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Do Metacognitive Instruction and Repeated Reflection Improve Outcomes?

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1. Introduction

Reflection - defined as thought about what one is doing - is essential to learning and professional practice, as described by several educational theories (Bishop-Clark & Dietz-Uhler, 2012; Kolb & Kolb, 2009; Schön, 1987). Kolb's Experiential Learning Theory maintains that learning occurs when "doing" is accompanied by "reflecting on one's doing" (Kolb & Kolb, 2009). Further, when students repeatedly reflect on their academic lives (i.e., learning, practices, and performance), it can enhance their metacognition, which includes the self-regulatory skills of planning, monitoring, and evaluating their learning (Schraw, 1998). Metacognition has been described as "thinking about one's thinking" and promotes lifelong learning abilities (Steiner & Foote, 2017). Unfortunately, Ambrose highlighted a lack of frequent, formal reflection and metacognition activity in the engineering curriculum (Ambrose, 2013). The present research aims to address this and investigate the outcomes.

To this end, in a fluid mechanics course at a large southeastern university, in-class problem-solving in a flipped classroom was coupled with intentional metacognitive skills instruction and repeated reflection to enhance undergraduate student metacognition. As part of this NSF IUSE study, intentional, step-by-step instruction in planning, monitoring, and evaluation was provided in conjunction with weekly exercises to support metacognitive skills development and problem-solving. Each week, students intentionally planned, monitored, or evaluated their problem-solving and were asked to reflect in writing about these self-regulatory skills used during their problem-solving efforts.

2. Background Literature

Metacognition has two major components, namely 1) knowledge of cognition, and 2) regulation of cognition (Cunningham et al., 2015). Knowledge of cognition entails what students know about their knowledge and includes knowledge of a) self or others, b) the task, and c) strategies (Wengrowicz et al., 2018; Cunningham et al., 2015; Flavell, 1979). Regulation of cognition corresponds to the control, or self-regulatory, aspect of learning and includes the skills of planning, monitoring, and evaluating (Cunningham et al., 2015; Schraw, 1998).

Tanner instructed biology students in metacognition as part of typical course practices by having them plan, monitor, and evaluate their learning through reflective questions (Tanner, 2012). Tanner adopted Schraw's framework of planning, monitoring, and evaluating to develop a matrix of reflective questions that are embeddable within course practices such as exams, class sessions, or homework. The "plan, monitor, and evaluate" reflective framework was used in the present research to pose weekly reflective questions to students to support their metacognitive development. Planning refers to selecting strategies and allocating resources for learning (Wengrowicz et al., 2018; Schraw, 1998). Monitoring occurs while the individual is working on the learning task (Cunningham et al., 2015; Schraw, 1998). Evaluating involves assessing one's performance and the effectiveness of the methods they used after completing the task (Cunningham et al., 2015; Schraw, 1998).

3. Methods

3.1 Study Participants

The participants in this study were junior and senior-level undergraduates taking a course in Fluid Mechanics at a large research university in the southeastern United States. These students were primarily pursuing mechanical engineering Bachelors' degree. Two cohorts of students participated in the study – 1) students completing the course in a flipped format *without* metacognitive instruction and repeated reflection during Spring 2021) students completing the course in a flipped format with metacognitive instruction and repeated reflection (i.e., experimental section) during Fall 2021. Approximately 85 students were enrolled during the Spring 2021 semester and comprised the first cohort. During Fall 2021, approximately 130 students were enrolled in the course and comprised the second cohort.

3.2 Reflective Questions

Each week, students were intentionally instructed or supported in planning, monitoring, and evaluating their problem-solving and were asked to reflect in writing about the use of these self-regulatory skills during their problem-solving. In addition, students reflected after exams. Table 1 lists the weekly reflective questions that were posed to the students, with each question being a planning (P), monitoring (M), evaluation (E), or post-exam question. The question type (i.e., P, M, or E) was alternated on a weekly basis to avoid reflection fatigue, and students were not asked to reflect during an exam week.

Table 1: Weekly Reflection Questions

Week	Reflection Question	Question Type	Cohen's Kappa
1	What did I already recall or not recall about this topic from the prerequisite Thermodynamics and Calculus Classes? Based on this, how can I better support and approach my problem-solving on this topic?	Planning	0.51
2	How am I clarifying the confusions I am having about my solution via resources or opportunities available to me before submitting the final solution?	Monitoring	0.90
3	Based on your work and experience with this week's in-class exercises (week 3), evaluate your performance as either good or in need of improvement, and state what you should do to either maintain your good performance or improve it if necessary.	Evaluation	0.73
4	How can I do a better job on this week's (week 4's) in-class problem-solving based on my work on the in-class problems during weeks 1-3?	Planning	0.60

Week	Reflection Question	Question Type	Cohen's Kappa
6	Will I do things differently in preparing for the next exam in Fluids based on my performance on this exam, and if so, what will I do differently?	Post Exam	0.84
7	As you work on this in-class exercise in week 7 in Fluids, are there other resources or strategies you should be using to complete the exercise more accurately or thoroughly?	Monitoring	0.73
8	What have I learned from working on the in-class exercises in Fluids since the start of the semester?	Evaluation	0.61
9	Surroundings in a classroom are believed to have effects on student learning. These include the conditions and objects that surround you. What impact, if any, are the surroundings in this Fluids classroom having on YOUR learning and comprehension? In your reflection, please include why the surroundings are impacting you in these ways.	Evaluation	0.89
11	Based on the experience of taking exam 1 in Fluid Mechanics, what did you do to prepare for exam 2?	Post Exam	0.75
12	What do you plan to do to enhance or maximize your performance on this week's (week 12's) in-class exercise in Fluid Mechanics?	Planning	0.73
13	What are you currently doing to prepare for your final exam in Fluid Mechanics? Please be honest in your response, as this question is meant to be supportive to you. Please discuss what you are doing now and not what you plan to do. If you are not doing anything, simply state as such and provide a quick explanation as a supportive note to yourself.	Monitoring	0.56
15	What are your thoughts about these weekly Canvas questions you've been answering related to the in-class exercises or exams in Fluid Mechanics?	Evaluation	0.70

The reflective responses were examined by two analysts using a content analysis and emergent coding schemes to identify the recurring themes. The analysts were engineering faculty members who conduct engineering education research (i.e., first and second authors). One of the analysts, who is highly experienced with content analysis, examined all of the responses each week and developed the coding scheme. A second analyst examined a subset (i.e., 15%) of the responses using the coding scheme. Their inter-rater reliability (IRR) based on the subset of responses was calculated using Cohen's Kappa. Their IRR scores were in the range of 0.51 to 0.90, as shown in Table 1. Based on Landis and Koch, Cohen's kappa values in the range 0.41 to 0.60 are indicative of moderate agreement, values between 0.61 and 0.80 indicate substantial agreement, and 0.81 or above are "almost perfect" (Landis & Koch, 1977). Although the IRR score was lower than desired for the week 1 question, this was the first occasion the analysts had conducted a content analysis together as well as a new experience for the second analyst. Since the inter-rater reliability scores were acceptable per these standards, the codes assigned by the first analyst were used as the final assigned codes.

Interestingly, many of the coding categories were close in meaning or overlapped from week to week despite the reflective questions being different. As shown in Table 1, although the reflection questions related to performance and learning, they still differed somewhat across the weeks. Examples of the coding schemes used are presented in the Results section with the coding results.

3.3 Final Exam

Similar final exams were administered to the two cohorts to enable comparison based on a direct assessment result. The final exam contained both multiple-choice and free-response questions. For the multiple-choice questions, although the twelve questions were not identical for the two cohorts, the concepts tested were the same, and the questions were of similar difficulty.

For the free-response questions, two of the three questions were identical across the cohorts, except for the numerical values, such as Pressure of 200kPa vs. 500kPa. The problem geometry was also the same for these two questions. The third free-response question differed slightly across the cohorts in terms of the geometry of the problem. In addition, students in one cohort were given parameter A and asked to solve for parameter B. In the other cohort, they were given parameter B and asked to solve for parameter A. Going from B to A or going from A to B was of equal difficulty. Therefore, for practical purposes, the third free-response question was equivalent across the cohorts.

An analysis of covariance (ANCOVA) was used to statistically compare the exam scores so GPA could be used as a control variable (Norusis, 2005). The GPA was based on the prerequisite coursework for the course and was gathered via a demographics survey. With ANCOVA, adjusted averages for the groups are computed based on the control variable, and these are presented in the results. In addition, practical significance was assessed using Cohen's d effect size. Small, medium, and large effect sizes have threshold values of d=0.20, d=0.50, and d=0.80, respectively (Cohen, 1987; Salkind, 2010).

4. Results

4.1 Participation in Reflection

Students exhibited strong and consistent participation in the weekly reflections across the Fall 2021 semester. Of the approximately 130 students enrolled during this term, the average number of reflections completed each week was 109 (84%), with a standard deviation of 13. To ensure participation and convey the importance of reflecting, the reflections were assessed each week. The teaching assistant assigned points based on the student having made an earnest attempt to respond to the question. The reflection points earned were worth 10% of the final grade, with the remaining portion of the grade determined only by exam performance.

4.2 Reflection Questions

A subset of results from the students' reflections will be presented in this section. They span weeks 4 through 8 of the semester and represent consecutive reflection questions related to planning (week 4), monitoring (week 7), and evaluation (week 8). Exam 1 occurred during week 5, and the post-exam reflection occurred during week 6.

4.2.1 Planning

Reflection Question: *How can I do a better job on this week's (week 4's) in-class problem-solving based on my work on the in-class problems during weeks 1-3?*

The results of the content analysis for this question are shown in Table 2, in descending order of response proportion. There were eight categories in the coding scheme, as given in Table 2. The most frequently mentioned categories were *Study or Review* and *Practice/Solve Problems* at 46% and 42% of the total responses, respectively, as one might expect.

However, the *Carefulness, Organization & Diligence* category was third in the ranking and associated with approximately one-third of the responses (i.e., 34%). The prevalence of this category highlights the perceived importance of these behavioral practices and traits, alongside studying and practicing problems. The following behaviors exemplify this category: paying attention to details, verifying work, maintaining pace with the assigned work, following a study routine, attending class, taking good notes, and using a formula sheet. Finally, a proportion of respondents (i.e., 17%) said they could do a better job on the in-class exercises through attempting the problem on their own, critical thinking, applying knowledge or using a structured approach to the problem. Based on these latter two categories, students displayed evidence of academic self-management in support of their problem-solving.

Table 2: Week 4 Planning Reflection Results

Coding Category	Description	% of Responses (n=99)
Study or Review; Prepare for class	Watch videos, read textbook, review notes, study content, etc.	46%
Practice or Solve Problems	Practice or solve problems	42%
Carefulness, Organization & Diligence	Work hard or steadily Pay attention to details Be patient or organized with work Double-check work Keep up with study or catch up if behind Follow reasonable study routine/schedule Attend class Take good notes Create/use formula sheet	34%
Independent Effort, Critical Thought, Application, or Problem-Solving Skill or Process	Attempt problem on one's own Use critical thinking Connect or relate concepts Use problem-solving skills or apply knowledge Use structured problem-solving process	17%
Get help from Instructor or TA (in-class or office hours)	Get help from or ask questions to the instructor, TA, or tutor	12%
Initial Phases of Problem-solving	Describe, understand, completely read, or analyze problem	10%

Coding Category	Description	% of Responses (n=99)
	Plan solution approach	
Get help or support from peers	Get or ask for help or support from classmates, friends, or other students	10%
Ease Nervousness or Have Confidence	Try to ease one's nervousness or lack of confidence about course performance	1%

4.2.2 Monitoring

Reflection Question: *As you work on this in-class exercise in week 7 in Fluids, are there other resources or strategies you should be using to complete the exercise more accurately or thoroughly?*

In their monitoring-based reflections in week 7, the students most frequently indicated the *lecture videos*, their *peers*, and the course *notes/slides* were the resources they should be using during the in-class exercise, as shown in the upper portion of Table 3. Relative to strategies, *practice* (with problems) was the top-mentioned strategy to use, being mentioned by 40% of respondents. This proportion was similar to the proportion of students who identified *practice* as a desirable planning activity in week 4 (i.e., 42%). Of the students who mentioned this strategy in week 4, 33% of them also mentioned it in week 7 during monitoring.

Carefulness, Organization & Diligence was the third most-frequently-mentioned strategy, with 27% indicating they should be conducting themselves and their work in this way. Interestingly, this category was mentioned by a similar proportion of respondents (i.e., 34%) in the week 4 planning reflection. Of the students who mentioned this approach in week 4, only 15% of them mentioned it again in week 7 during monitoring. Was it possible the remaining students were already applying *Carefulness, Organization & Diligence*, and therefore it was not "another" strategy they should be using? In Table 3, *Independent Effort, Critical Thought, or Problem-Solving Skill* was the second most-frequently-mentioned strategy, with 31% saying they should be pursuing these types of actions. This represents an increase in the occurrence of this category from the week 4 planning reflection, where 17% of the responses were representative of this category. Similar to the planning-based reflections in week 4, the second and third most-frequent strategies in Table 3 suggest realization by the students of the importance of academic self-management for solving problems.

Table 3: Week 7 Monitoring Reflection Results

Coding Category		Description	% of Responses (n=99)
Resources	Lecture Videos	Videos assigned for pre-class learning	37%
	Peers	Fellow students, friends, or classmates	27%

Coding Category		Description	% of Responses (n=99)
	Notes or Slides	Course/topical notes or slides	21%
	Textbook	Course textbook	16%
	Professor	Professor/instructor, including instruction, questions/answers, etc.	15%
	Other or External Resources	External resources (YouTube videos, general online resources, FE exams, etc.)	14%
	Office Hours	Office hours with instructor or TA	5%
	Tutor	Tutoring center or tutor	4%
	TA	Teaching Assistant	2%
Strategies	Problems: Review, practice, do	Review, practice, or do problems or examples	40%
	Independent Effort, Critical Thought, or Problem-solving Skill	Attempt problem on one's own Use critical thinking Connect or relate concepts Use problem-solving skill or apply knowledge Use structured problem-solving process, including initial phases of problem-solving	31%
	Carefulness, Organization & Diligence	Work hard or steadily Pay attention to details Be patient or organized with work Double-check work Keep up with study or catch up if behind Follow reasonable study routine/schedule Attend class & be prepared Take good notes Create/use formula sheet or study guide	27%
	Content: Revisit	Revisit content (pre-requisite & current)	14%
	Content: New: Learn or Understand	Learn or study new course content, concepts, theory	7%

4.2.3 Evaluation

Reflection Question: *What have I learned from working on the in-class exercises in Fluids since the start of the semester?*

In Table 4, which summarizes the week 8 evaluation reflection responses, the most frequently mentioned type of learning that occurred pertained to *Independent Effort, Application, or Problem-solving Skill*. Specifically, 50% of respondents said they had learned to attempt problems on their own, how to apply content knowledge or connect concepts to solve problems, or how to follow a structured process for solving problems. Interestingly, the prevalence of this category increased from week 4 (planning) to week 7 (monitoring) to week 8 (evaluation). This category was mentioned more frequently than *Content Understanding* as a point of learning, which was mentioned by 38% (Table 4). Many respondents (41%) realized that the in-class exercises enabled *Preparation and Feedback Gains*. Finally, a substantial proportion of students (i.e., 30%) mentioned *Carefulness, Organization & Diligence* as a point of learning for them. Of those students who mentioned this category during week 7 (monitoring), 33%

mentioned it again in week 8 as a learning point. The prevalence of these top categories in Table 4 suggests the development of self-regulatory, self-managing behaviors by the students.

Table 4: Week 8 Evaluation Reflection Results

Coding Category	Description	% of Responses (n=115)
Independent Effort, Application, or Problem-solving Skill	Attempt problems on one's own Problem-solving skill or ability Application of content knowledge Connection of concepts to solve problems Following of structured problem-solving process, including initial phases of problem-solving	50%
Preparation & Feedback Gains	Gained preparation (e.g., for exams) Learned what to expect on exams Gained feedback on understanding, knowhow, or abilities	41%
Content Understanding	Understanding of course concepts or content, including specific fluids concepts or principles	38%
Carefulness, Organization & Diligence	Work hard or make a good effort Be organized with work Keep up with study or catch up if behind Follow reasonable study routine/schedule Be prepared for class Create/use formula sheet or study guide	30%
Peer Support	Peers are helpful for learning How to work with peers	10%
Practice Important	Practice with problems is important in this course	9%
Personal Attributes or Feelings	Learner characteristics Gained confidence Learned about overconfidence Gained motivation, interest, or engagement Gained comfort in asking for help	9%

4.3 Exam Results

The final exam results for the two cohorts are shown in Table 5. Recall that the experimental cohort experienced a flipped classroom with metacognitive instruction and support for problem-solving, while the control cohort did not experience this metacognitive instruction and support in the flipped classroom. This included formal instruction in planning, monitoring, and evaluating problem-solving and repeated reflection related to planning, monitoring, and evaluating. The results are presented separately for the multiple-choice versus the free-response questions. A statistically and practically-significant difference between the two cohorts was found with the free-response scores in favor of the cohort that had received the metacognitive support ($p < 0.0005$; $d = 0.97$). The adjusted average was 81.7% for this cohort versus 66.1% for the cohort that had not received the metacognitive support. For the multiple-choice questions, the adjusted averages were very similar for the two cohorts, with $p = 0.69$ and an effect size of $d = -0.06$. With the free-response questions, students had to demonstrate their problem-solving processes, which were a key component of the metacognitive instruction and weekly reflection questions. Thus, it's reasonable that there was an increase with the free-response questions versus the multiple-choice questions (necessarily).

Table 5: Exam Results Comparisons: Flip vs. Flip w Metacognitive Support

Exam Component	**Adjusted Mean Percentage %** n		**ANCOVA *p***	**Effect Size *d***
	Flip	**Flip + Metacog**		
Multiple-Choice Questions	**58.9** 70	**58.0** 111	0.69	-0.06
Free-Response Questions	**66.1** 70	**81.7** 111	<0.0005	0.97

5. Summary

In this study, undergraduate students were instructed weekly in planning, monitoring, and evaluating their in-class problem-solving in a Fluid Mechanics flipped classroom. They subsequently reflected in writing about the use of these skills during their problem-solving efforts. Students exhibited consistent and earnest participation in the weekly reflections across the Fall 2021 semester. A structured content analysis of the reflections suggested the development of self-regulatory and self-managing behaviors for their academic and problem-solving pursuits. Specifically, when asked to evaluate their leanring points in week 8 from having completed the in-class exercises, the top four categories included *Independent Effort, Application, or Problem-solving Skill* (50%), *Preparation & Feedback Gains* (41%), and *Carefulness, Organization & Diligence* (30%). There was a statistically and practically-significant difference in the free-response scores in favor of the cohort that had received the metacognitive support ($p < 0.0005$; $d = 0.97$). With these questions, students had to demonstrate their problem-solving processes, which were a key component of the metacognitive instruction and weekly reflection questions. Thus, it's reasonable that there was an increase with the free-response questions versus the multiple-choice questions (necessarily).

6. Conclusions

These preliminary results pointed to desirable impacts of metacognitive instruction and repeated reflection with respect to student outcomes and development of self-regulatory behaviors. However, the positive outcomes were accompanied by lessons learned. One of the key lessons we learned was the need to be very specific as to what we wanted students to reflect on. For example, at week 2, we asked the following question, which ultimately was not specific enough:

How am I clarifying the confusions I am having about my solution via resources or opportunities available to me before submitting the final solution?

We had intended for students to respond specifically about their solution to the *in-class exercise* during *week 2* as part of *monitoring* their in-class problem-solving. However, the question did not specify as such. Therefore, some of the students' responses pertained to problem solutions completed outside of class or to their *plans* for solving problems in the future. It's also plausible students may have extended this question to other courses, since we did not specify "Fluid Mechanics." Thus, we found that it's very important to be highly specific in what we want students to reflect on.

We also encountered challenges in the students completing actual *Monitoring* reflections. This type of reflection should be completed while the activity (i.e., problem-solving) is in progress. However, not all students had laptops for responding to the reflection questions during class. Therefore, the "monitoring" reflections became "evaluation" reflections written outside of class after the problem-solving was complete. Also, during problem-solving activities, the students' focus may have been on solving the problem versus reflecting on their processes for doing so. Thus, having students truly monitor their in-class problem-solving can present challenges. In the future, we plan to expand our reflective prompts to include work and activities both inside and outside the classroom related to problem-solving. In this way, students may be able to easily monitor their activity, for example during pre-class preparation for their problem-solving in the flipped classroom. Thus, we plan to take a "broader" approach to ask students to plan, monitor, and evaluate their activity in support of their problem-solving efforts.

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