	
No. Male / Female	8 / 11 = 0.7		14 / 8 = 1.8	
No. White / Other	16 / 3 = 5.3		20 / 2 = 10.0	

Instructors

There were two instructors: one for Course 1 and one for Course 2. They were the primary leads in their respective courses. They remained the same for both course offerings. Initially, the instructors attended a pre-semester workshop offered by the research team that motivated reflection integration and oriented them to implementing reflection in their courses. In year two, this workshop highlighted some lessons learned and results from the prior year. Through an online Canvas Free course, instructors were encouraged to practice what they learned by attempting to grade sample student reflections. Both instructors completed some of this training in their first year and returned in the second year to review or complete more. Starting in Fall

2023, the instructors watched video content explaining each MRS through example student reflections. A member of the research team checked in with the instructors periodically across the semesters in which reflection was implemented.

B. Reflection Implementation

To observe changes in students' engagement in the MRSs, both courses included written reflections linked to specific coursework. Table 2 summarizes the reflection implementation by cohort. Between cohorts, the courses had a similar number of reflections implemented. Reflections were assigned and graded via Canvas, a learning management system that students used for their coursework. Each course implemented reflection in association with different assignment types. Researchers have called this reflection-coursework linkage 'anchoring,' wherein students complete a typical engineering assignment and a separate reflection prompts students to reflect on a difficult aspect of the assignment [22]. For Cohort 1, Course 1 anchored the reflections in project milestones and Course 2 anchored them to lab reports. For Cohort 2, Course 1 anchored the reflections to homework of basic statistics and computational tools while Course 2 anchored them to lab reports. The Course 1 instructor felt the reflections were better implemented in conjunction with assignments that emphasized learning basic skills, some of which were then used in project.

Table 2. Cohort and Course Reflection Implementation

	Cohort 1		**Cohort 2**	
Course & Semester	Course 1 Spring 2023	Course 2 Fall 2023	Course 1 Spring 2024	Course 2 Fall 2024
Assignment Anchors	Project milestones	Lab reports	Homework	Lab reports
No. Reflections Implemented	5	6	5	6
Reflections Coded	Ref. 2, Ref. 4	Ref. 3, Ref. 5	Ref. 2, Ref. 5	Ref. 2, Ref. 5

Following the submission of an anchor assignment, students were assigned the associated reflection. Students typically had two days to complete the reflection. For each reflection, students were asked three questions, each corresponding to a metacognition regulation strategy (i.e., Monitoring, Evaluating, Planning). The Monitoring and Evaluating strategies had consistent prompts for both cohorts, while the Planning dimension differed. The following prompts were given for the Monitoring and Evaluating strategies in each reflection assigned.

> Monitoring: 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.
>
> Evaluating: How have you tried to overcome this difficulty? Include a description of how your approaches have been successful or unsuccessful and what you learned.

The following prompt was given to Cohort 1 for the Planning strategy.

> Respond to ONE of the prompts below, NOT BOTH:
> 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.

OR
If you were successful in addressing this difficulty: Discuss when and how you might use these approaches in the future.

Students seemed to have difficulty understanding the expectations for the prompts. For Cohort 2, the alterative prompt was reworded to provide additional direction for planning.

Respond to ONE of the prompts below, NOT BOTH:
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.
OR
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.

Each semester, expectations for writing reflections were set via a detailed rubric describing what each metacognitive element should entail. The rubric was posted on Canvas as a document and was pointed to in each reflection assigned. An example rubric is shown in the Appendix Table 1A. Table 3 shows a short-hand version of this rubric for easy reference. For Cohort 1, the Planning - Application element was used to assess students' responses to the Planning alternative response, which was used when students felt they had successfully addressed their difficulty. For Cohort 2, regardless of the Planning prompt, students' responses were to have the Goals, Steps, and Justifies elements, meaning the Application element was removed from the rubric. Within Canvas, for each reflection, students received ratings for Monitoring, Evaluating, and Planning as well as rubric aligned written feedback.

Table 3. Simplified Version of Rubric for Students

Dimension	**Element**	**Developing**	**Emerging**	**Insufficient Evidence (IE)**	**No Attempt**
		Minimum Element Assessments			
Monitoring	Difficulty Experience Identification Standard	2 SD[a]+2 V[b] OR 3 SD	1 SD+2 V OR 2 SD	2 V	Not enough for IE OR Nothing written in this regard
Evaluating	Actions Assessment Change/ Confirmation	1 SD + 2 V OR 2 SD	1 SD+ 1 V OR 3 V	2 V	Not enough for IE OR Nothing written in this regard
Planning	Goal Steps Justifies **OR** Application (Cohort 1 only)	1 SD + 2 V OR 2 SD **OR** SD	1 SD+ 1 V OR 3 V **NA**	2 V **OR** V	Not enough for IE OR Nothing written in this regard

[a] SD = Sufficiently Detailed, [b] V = Vague

Other than the rubric, instructors provided additional resources to familiarize students with metacognition and the reflection assignment expectations (Table 4). For Cohort 1 Course 1, resources were limited and relied predominantly on written feedback from the research team. However, after the Cohort 1 Course 1 first reflection it was evident that students were confused by some language, so hints were embedded in the instructions for reflections going forward. One hint clarified that a learning difficulty was "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)." The terms goals and actions were also differentiated.

> "*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."

For Cohort 2 Course 2, four videos were developed and made available as reference. One explained the concept of metacognition and introduced reflection; the remaining three described each of the MRSs with student assessed examples. These videos and resources were not specifically related to an assignment, but these videos used student sample work to explain the levels of engagement for each MRS.

for Cohort 2 Course 1, the video content was assigned with Reflections 1 to 3. With each reflection focusing on one MRS video and the addition of that MRS reflection prompt. The instructor also added a quizzes covering the content of the first two videos (Metacognition & Reflection and Monitoring) to better ensure students were viewing the videos.

For Cohort 2 Course 2 the video content was again made available for reference but not assigned. Course 2, a handout on deep learning strategies was made available to students in response to students indicating they were not familiar with learning strategy options. Further, to mitigate some student resistance to reflection, two peers volunteered to create videos on what they saw as the benefits of reflection, while acknowledging their initial reactions to reflection. The instructor also had the students do a team reflection in class after the first reflection to provide a means of clarifying the MRSs.

Table 4. Student Resources for Reflection

Course	**Cohort 1**	**Cohort 2**
Course 1	• Rubric • Hints added after Reflection 1	• Rubric • Videos (assigned) • Hints from Cohort 1, Course 1 • Quiz on first two videos
Course 2	• Rubric • Videos (Metacognition & Reflection, Monitoring, Evaluating, Planning) (reference) • Hints from Cohort 1, Course 1	• Rubric • Videos (reference) • Hints from Cohort 1, Course 1 • Deep learning handout • Video from peers about value of reflection • Team reflection

C. Data Collection and Analysis

The reflection data were collected and downloaded from Canvas into Excel. Consenting participants were assigned a unique research identifier for participant privacy and confidentiality. Their data was saved for analysis.

Two reflections per course (Table 1) were chosen to be coded as they took place in similar weeks of each semester (towards the middle and end of the semester), prompted students to respond to all three MRS prompts, and were not assigned one after the other. This longitudinal cohort study aimed to analyze earlier and later semester MRS levels. The researchers decided not to analyze the first reflections of each semester as they were interested in having students have some familiarity with reflections in the respective courses.

To code the reflection data, this study used an edited coding scheme based on a previous iteration of analyzing reflection [6] (Table 5). The MRS elements were identified in each student response and color-coded based on the dimension they connected to. After the elements were identified, each element was coded with a level of engagement based on what was written. As described in previous work [22], the "vague" level was assigned when superficial information was provided; the "none" level was assigned if there was no presence of the element; and the "sufficiently detailed" level was given to students with high engagement in their responses. An example of this is in the second reflection assignment of Course 1.

Table 5. ***A priori*** **coding scheme [20]**

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

Below is a response for the monitoring strategy that has been broken up by elements.

> [Difficulty] *I think that the difficulty that I am most concerned about right now is that I struggle with coming up with solid problem statements and objectives.*
> [Experience] *I feel like I am not getting the right information put into each one. I also feel like I am adding too much information for the problem statement or possibly already adding a solution to it. For the objectives, I feel like I just do not even know the right information to put in them.*
> [Identification] *I know that this is a difficulty because my answers in class were not similar to the examples that the professor gave us.*
> [Standard] *The Nana's cookies example was very hard for me when we did the quizzes about the problem statement and objectives.*

Continuing with this example, each Monitoring element was coded separately. The first sentence [Difficulty] states a difficulty the student was facing and was coded as a "vague" level as the student didn't elaborate or specify their learning concern beyond general topics. In the next section of sentences [Experience], the student was describing the context and experience in which the learning concern arose. This part was marked as "sufficiently detailed" because the student described their experience of the problem getting solved with feelings and greater context as to how they may have struggled in this assignment. In the third part [Identification], as the student described an indicator from a credible (i.e. professor's examples) but provided no further explain of how they knew they were having a difficulty, this text was coded "vague". For the last part [Standard], there was no explicit reference to a learning expectation or standard, so the text was marked as "none". This text actually reiterates the Difficulty and adds to the Experience. This process of analyzing and qualitatively coding students' reflections was done for each student reflection and each MRS.

To ensure the coding was robust, two novice coders worked through multiple trainings of 10 student reflections each with an experienced coder. In each coding training, the novice and expert coders would code separately for a specific MRS and then meet and compare their codings. For any differences, coders discussed and clarified definitions. One novice coder was trained to code the Monitoring responses; the inter-rater reliability results are shown in Table 6. After Training 3, the expert coder reviewed the novice coder's coding for the 'Standard' element on an additional 10 examples. IRR was 100% similarity for 10 items.

Table 6. Coder training inter-rater reliability for Monitoring.

Monitoring	Training 1	Training 2	Training 3
Difficulty	90 %	90 %	90 %
Experience	50 %	80 %	80 %
Identification	80 %	60 %	80 %
Standard	70 %	80 %	70 %

The *a priori* coding scheme was applied to all the student reflections for Cohort 1 and Cohort 2. To facilitate frequency counts of the qualitative data, the codes were translated to a score. If the student did not write anything that related to any elements in the coding scheme, students were given a 'None' (N) which was translated to zero. For 'Vague' (V), it was inputted as a one.

‘Sufficiently Detailed’ (SD) was translated to two. Visualizations of the frequency of students’ levels for each MRS element were used to make comparisons across courses and cohorts.

V. Results

In each reflection, each metacognitive regulation strategy was coded for each student. The results are presented in the order of metacognitive dimension (i.e., Monitoring, Evaluating, and Planning). Figures 1-6 show each dimension’s elements and the number of students per level of engagement in each reflection.

Monitoring. The Monitoring elements varied in levels of engagement across both courses and semesters. Cohort 1 students provided vague descriptions of their Difficulty across the reflections analyzed (Figure 1). Fifty percent or more students, described their Experience in sufficiently detail. For the Identification and Standard, students’ reflections were found to rarely write about these elements. Though, students’ use of the Standard element did increase substantially for Ref. 5.

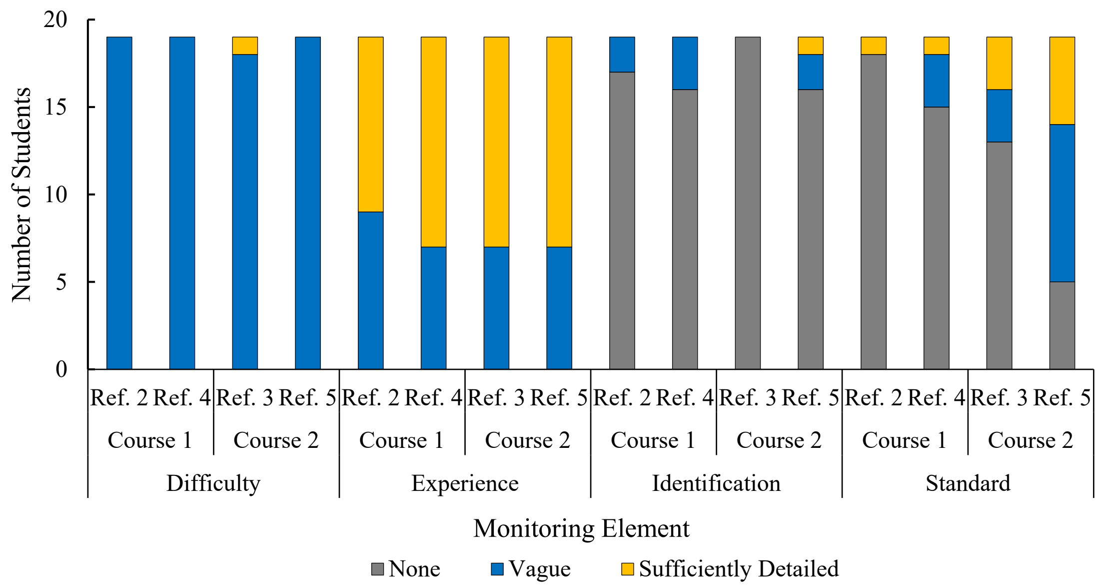

Figure 1. Monitoring Element for Cohort 1

Cohort 2 students generally provided more Monitoring details in their responses as can be seen from the greater percentage of vague and sufficient detail codes as compared to Cohort 1 (Figure 2). While students’ responses to the Difficulty element showed more sufficient detail, what is more notable is the increased inclusion of Identification and Standard in students’ reflections.

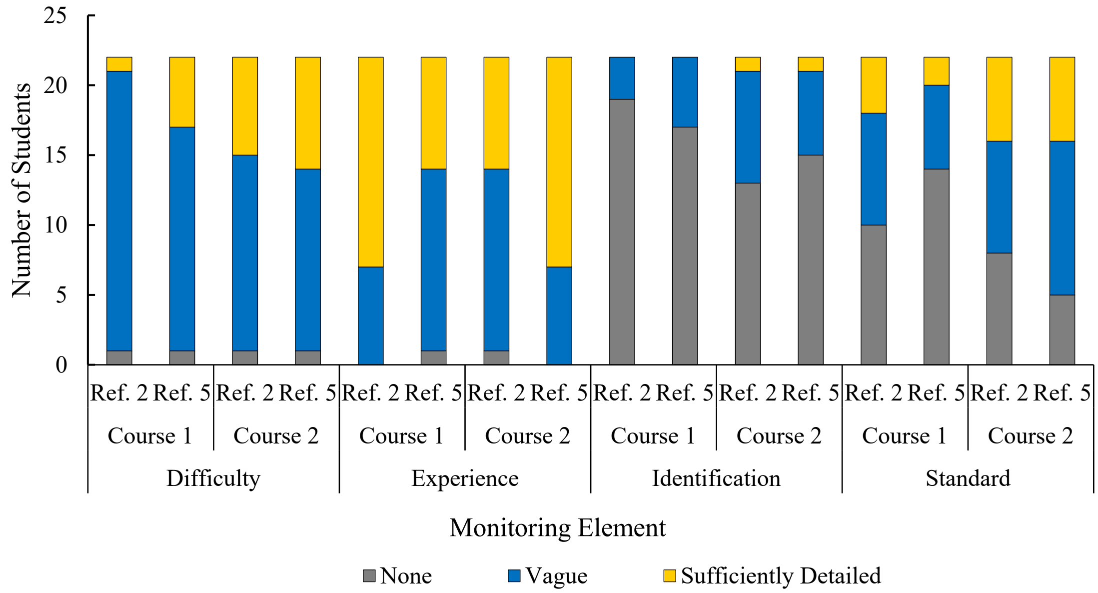

Figure 2. Monitoring Element for Cohort 2

Evaluating. For Cohort 1, students' responses to the Evaluating elements varied in levels of engagement across the two courses and all reflections (Figure 3). For this MRS, more students tended to write reflections that included all of the elements than was the case for Monitoring. For the Actions element, students' reflections were often vague. For the Assessment element, students' responses were mainly had vague with a few students not engaging in this element. A few more students did not provide a Change/Confirmation element in their reflections. Cohort 2 students' reflections were similar to those of Cohort 1 (Figure 4), though there was notably less detail provided for the Assessment element.

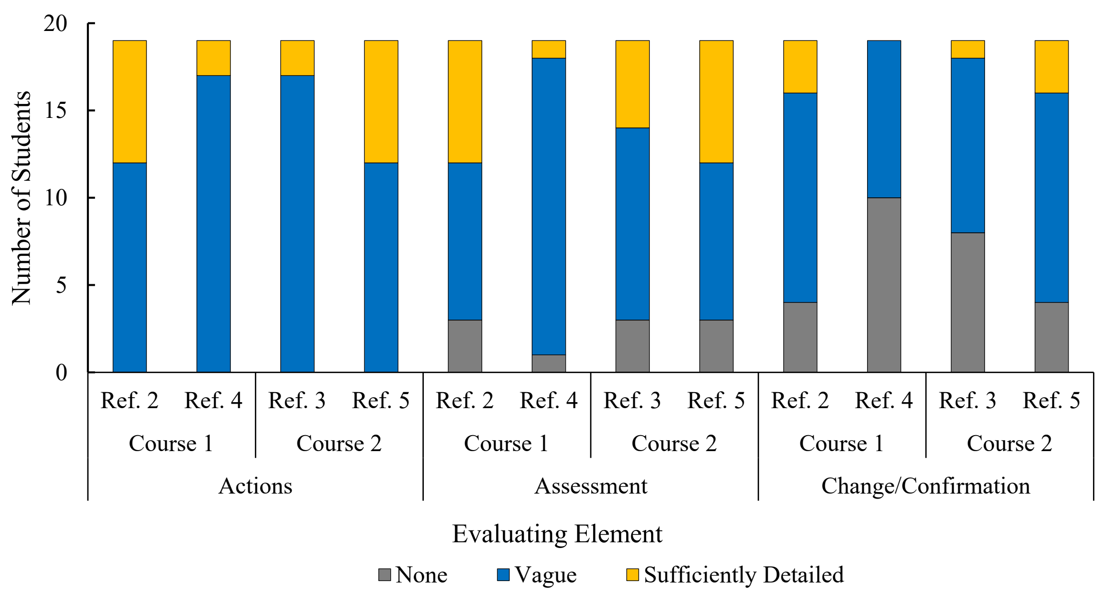

Figure 3. Evaluating Element for Cohort 1

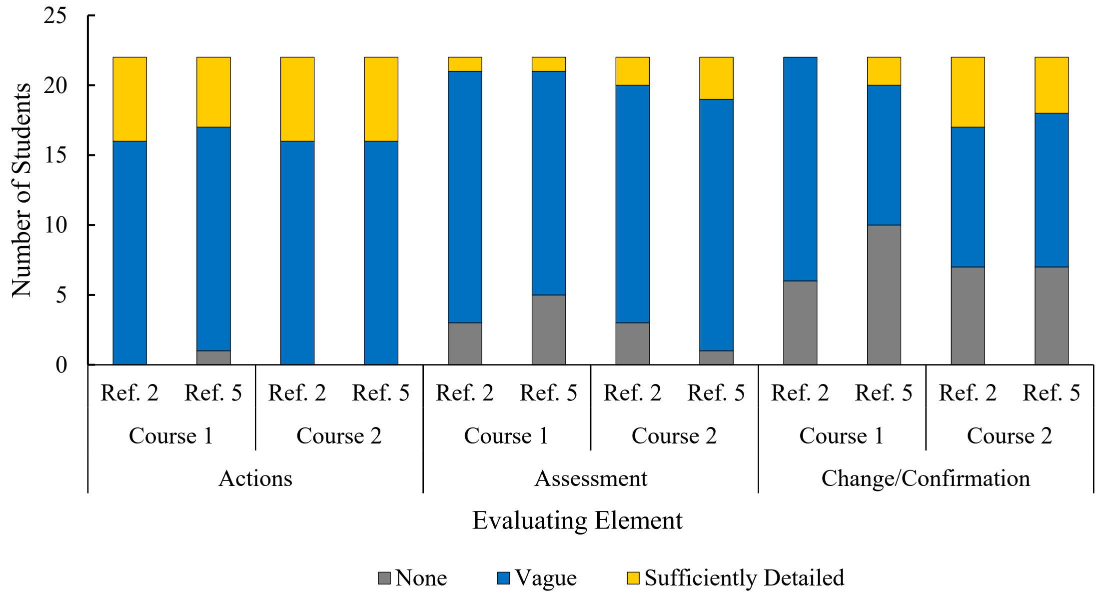

Figure 4. Evaluating Element for Cohort 2

Planning. As a reminder, for Planning, Cohort 1and Cohort 2 Class 1 students could respond to one of two prompts that were assessed differently. Cohort 1 students predominantly responded to the first prompt (Figure 5) for should have provided Goal, Steps and Justifies elements in their responses. Cohort 1 students' responses for the Planning element varied within courses and across courses for each element (Figure 5). For those responding to the Planning - Outline prompt, the Goal element was attempted by at most six students. The Steps element showed a small increase in sufficient detail within each course. The Justifies element showed a decline in non-responses across each course. For the Planning - Transfer prompt, only a few students responded to this prompt in Course 1 Ref. 2 and Course 2 Ref. 5. Only vague response.

For Cohort 2 (Figure 6), there was less variation in the Planning details students provided in their reflections within each course. When responding to the Planning – Outline prompt, Course 1 students did not provide a Goal. They provided predominately vague steps and justifications that did not improve across the course. Course 2 students' responses to the two prompts were all coded for Goals, Steps, and Justifies. Course 2 students increasingly did attempt to provide Goals, though they were often vague. These students did provide more detail in their steps and justifications, though these did not vary across the course.

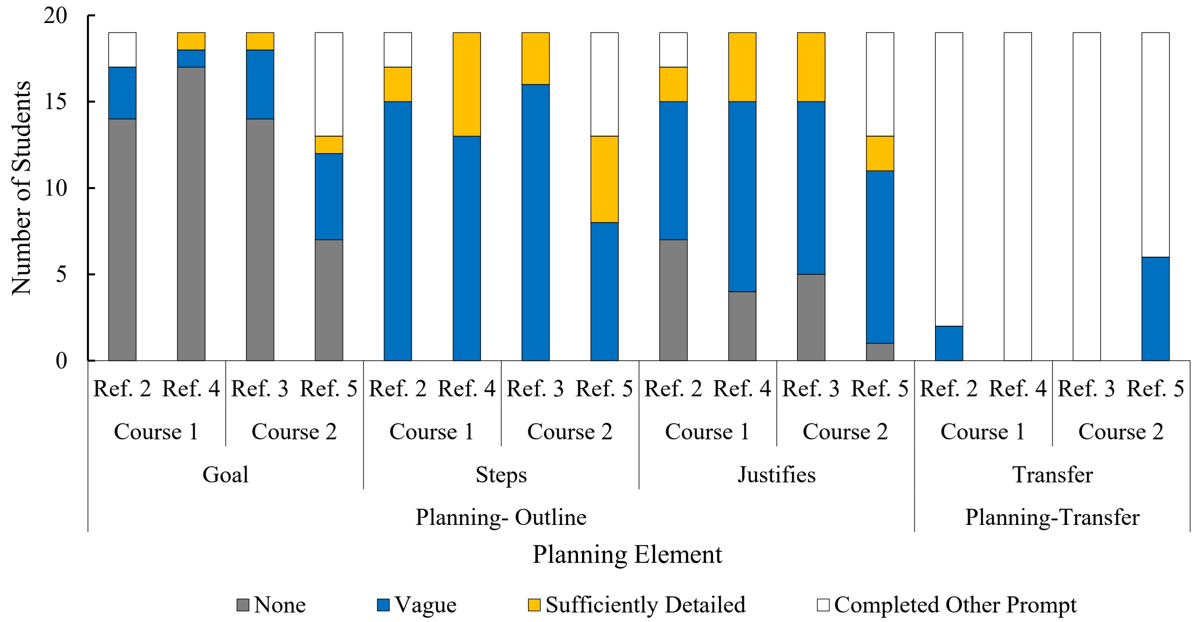

Figure 5. Planning Elements for Cohort 1

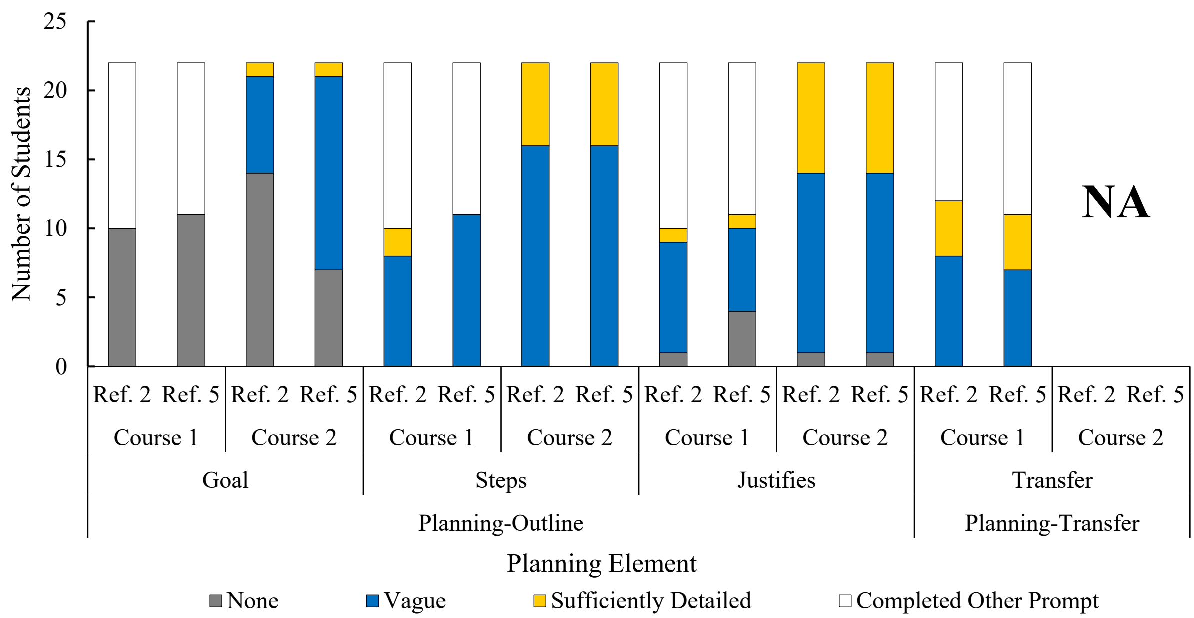

Figure 6. Planning Elements for Cohort 2

VI. Discussion

The purposes of this study were to examine changes in students' MRSs engagement across two semesters and examine if there were differences in students' employment of MRSs when instructors were new to reflection and in their second year of implementing reflection. Each MRS is discussed below.

Monitoring. For the Monitoring strategy, students' responses to the prompt may indicate students' level of understanding of a topic and/or their ability to articulate what they understand about the topic. Students' vague descriptions of their difficulty was similar to prior studies where students reflections were generally vague [23] and they had difficulty monitoring [6]. Most instructors have experienced students coming to them with a problem but not being able to explain what the problem actually is. They can describe what they were doing but not why they believe something is not right. For both Cohorts 1 and 2, this same phenomenon is evidence in students being more able to provide an explanation of their experience (e.g., what assignment, when, where, progress, feelings) than describe their difficulty (i.e., specific part of a topic) or what technical evidence they had that the difficulty was occurring. Students may have an easier time describing the what, when, where of the assignment and their emotions as compared to providing technical and objective evidence. It could be that students did not differentiate between Experience and Identification which leads them to provide only the back-story of their difficulty (Experience)and not the details of the difficulty itself (Identification). Relating their difficulty to a Standard requires students abstract from the instance of their difficulty to why they need to address their difficulty. This requires that students be or become aware of either learning expectations for the assignment or course, expectations for success in their field or future career, or their own personal desires for their learning. This abstraction was challenging for students.

Except for the increase in detail for Standard for Cohort 1, Course 1, Cohort 1's engagement in the monitoring strategy remained flat across the two consecutive courses. The lack of change in students' engagement may reflect that this was the first time instructors were implementing reflection. For Course 1, since the research team was supplying feedback, students may not have been paying much attention to feedback or the reflection assignments; instruction in class may have been limited. For Course 2, the jump in students' attention to Standard may indicate written feedback or a classroom conversation about this element. From Cohort 1 to Cohort 2, there is a positive change in the detail provided in students' description of their difficulty and its identification as well as their ability to at least call out a standard related to their difficulty, if not elaborate on the connection. This change also enabled some within and across course improvement, indicating students were becoming better at articulating their difficulty and how they identified it.

Evaluating. The Evaluating strategy engages students examining how the learning strategies they employed to address their difficulty worked and consider how their thinking about the learning strategies has changed. Across all elements, students' responses reflections were vague, similar to [6], [24]. Students' vague or lack of Assessment and discussion of how their thinking has changed may suggest that students are unsure how to critically evaluate their performance/use of learning strategies, despite examples in the video content they had access to. The Change/Confirmation element, like the Standard, requires student to engage in more abstract thinking about how they learn.

From Cohort 1 to Cohort 2, there was no noticeable improvement in the Evaluating strategy. In fact, there was a drop in the detail students provided for the Assessment element. The lack of improvement within and across courses for Cohort 2 and as compared to Cohort 1 may indicate a need for additional instructor training to help them develop ways to discuss and demonstrate the Evaluating elements in class. The Evaluating strategy is at the heart of metacognition and lifelong learning. Without an attempt to gain insight from one's use of learning strategies, one cannot improve their selection and use of learning strategies.

Planning. Through the Planning strategy, students are afforded an opportunity to take what they have learned from trying to address their difficulty and set a course of action to further improve their learning or their use of the learning strategy. For Cohorts 1 and 2, goal setting was not part of many students' reflections. Students provided steps, though they often lacked detail. The high percentage of vague responses agreed with a past study [6] and could be an indicator of lack of understanding between goals and steps [23]. Students also provided no or little justification for their steps, this element again requires abstract thinking.

From Cohort 1 to Cohort 2, changes seen may be related to several things. For Course 1, the reflection anchor changed from projects to computation tool assignments. Few Cohort 1 students felt they had overcome their difficulty at the time of reflection, perhaps because the project was ongoing. Nearly half of the Cohort 2 students felt they had resolved their difficulty. For those still working on the difficulty, the detail in their Planning responses was quite similar to Cohort 1. For Course 2, more students provide something of a goal and justification for their steps.

Overall, students showed slight improvement in their engagement in some of the elements of the MRSs within the two-semester course sequence. The two instructors saw some improvement in students' use of the MRSs in their second year of instruction. The results of this study have been seen in other studies, but the persistence of students' low ability to engage in MRSs adds something new to the literature.

Implications for Developing MRSs with Reflection

There are a few key takeaways from this study for new instructors and those new to reflection. First, instructors need to be aware that learning to learn takes time and needs to be nurtured and practiced. Unlike learning how to apply an equation, which students are likely to accomplish in a semester, perfecting one's ability to engage with the MRSs will not happen on that timescale. The slow attainment of abilities with the MRSs needs to be discussed with students (repeatedly) and means of accounting for student growth, as opposed to performance, need to be accounted for in how reflection contributes to the overall course grade.

Second, there are specific points on which instructors should focus their energies to help students engage better in the MRSs.

- Detail in writing. The focus here is not on detail for details' sake but for sensemaking purposes. The students need to write enough detail to enable them to dig into their difficulties and ultimately engage in sensemaking. This practice with technical language and concepts not only serves to help students sort through their learning but improved their technical communication beyond the reflections.
- Evidence. Students appear to need examples of what it looks like to gather evidence to determine whether a learning strategy is working or not. They often rely on their grades or indicators of correctness to make such assessments, but such a reliance on external feedback does not enable them to take responsibility for their learning.

- Abstraction. Across the MRSs, there are elements in which students need to engage in abstraction which is sensemaking. Why am I learning what I am learning? (Standard) What do I believe about how I learn best or can learn more effectively? (Change/Confirmation), and What do I believe this course of action will work? (Justifies) are questions students should increasingly be able to answer as they move through their engineering curricula.
- Feedback reading. Students need to be encouraged to read their feedback and seek help if they do not understand their feedback.
- Metered introduction of MRSs. When students are engaging in reflection for the first time, it may be better to introduce the MRSs one at a time. This enables the students to focus on one new MRS over the course of three reflections and integrate feedback on the previously introduced MRSs.

VIII. Limitations

There were two notable limitations that restrict the generalizability of the results. The sample size was small. If a similar but quantitative study were desired to look for significant differences in MRS use, a larger sample size would be preferred. The setting was a first to second year course sequence. More advanced students may produce reflection with different employment of the MRSs. However, there is evidence that students in upper-division courses with little prior exposure to reflection performed similarly [6] [7], indicating that more technical education does not necessarily translate to improved use of the MRSs.

IX. Conclusion

The focus of this study was on students' development of metacognitive regulation strategies through reflection. Two cohorts of students taking a consecutive first- and second-year engineering course sequence engaged in multiple reflections anchored to standard technical course activities. A qualitative examination of their engagement in multiple elements of Monitoring, Evaluating, and Planning revealed a low level of detail in their reflections, perhaps indicating a low level of engagement in metacognition across all elements. Further, many students do not employ evidence from their work/learning to make sense of their learning. Finally, most students struggled with the abstract elements of metacognition. While the two instructors in this study saw some improvement in students' abilities from Cohort 1 to Cohort 2, many of these issues still need to be addressed.

Future work may track these students into their junior and senior year reflection experiences. Such a study would enable a better understanding of students' longitudinal development of metacognitive regulation and establish some expectations for the pace and trajectory of students' growth. Future work may also entail connecting instructor interviews to the results presented here. Such a study would help unpack instructors' thinking about their reflection implementation from Cohort 1 to Cohort 2 and better explain some specific course-level results as well as reveal lessons learned and future intentions with regards to reflection integration.

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Appendix

Table 1A: Sample Rubric (Course 1 Spring 2024)

Item	Proficient	Developing	Emerging	Insufficient-Evidence	No Attempt
Identify a specific learning need [Monitoring]	**Difficulty:** Clearly identify a learning concern **Experience**: Clearly describe experience in which learning concern arose **Identification:** Describe how the learning concern was identified (the evidence) **Standard:** Make explicit tie to learning expectations or other standard	Minimum: 2 proficiency items with sufficient detail plus 2 with only vague details OR 3 proficiency items with sufficient detail	Minimum: 1 proficiency item with sufficient detail plus 2 proficiency items with only vague details OR 2 proficiency items with sufficient detail	Minimum: 2 proficiency items with only vague details	Nothing written in this regard
Evaluate how your learning strategies are working [Evaluating]	**Actions:** Clearly describe actions taken or not taken to address the learning concern **Assessment**: Assess actions taken to improve learning **Change/Confirmation:** Express change in or confirmation of one's thinking (about learning strategies or learning concern) as a result	Minimum: 1 proficiency items with sufficient detail plus 2 proficiency items with only vague details **OR** 2 proficiency items with sufficient detail	Minimum: 1 proficiency item with sufficient detail plus 1 proficiency items with only vague details **OR** 3 proficiency items with vague details	Minimum: 2 proficiency items with only vague details	Does not meet the minimum requirements for Insufficient Evidence **OR** Nothing written in this regard
Create a specific plan to improve your learning [Planning]	**EITHER** **Goal:** Describe a clear goal **Steps:** Articulate action(s) to be taken **Justifies:** Explains/justifies choices being made to move forward **OR** **What:** Clearly identify learning strategies or content/skills of use in future **Application:** Clearly describe potential application for learning strategies or content/skills to future **NOT BOTH**	**EITHER** Minimum: 1 proficiency item with sufficient detail plus 2 proficiency items with only vague details **OR** 2 proficiency items with sufficient detail **OR** Some details on both learning strategies or content/skills of use in future AND their potential application **NOT BOTH**	**EITHER** Minimum: 1 proficiency item with sufficient detail plus 1 proficiency items with only vague details **OR** 3 proficiency items with vague details	**EITHER** Minimum: 2 proficiency items with only vague details **OR** Vague details on learning strategies or content/skills of use in future **OR** their potential application **NOT BOTH**	Does not meet the minimum requirements for Insufficient Evidence **OR** Nothing written in this regard