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Work in Progress: Metacognition in Motion - Supporting Student Success in a Fluid Flow Course

Solange Genevieve Bolger, The University of Iowa
Shaun P. Vecera, The University of Iowa
Prof. Jennifer Fiegel, University of Missouri - Columbia

Dr. Jennifer Fiegel is Professor and Chair of the Department of Chemical and Biomedical Engineering at the University of Missouri. She earned her B.S. in Chemical Engineering from the University of Massachusetts at Amherst and her Ph.D. in Chemical and Biomolecular Engineering from the Johns Hopkins University. Her bench research focuses on developing advanced drug delivery systems, particularly inhalable and sprayable therapeutics, to treat bacterial infections affecting the respiratory system and skin. In parallel, Dr. Fiegel leads engineering education research centered on how students learn, think, and make ethical decisions. Her work emphasizes the integration of cognitive and metacognitive strategies into engineering instruction, along with the development of faculty and teaching assistants as reflective educators. Through both her technical and educational research, she is committed to interdisciplinary collaboration and preparing the next generation of engineers to create meaningful impact.

Metacognition in Motion - Supporting Student Success in a Fluid Flow Course

Background

Undergraduate engineering training requires students to master substantial conceptual and procedural knowledge and apply it flexibly to new and increasingly complex problems [1]. Yet most students begin their undergraduate training without explicit instruction in how to learn in ways that support long-term retention and knowledge transfer [2]. At the University of Iowa, 75% of engineering students report that their study habits were not developed through direct instruction from educators. Limited instruction on how to learn may contribute to the continued use of strategies, such as cramming and note rewriting, that lead to short-term fluency without strengthening durable retrieval [3]. While many student success efforts on college campuses focus on structural supports that occur inside (e.g., flipped classrooms) or outside (e.g., tutoring) the classroom, they often do not explicitly instruct students on how to learn or study [4-5]. Thus, embedding deliberate instruction and practice in study strategies that promote enhanced learning and knowledge transfer may strengthen engineering students' training.

The current work evaluates a semester-long pilot of a metacognitive learning intervention implemented for engineering students in a sophomore-level, chemical engineering Fluid Flow course. The course was selected for study because the instructor was actively exploring ways to improve student learning and had independently implemented metacognitive strategies in the course, creating an opportunity to examine their impact in an authentic instructional setting. The intervention draws on the 3Ms framework (mindset, metacognition, and memory), which distills decades of empirical learning research from cognitive psychology to support effective learning and instruction [6]. Mindset refers to fostering students' beliefs and attitudes about learning and intelligence that may influence their learning [7]. Metacognition refers to the process by which learners combine knowledge of a task, knowledge of their own abilities, and knowledge of learning strategies to plan their learning, monitor their progress toward a learning goal, and evaluate the outcome of the task [8]. Memory refers to learning strategies that facilitate long-term retention and application of knowledge, such as studying over several time blocks, retrieval practice, and interleaving (i.e., intermixing different problem types) [3].

Ultimately, the intervention aimed to help students become more effective self-regulated learners [9-10]. As self-regulated learners, students take active responsibility for setting goals, monitoring their progress, and adapting their learning strategies in response to their performance [10]. Self-regulated learners are not merely successful or motivated; they are also metacognitively aware and strategic, using planning, monitoring, and reflection to guide their learning [11]. For STEM students, being a strong self-regulated learner is associated with greater academic achievement [12-13], and greater learning gains [14-15]. Prior meta-analytic work on self-regulated learning interventions in primary and secondary schools in Germany indicates that students in the early stages of development, particularly those in elementary or intermediate grades, tend to benefit most from instruction in learning strategies [16]. However, for developmentally advanced students, practice applying these learning strategies, along with metacognitive reflection, yielded substantial learning. Thus, interventions that not only instruct students in evidence-based learning strategies but also provide opportunities to engage with them may be most meaningful for college students.

The current study evaluates a semester-long metacognitive intervention embedded in an undergraduate Fluid Flow course for chemical engineering students. Two primary aims guided this work: (1) to evaluate the effectiveness of the intervention in the course, and (2) to examine associations between student engagement, student confidence, and course performance. Primary outcomes included course grades and changes in students' reported use of learning strategies over time. The study further assessed whether the degree of participation in the metacognitive activities was associated with differential academic outcomes and use of academic supports (e.g., peer study, supplemental instruction). Together, these aims were designed to evaluate whether structured, repeated engagement in metacognitive processes is associated with meaningful variation in learning behaviors and achievement among students in the course.

Methods

Participants

The sample consisted of 45 undergraduate chemical engineering students in a 2-credit-hour Fluid Flow course, a required chemical engineering course taken within the major during the spring semester of their sophomore year. The course was structured with 2×50-minute lectures and 1×50-minute discussion section each week. During the discussion section, students completed warm-up problems independently and then worked on longer group problems on whiteboards, with an instructional team consisting of the professor and three undergraduate teaching assistants available to answer questions. Final course grades were determined based on performance on four exams (60%), with the option to retake exam 1; completion of homework and discussion section problems (15%); weekly challenge assignments (15%); and a final project (10%).

Simultaneously, students were taking a Chemical Engineering Thermodynamics course. In the semester prior to this course, students completed a core engineering thermodynamics course taken by students across engineering and two major-specific courses: Material and Energy Balances and Computational Tools for Chemical Engineering.

This study was reviewed by the institutional review board and determined not to be human subjects research; it involved retrospective analysis of de-identified data from a prior semester, with all records de-identified by an honest broker to ensure FERPA compliance.

Metacognitive interventions

Students were assigned 10 metacognitive assignments as part of their regular weekly assignments over a 16-week semester that were designed to target core aspects of metacognition, including planning, monitoring, and evaluation of learning. Each assignment took approximately 15-30 minutes to complete. All metacognitive assignments, except the Metacognitive Awareness Inventory assigned in week 1, were completed as part of the weekly challenges and accounted for 50% of the weekly challenge grade (~7.5% of the final grade).

To assess changes in metacognitive functioning over the semester, students completed the Metacognitive Awareness Inventory (MAI) at the beginning (week 1) and toward the end (week 13) of the course. The MAI is a 52-item self-report measure that assesses two broad components of metacognition: knowledge of cognition (i.e., declarative, procedural, and conditional knowledge) and regulation of cognition (i.e., planning, monitoring, debugging, and evaluation)

[17]. Items are rated on a 5-point Likert scale (0 = I do this never, 1 = I do this infrequently, 2 = I do this inconsistently, 3= I do this frequently, 4 = I do this always). During the week 1 discussion, students completed and submitted the MAI as their first warm-up assignment (worth 2 points out of 184 total HW points, or 1% of the HW grade). During week 13, the MAI was assigned as a weekly challenge. Internal consistency (Cronbach's α) of the full measure was excellent at both time points (αs= 0.938 and 0.964, respectively). The high internal consistency shows that the MAI operated reliably in this sample, but this metric does not directly indicate whether students responded attentively.

During week 2, students completed a seven-question reflection that included: (1) rating the academic difficulty of the prior semester as (a) easier than expected, (b) about what I expected, or (c) harder than expected; (2) describing their overall effort in engineering courses last semester; (3) naming two things they did well when preparing for assignments and exams in the prior semester; (4) identifying areas in which they scored high on the MAI; (5) identifying areas in which they scored low on the MAI; (6) specifying two to three strategies or resources they planned to start or continue using and how they would implement them; and (7) stating their goal for the Fluid Flow course.

Before each of four major exams, students completed a structured "exam prep". These exam preps prompted students to:

a) Evaluate their performance in the prior semester (exam prep 1 only) or on the last exam (exams 2, 3, and final),
b) Reflect on the effectiveness of the study strategies they previously employed
c) Rate their confidence in mastering course concepts to be assessed on the upcoming exam using a 5-point Likert scale ranging from 1 (Not confident) to 5 (Completely confident). Sample items include "How confident do you feel that you: Know the difference between gauge, absolute, and atmospheric pressure and how to apply them in calculations"; "How confident do you feel that you: How confident do you feel that you: Are able to use the hydrostatic equation to derive the pressure difference between two points, such as in manometers"; and "How confident do you feel that you: Are able to calculate frictional losses due to the pipes, sudden contractions and expansions, fittings, and valves."
d) Generate a personalized study plan for the exam.

These activities were intended to scaffold planning and decision-making, encouraging students to move beyond habitual study behaviors and engage in more deliberate, goal-directed preparation based on their prior performance.

Following the first three exams, students completed a corresponding "exam wrapper", a structured post-exam reflection designed to promote metacognitive monitoring and evaluation [9] (samples of cognitive wrappers can be obtained from: https://www.cmu.edu/teaching/designteach/teach/examwrappers/ and https://learning.uiowa.edu/learning-iowa-framework). In these reflections, students reviewed their exam performance, analyzed sources of error or misunderstanding, reworked problems on which they score less than 90%, identified how they prepared for the exam (hours spent preparing, percentage of time spent studying with others including peers, teaching assistants, and professors relative to their time spent studying independently, and strategies used to study), and set specific goals for adjusting their study approach for the next exam. These post-exam activities emphasized regulation of learning by explicitly asking students to link outcomes to strategy use.

Data analytic plan

Descriptive statistics were computed for all primary variables. Associations among our outcome variables (i.e., exam/course performance and change in MAI scores) and predictors were examined. For predictors with repeated measurements, we assessed the extent of change across the semester using repeated-measures general linear models (GLMs). Relevant between-subjects predictors (e.g., number of metacognitive interventions completed) were included, and partial eta-squared values were reported as measures of effect size. Where repeated-measures effects were significant, planned contrasts were evaluated to characterize the nature of change across time. For predictors not assessed repeatedly, parametric tests of mean differences, including independent-samples *t* tests and one-way ANOVAs, were used.

Students were provided with a list of study strategies and asked to indicate which they used to prepare for the exam. These study strategies varied in effectiveness, ranging from reading the textbook to working through practice exam questions. Strategy effectiveness was determined by findings in the published literature [2, 3, 6]. We coded the number of ineffective and effective strategies students used to evaluate how strategy use changed over time. Exploratory analyses were conducted to identify patterns of broader study habits among lower- and higher-performing students. Student performance was determined by classifying students into quartiles by exam grade, and we evaluated patterns among students. Students naturally separated into two subgroups: those whose quartile membership remained consistent across the semester and those whose performance fluctuated while remaining generally low or high. Given small subgroup sizes, these analyses were considered hypothesis-generating.

Given our modest sample size, effect sizes were reported for both significant and nonsignificant effects to provide information about the magnitude and direction of observed associations. Variables $p \leq .10$ are reported as "trending toward significance." The present analyses are intended as pilot work to inform hypothesis refinement, measurement considerations, and sample size planning for future, adequately powered studies.

Data preparation

All dependent variables were examined for substantial skewness (i.e., skewness > $|2.0|$) and for outliers (values > $|3|$ SDs from the mean). To reduce the influence of extreme values while retaining cases, winsorized values were recoded to the nearest value within ± 3 SDs of the mean. Variables winsorized included the total number of metacognitive assignments completed and MAI change scores.

Results

Course performance

Overall, students performed strongly in the course (mean = 82.06, SD = 9.05; Table 1). Original performance on Exam 1 was moderately and positively correlated with performance on subsequent exams ($r = 0.33, p < .05$; $r = 0.44, p < .01$; $r = 0.39, p < .05$). Exam 1 retake performance was more strongly, but still moderately and positively associated with performance on subsequent exams ($r = 0.38$, $p < .05$; $r = 0.44$, $p < .01$; $r = 0.39$, $p < .01$). Performance on Exam 2 was strongly related to performance on Exams 3 and 4 ($r = 0.70$ and 0.65, p(s) $< .001$), and performance on Exams 3 and 4 was similarly strongly correlated ($r = 0.71$, $p < .001$). Final grades were based on exam grades, a final course project, and weekly in-class work.

Table 1. Descriptive statistics for exam scores and final course performance.

Score	Exam 1 Original	Exam 1 Retake	Exam 2	Exam 3	Exam 4	Final Grade
Min	32.00	39.50	40.00	28.00	12.00	54.20
Max	100.00	100.00	95.00	99.00	92.00	95.20
Mean	78.00	83.84	73.98	82.44	67.40	82.06
SD	15.49	13.56	12.63	14.19	17.10	9.05

<u>Engagement in metacognitive interventions and metacognitive awareness</u>

Most students completed all metacognitive assignments: 68.90% ($n = 31$) completed 10, and 13.30% ($n = 6$) completed 9 assignments. On average, students reported inconsistent engagement with metacognitive strategies at both the start and end of the semester, as reflected in their MAI scores ($M = 137.81$, $SD = 25.45$; $M = 141.84$, $SD = 30.05$). Students' change in their MAI score from the beginning to the end of the semester varied widely (minimum = -74.00, maximum = 58.50, $M = 4.15$, $SD = 24.24$).

The number of metacognitive interventions completed was first examined as a potential proxy for the development of metacognitive awareness across the semester. Those who completed more metacognitive interventions performed moderately to strongly better in the course (Figure 1A; $r = 0.39$, $p < .01$). An increase in MAI scores over the semester was moderately associated with better course performance ($r = 0.34$, $p < .05$). Greater completion of metacognitive interventions was characterized by greater variability in MAI change (Figure 1B), suggesting that engagement with the interventions alone did not produce uniform changes in MAI scores across students.

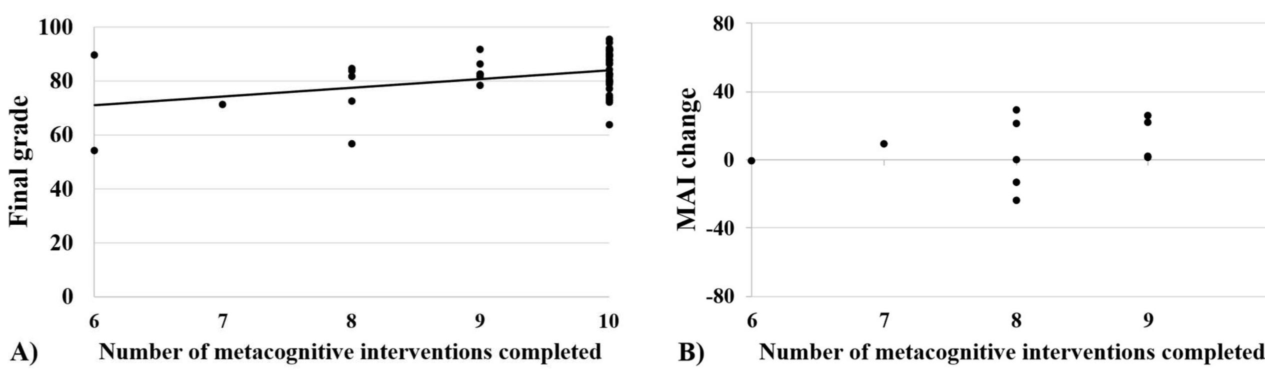

Figure 1. A) Final course grade as a function of the number of metacognitive interventions completed; B) Change in MAI score over the semester as a function of the number of metacognitive interventions completed

We used a repeated-measures GLM to evaluate whether changes in MAI scores across the semester were associated with final course performance. MAI scores showed a moderate increase across the semester, $F(1, 40) = 4.87$, $p < .05$, $\eta p^2 = .11$. Students who performed better in the course did not differ in their overall levels of MAI, $F(1, 40) = 0.04$, $p =$ n.s., $\eta p^2 = .00$. However, students with higher final course grades exhibited moderately greater increases in MAI scores over time, $F(1, 40) = 5.35$, $p < .05$, $\eta p^2 = .12$. Planned contrasts were conducted to examine the relationship between MAI and final course performance at the beginning and end of the semester. Neither the start nor the end-of-semester MAI was significantly associated with final course performance (Figure 2). Overall, course performance appeared to be more strongly related to change in metacognitive awareness across the semester than to absolute levels of metacognitive awareness at either time point.

Perceived difficulty of prior semester

About half of the class perceived their prior semester as "about what they expected" (n = 22), and the other half perceived it as "harder than expected" (n = 21). One student who reported the prior semester as easier than expected was excluded from analyses due to low sample size. Independent-samples *t*-tests indicated that, overall, students who perceived the prior semester as more difficult than expected performed worse across exams and earned lower final course grades than those who reported that last semester was about as difficult as they expected. Effect sizes were moderate-to-large for Exam 2 ($d = .71$) and moderate for Exam 3 ($d = .58$) and final grade ($d = .56$); the difference on Exam 1 retake scores was moderate in magnitude but reached only trend-level significance ($d = .42$) and the differences on Exam 1 original scores and Exam 4 scores were small-to-moderate in magnitude but nonsignificant ($d = .30$, $d = .36$, respectively). Student perceptions were not related to their MAI scores nor their completion of metacognitive interventions.

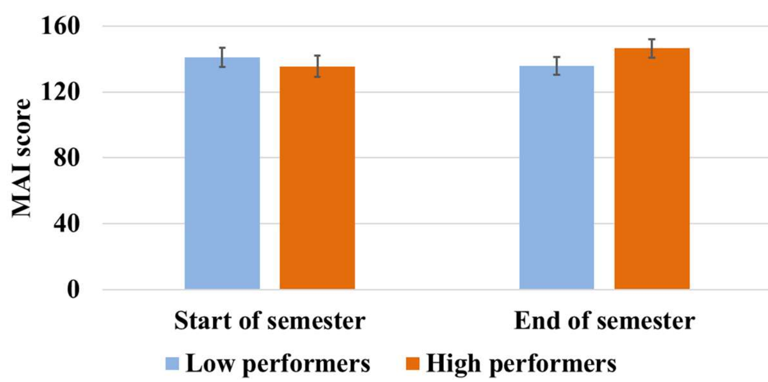

Figure 2. MAI scores at the start and end of the semester by course performance (low versus high performance).

Confidence in course material

Throughout the semester, students reported feeling somewhat to fairly confident in their knowledge of the concepts covered on each exam (Exam 1 confidence = 3.80 ± 0.65; Exam 2 confidence = 3.87 ± 0.68; Exam 3 confidence = 3.85± 0.70; Exam 4 confidence = 3.87 ± 0.69; mean ± SD). Student confidence in course material did not change significantly across the semester, and low and high performers were equally confident on exams. When exam score was modeled as a continuous predictor rather than in quartiles, confidence did not predict subsequent exam performance. These null findings may indicate that students' confidence reflects subjective fluency with the material rather than conceptual understanding or application; however, the limited sample size constrained the power to detect subtle effects.

Study habits and strategies

On average, students spent approximately 5 hours studying for exams across the semester, with about 75% of their study time studying with peers and 25% spent studying alone. Most students reported using a mix of effective and ineffective study strategies (Table 2), with only 2 to 4 students endorsing the exclusive use of effective strategies for any given exam. Across the semester, greater time spent studying for exams was negatively related to performance on the exam. This negative effect was moderate to large for exam 2 ($r = -0.45$, $p < .01$). Exam 1 original and retake ($r(s) = .031, .002$, respectively) and exam 3 ($r = -0.13$) did not reach significance. It should be noted that students often reported the number of hours they spent studying rather than the number of days or sessions. Thus, our sample size is significantly constrained for these analyses. A greater proportion of time spent studying with peers was positively related to exam performance across the semester. This effect was moderate for exam 2 ($r = 0.31$, $p < .05$) and did not reach significance for exam 1 ($r(s) = -0.07, -0.04$ for both original and retake) nor exam 3 ($r = -0.018$).

Table 2. Item-specific endorsement levels of study strategy use. * = ineffective strategies; + = effective strategies.

	N (%) Endorsement of Study Strategy Use		
Study Strategy	**Exam 1**	**Exam 2**	**Exam 3**
Reviewing class notes*	41 (93.2%)	38 (90.5%)	41 (95.3%)
Reviewing course lecture videos*	9 (20.5%)	8 (19.0%)	7 (16.3%)
Reading textbook*	5 (11.4%)	4 (9.5%)	4 (9.3%)
Working through practice exam questions or additional problems+	39 (88.6%)	39 (92.9%)	39 (90.7%)
Reworking old homework and discussion problems+	31 (70.5%)	27 (64.3%)	31 (72.1%)
Keeping track of time while solving problems+	4 (9.1%)	8 (19.0%)	12 (27.9%)
Attending supplemental instruction/exam review sessions+	17 (38.6%)	17 (40.5%)	14 (32.6%)
Creating one's own study guide+	11 (25.0%)	14 (33.3%)	17 (39.5%)
Explaining concepts to someone else+	16 (36.4%)	11 (26.2%)	13 (30.2%)

Greater use of effective study strategies did not emerge as a significant predictor of exam performance across the semester. However, the use of more ineffective study strategies was a negative, moderate-to-strong predictor of worse exam performance on exam 3 ($r = -0.43$, $p <$

.01). This relationship nearly reached trend level for Exam 2 ($r = -0.25$, $p = .11$) and was nonsignificant for exam 1, original scores and retake scores (r(s) = -0.08, -0.08, respectively).

We conducted a repeated-measures GLM to evaluate whether the use of ineffective study strategies increased over time and whether this was associated with increases in MAI scores. We found that ineffective strategy use did not significantly change across the semester, $F(2, 74) = 0.18$, p = n.s., $\eta_p^2 = .01$. We also found that students with greater MAI change did not use fewer ineffective strategies overall, $F(16, 37) = 0.06$, p = n.s., $\eta_p^2 = .00$. However, we did find a significant and moderate interaction between time and MAI change, $F(2, 74) = 4.21$, $p < .05$, $\eta p^2 = .10$. Planned contrasts indicated that students who showed greater increases in MAI scores exhibited trend level reductions in ineffective strategy use by the end of the semester, $t(37) = -1.92$, $p < .10$, $\eta_p^2 = .09$. When we evaluated whether use of effective strategies increased over time and whether this was associated with increases in MAI scores, effects were nonsignificant.

<u>Exploratory analysis of changes in course performance</u>

We evaluated how exam quartile membership changed over the semester and why some students may have changed quartile membership. In the lowest-performing quartile, two subgroups emerged: those who remained in the lowest quartile throughout the semester ($n = 6$) and those whose performance occasionally improved on specific exams (e.g., moving into a higher quartile on one exam) but remained in the lower quartile overall performance was more variable but remained low ($n = 5$). Given that group sizes are small, we treat these analyses as exploratory. It appears that students who remained in the lowest quartile were less confident in the material throughout the semester relative to low performers whose performance was more variable (d(s) = -1.64, -1.52, -0.74, -0.98). No other predictors emerged for these groups.

In the highest-performing quartile, two subgroups also emerged: those who remained in the highest quartile throughout the semester ($n = 7$) and those whose performance was more variable but remained high ($n = 4$). Those who remained in the highest quartile appeared to have higher MAI scores at the beginning of the semester relative to those with more variable but high performance, $t(9) = -1.87$, $p < .05$, $d = -1.17$. No other group differences emerged.

<u>Summary of Results</u>

Greater completion of metacognitive interventions and greater increases in MAI scores were both moderately associated with higher final course grades. We used a statistical approach to evaluate the relative influence of change in MAI over time separately from the influence of average metacognitive awareness on final course grade. We found that a stronger final course grade was associated with an increase in MAI across the semester, but not to student's average metacognitive awareness.

Students who perceived that their prior semester was harder than they expected performed worse across several exams and performed more poorly in the final course than their peers who perceived that their prior semester was about as hard as they expected. These perceptions were unrelated to MAI scores or intervention completion. Perceived confidence in course material remained stable across the semester and was not related to exam performance. Greater time spent studying was negatively associated with exam performance, whereas spending a greater percentage of study time with peers was modestly positively associated with performance. Use of ineffective study strategies was associated with worse performance on one exam. Students who demonstrated larger increases in MAI scores over time showed trend-level decreases in ineffective strategy use, however ineffective strategy use did not decline for the overall sample. Exploratory analyses suggested that students who remained in the lowest performance quartile reported consistently lower confidence on exam material, whereas students who consistently performed in the highest quartile entered the semester with higher baseline MAI scores.

Discussion

Our evaluation of the pilot metacognitive intervention provides preliminary evidence that embedding brief, structured metacognitive interventions directly into undergraduate engineering coursework may support students' development as self-regulated learners and be meaningfully associated with academic outcomes. In our sample, greater intervention completion was moderately related to higher course grades, suggesting that repeated engagement with metacognitive processes such as planning, monitoring, and evaluation may help students make more strategic study decisions. Additionally, those with larger increases in Metacognitive Awareness Inventory (MAI) scores showed small-to-moderate trend-level reductions in ineffective strategy use. Taken together, these results suggest that growth in metacognitive skills may transfer to more effective study strategies when paired with course-specific activities.

Students who reported that their prior semester was harder than expected had significantly poorer academic outcomes than those who reported it to be about as difficult as expected. Notably, student perceptions were not associated with MAI scores or with completion of metacognitive interventions. This perception may reflect personal judgments about ability that relate to a student's mindset about their abilities. For example, students who perceived their prior semester as more difficult than expected may believe their difficulties are due to lower intelligence or a lack of natural talent for engineering (for a discussion of the role of mindset in academic achievement, see [18]). Given our results, these students may not report lower metacognitive awareness and may engage in metacognitive activities, yet they still perform relatively worse than other students because they perceive challenging coursework as indicating that they do not have the ability to succeed in engineering. For engineering educators, openly discussing mindset may reduce the influence of student perceptions of difficulty on academic outcomes. As we collect more data, we plan on testing whether mindset or perceptions of difficulty moderate the relationship between the acquisition of metacognitive skills and course performance.

Among students in the lowest-performing quartile, several performed more strongly on specific exams over the semester, whereas several others maintained performance in the lowest quartile across exams. What appeared to differentiate these groups was their confidence in the material: students who consistently performed poorly were the least confident in the course material. These results stand in contrast to our findings that confidence in the larger sample was not associated with exam performance. For engineering educators, assessing students' confidence of course material may help determine whether students could benefit from a more focused intervention or from the allocation of learning supports.

Several interesting findings emerged from our direct evaluation of student-endorsed study strategies. The number of hours studied appeared to be negatively associated with performance on exams. These results suggest that there may not be an incremental benefit to studying for many hours; rather, the nature of the hours studied may matter most, fitting with a large literature that identifies the most effective learning strategies (see [3, 6]). Although more hours spent studying with peers were moderately related to stronger performance on exam 2 ($r = 0.31$), these effects were inconsistent across exams. At the institution where this intervention was piloted, students may attend supplemental instruction, which is a peer-assisted study session [4, 19, 20]. Although attendance at supplemental instruction is associated with improved course outcomes, these effects may be moderated by self-regulated learning skills, the effective distribution of supplemental instruction, and whether instructors utilize evidence-based teaching principles [4]. For engineering educators, recommending the use of resources such as supplemental instruction, along with metacognitive interventions, may increase student success. The current study is underpowered to detect small effects, however, and our future work plans to evaluate such hypotheses.

We found that the association between the use of more ineffective strategies (e.g., reviewing class notes, reviewing course lecture videos, reading the textbook) in exam preparation and worse exam performance strengthened over the semester. Although time did not emerge as a significant factor in our analyses, students who showed larger increases in MAI scores exhibited moderate, trend-level reductions in ineffective strategy use by the end of the semester. Students may be motivated by the prospect of more efficient learning. Instructors could leverage this motivation to facilitate learning by highlighting that the use of ineffective strategies relates to poor course outcomes and that many of these strategies require substantial time may encourage students to adopt more effective learning strategies.

Future Directions

The present findings should be interpreted in light of several limitations. We did not systematically collect data on potentially important confounding variables such as student demographics, external course load, employment commitments, or other competing demands. Although some students referenced these factors in their written materials, these data were not gathered in a structured way and therefore cannot be incorporated into the current analyses. Future work will intentionally assess these variables to better contextualize student performance and strengthen interpretation of results.

A primary next step is to expand the sample by including an additional cohort from a subsequent semester, increasing the anticipated total sample to approximately 100 students. This larger sample will provide greater statistical sensitivity and allow for more robust analytic approaches. We also plan to conduct a systematic analysis of students' written reflections to better understand their experiences with and perceptions of the metacognitive intervention, which will inform continued refinement of the approach.

Conclusions

This initial study provides preliminary evidence of the effectiveness of metacognitive interventions in an undergraduate Fluid Flow course. The intervention appeared to positively affect several indices, including improved course performance, increased metacognitive awareness, and reduced use of ineffective study strategies. Importantly, the interventions were designed to be efficient and effective, indicating that some students may not require intensive interventions to achieve beneficial gains in their metacognitive awareness and use of metacognitive strategies. Ultimately, integrating evidence-based learning strategies more explicitly and experientially may offer a meaningful opportunity to increase student success.

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