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Empowering engineering students to become more effective and self-regulated learners through course-integrated learning strategies intervention: a pilot study in a solid mechanics course

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Teaching Students to Engage in Active and Deep Learning through Course-integrated Learning Strategies Intervention: a Pilot Study in Solid Mechanics Class

Introduction and Literature Review

Although learning is pivotal both within and beyond the classroom, it remains an underemphasized skill in engineering education. Ineffective learning strategies can hinder students' academic progress and their adjustment to the demands of university life, particularly in the challenging context of engineering courses. Many students intuitively rely on strategies such as rereading, highlighting, repetition, and memorization (Dattathreya, & Shillingford, 2017). However, these approaches often fall short of fostering the higher-order thinking required for success in engineering disciplines. Consequently, critical learning outcomes—such as conceptual mastery, problem-solving, and synthesis—become difficult to achieve without adequate support for learning skills.

To address these challenges, learning assistance is frequently offered outside the classroom. Common models include learning-to-learn courses, supplemental instruction, remedial programs, and learning assistance centers (Simpson et al., 1997). While valuable, these resources are typically extracurricular (i.e., not integrated into the core curriculum) and generic (i.e., not tailored to specific disciplines). When learning skills are presented in overly broad contexts, students often struggle to apply them effectively in discipline-specific scenarios (Mayer & Wittrock, 2006). In contrast, in-class interventions hold promise for enhancing students' self-regulated learning. McGuire (2015), for instance, advocates for a one-time lecture on learning strategies and metacognition. However, for such interventions to be effective, students require more than isolated instruction; they need opportunities to apply these strategies across diverse contexts. This includes instructors modeling how to recognize when specific strategies are useful and providing ongoing feedback (Wingate, 2007). Some instructors embed learning strategies into course activities without explicitly explaining how or why they work. While this approach may help students see the relevance of these strategies within specific contexts, it often fails to support their transfer to novel situations. Successful transfer of learning requires the development of reflective expertise (van Merrienboer et al., 1992)—a form of metacognitive skill that enables students to not only execute a strategy but also understand its underlying principles. This expertise involves constructing explicit knowledge and schemas that allow learners to decontextualize and adapt skills beyond the training environment (Hesketh, 1997; Reeves & Weisberg, 1994).

This paper reports on our study of course-integrated learning interventions and their impact on student learning in engineering classrooms. We specifically study this in a Solid Mechanics course in a mechanical engineering curriculum. Specifically, we introduced three activities that promote effective learning. First, *concept mapping* was promoted so that students can practice *organizing* important concepts (Hunt & Einstein, 1981), and *elaborate* on what they have learned by connecting new information to existing knowledge (Alexander, 1996). Second, *learning journals* were introduced where students can practice *metacognitive awareness* on what they know and don't know to guide their next steps in learning (Zimmerman, 2000). Third, students were asked to *actively recall* what they had learned so that they could self-test what they remember and enable long-term retention of the materials (Roediger & Butler, 2011). We study the correlation of the training program participation with student learning outcomes, measure student self-reported changes in learning behavior and strategies, and assess the impact of the training program on various demographic groups.

Method

Class Overview

A pilot course-integrated learning strategies intervention approach to teach students metacognition and learning strategies was piloted in a Solid Mechanics class in the Spring 2024 quarter at a public research university in the United States. This class was chosen for this pilot intervention for its timing in the student's academic career and the nature of the content. It is an upper-division foundational class that many students find to be one of the first challenging courses to learn. Training students on how to learn in this course is particularly meaningful. It is hoped the students will apply the learning skills in later courses. The course was 10 weeks long and covered the fundamentals of solid mechanics, including stress and strain from various loading (axial, shear, bending, torsion, combined), stress and strain relationship, etc. The class met three times a week: on Tuesday and Thursday, the class meets for an 80-minute lecture taught by a professor, where new concepts were introduced; on Friday, the class met for a 50-50-minute-long discussion session, which was led by a Teaching Assistants (TA), where problem-solving about same week's content was practiced. There were two 50-minute long quizzes, one in week 3, one in week 8, and a 3-hour long final exam.

The Intervention

The course-integrated learning strategies intervention was introduced to students in the name of the "Learn Smart" program. A program introduction lecture was given in week 4 (lecture 9) after quiz 1. Then, a series of supplemental learning strategy training materials and assignments were given throughout the rest of the quarter.

In the introduction lecture, students were given an overview of a collection of science-based effective self-regulated learning tools, including cognitive learning strategies, growth mindset (Dweck, 1999), metacognition, and motivation, and a set of cognitive strategies such as active recall, concept mapping, spaced learning, and interleaved learning. The lecture focused on the science of human learning to help students understand why these learning strategies are effective. The lecture also discussed some of the commonly used but ineffective learning strategies and why they should be reduced. Following the introduction lecture, extra credit assignments were given to encourage the usage of active recall, concept mapping, and spaced learning. Additionally, textbook pre-reading assignments and group peer discussion videos were also available as extra credit throughout the entire course. Feedback was given to students for the first two active recall, concept mapping, and weekly schedule assignments, and the rest was graded for completion. Students were also given a weekly learning journal, which prompts students to reflect on their learning for the last week, the utility values of the learning strategies they used for the prior week, and monitor their learning progress as well as make necessary adjustments. The learning journal assignments (through Google Form) were mandatory up to week 5, and became extra credit assignments later in the quarter, as feedback was received from students that some of them did not find the learning journals helpful for learning.

The exam for the course was redesigned to promote and enhance metacognition by explicitly separating questions into various levels of learning outcomes according to Bloom's taxonomy: remember, understand, apply, analyze, evaluate, and create. Due to the limited time of in-person exams, only the first four levels were tested. Both quizzes and final exams were closed books and closed notes; students were given the equations they needed to use.

Participants

There were a total of 129 students in the class, with 31 female, 94 male students, and 4 others. And 46 students were first-generation students, and 40 were Underrepresented Minority (URM) students.

Data Collection

Multi-faceted data were collected: students' demographics (gender, First-generation college student or not, URM or not), course assignments and assessment grades (two quizzes and final exam), overall course grade, learning strategies completion status, and responses to weekly Learning Journal surveys. In addition, a Beginning-of-Quarter survey and an End-of-Quarter survey (Appendix 1) were used to gather information on students' familiarity with various learning techniques. Learning Journals then serve as a weekly reflection and planning method for students' learning. In particular, the weekly learning journals asked students to indicate their time spent on learning activities in the past week and to rate the confidence level of their cumulative knowledge through the course progression on a Likert scale. Furthermore, the following open-ended questions were asked in each weekly Learning Journal:

"Please describe the main learning activities you participated in and learning techniques you used (refer to the different learning techniques at the beginning of the quarter survey), and roughly how much time you spent on them each."

"Plan for upcoming week's MAE 131A learning activities. Very briefly, describe what you expect to adjust to your learning activities and the techniques to use."

Data Analysis

The research questions this study aims to answer are:

R1. What kind of change does this training program generate in the students' self-reported learning behaviors and strategies?

R2. What are the student's overall self-reported learning behaviors throughout the training program?

R3. What is the correlation of the training program participation with students' learning outcomes?

We used mixed research methods to answer the above questions.

Quantitative data gathered from beginning and end-of-quarter surveys and learning journals, as well as students' grades and demographic data, were used for quantitative analysis. Some Likert scale questions in the surveys were mapped to a scale from 0 to 5 for quantitative analysis. In addition, course grades for prerequisite courses, including Statics/Introduction to Dynamics and Introduction to Differential Equations, were used alongside the cumulative grade point average (GPA) after the Spring 2024 quarter and the GPA obtained in the Spring 2024 quarter to contextualize data. Correlation coefficients were calculated to analyze the correlation between the use of various learning techniques and students' performance. T-tests were conducted to determine where there were significant changes in students' familiarity or thoughts about various learning strategies.

Open-ended responses to weekly learning journals were thematically analyzed individually and coded in ATLAS.ti to identify trends in student learning strategies. Agreements were made on the learning strategies to be coded and on when to code for each strategy. After the coding process, the presence of learning strategies and corresponding groups was captured in a database. These were comparatively analyzed to identify trends in student learning strategies in relation to the course progress and their performance.

Results and Discussion

In this section, we will discuss the results of each research question.

R1. What kind of change does this training program generate in students' self-reported learning behaviors and strategies?

In this pilot study, we aim to steer students to use some more effective learning strategies more often in their learning, such as retrieval practice, spaced learning, interleaved learning, elaboration, creating mental images, summarization, self-explanation, non-linear reading, non-learning note-taking; while reducing the use of ineffective learning strategies such as highlighting or underlying, rereading, linear reading, etc. All of these learning strategies were discussed in the introduction lecture. In addition, there is a retrieval practice - active recall after each Tuesday and Thursday lecture, concept mapping, and schedule planning assignment each week. In other words, we created assignments to provide the students with hands-on experience using these learning tools and receive feedback. We found it challenging to collect artifacts for other learning strategies such as elaboration, non-linear or reducing highlighting while reading, etc.

To compare the pre-and-post intervention difference, students were given two learning strategies surveys: one in week 1, and one after the final exam (Appendix 1). The two surveys overlap on the questions that inquire students' use of learning strategies, and demographics. In addition, the end-of-quarter survey asked students about their experience of the Learn Smart program. Out of the 129 students in the class, there were 118 students who completed the beginning-of-quarter survey, 112 students who completed the end-of-quarter survey, and 98 students who completed both the beginning-of-quarter and end-of-quarter surveys.

To understand the pre-and-post-intervention difference, T-tests with 5% significance level were conducted on students' responses about learning strategies, growth mindset, motivation, and questions (Appendix 1).

The learning strategies that showed significant change pre-to-post intervention are summarized in Table 1. As shown in Table 1, students became significantly more familiar with the technique of "reading textbooks before lectures", "active recall", and "summarization of materials learned last week" after the intervention compared at the beginning of the quarter, or pre-intervention. Additionally, students were disincentivized by the ineffective learning technique of highlighting the textbook. Students also gained knowledge about learning techniques and felt more confident to apply them at the end of the quarter. This may be due to the intervention which showed the effectiveness of different learning techniques, and to the extra credit assignments which incentivized students to practice these learning techniques. Additionally, learning strategies such as active recall may be easy for beginners to do well, contributing to students' increased familiarity. On the other hand, it is interesting to see that more students felt they could not change their basic intelligence and that fewer students like to understand the course content deeply at the end of the quarter. This may be caused by the quizzes and exams being quite difficult, which decreased the students' morale.

For students who had Quiz 1, Quiz 2 and the final exam scores (n = 115), additional post hoc analyses were conducted by creating an ordinal variable that grouped the students by the amount of participation in the activities in three levels (did not participate, n = 32; participated in less than half of the activities, n = 52; participated in half or more, n = 31). When we looked at students' performance in summative assessments, there were no significant differences in the Quiz 1, Quiz 2, or Final exam grades between the three groups (generalized linear regressions, all *F*s < 1, all *p*s > 0.5) or by whether the students have participated in any activities or not (participated vs. did not participate, all *F*s < 1, all *p*s > 0.3).

Interestingly, for students who filled out both the pre- and post-class surveys (n = 90), more than half of the students who participated in half or more (≧ 50%) of the activities showed an increase in their growth-oriented mindset after participating in the intervention (20 out of 30 students, $\chi^2(2) = 15.2$, $p < 0.001$).

Table 1: Students' self-report on Learning Strategies, growth mindset, motivation

	Beginning of Quarter Survey (N=118)		End of Quarter Survey (N=112)			
Familiarity with Learning Strategy (scale from 0 to 5)	**Mean**	**STD**	**Mean**	**STD**	**T-test P-value**	**Change in Mean Value**
Pre-reading Textbook	2.492	1.153	2.938	1.268	0.006	+0.446
Highlighting Textbook	2.627	1.239	2.304	1.300	0.055	-0.324
Active Recall	2.975	1.499	3.616	1.202	0.000	+0.641
Active Recall Within Lecture Day	2.534	1.363	3.143	1.214	0.000	+0.609
Summarization of Knowledge from Last Week	2.898	1.284	3.295	1.136	0.014	+0.396
Self-evaluation about knowledge and confidence, Learning Strategies (scale from 1 to 7)						
Knowledge about Learning Strategies	4.949	0.959	5.473	0.939	0.000	+0.524
Confidence to Apply Learning Strategy	4.729	1.018	5.018	1.082	0.038	+0.289
Growth mindset						
"I can't change my basic intelligence." (1 = strongly agree to 6 =	4.186	1.513	4.563	1.426	0.054	+0.376

strongly disagree, High score shows higher growth-oriented mindset)						

Other strategies which was surveyed but did not show significant change in familiarity level from the beginning to the end of the quarter include the following: rereading textbook, reviewing notes, reviewing problem solutions, taking notes from slides or textbook, rewriting notes, imagery from text, concept mapping, taking verbatim notes, elaboration, self-explanation, explaining concepts, memorization, using mnemonics, generating real-life examples, answer practice questions, reviewing graded work, spacing out learning, cramming before exams, interleaved practices, and ensuring sufficient sleep. All of these techniques were mentioned during the lecture about smart learning. However, among these listed strategies, extra credit assignments were only given for doing concept mapping. The lack of significant change for the techniques, except concept mapping, may be explained by the lack of practice students have with them, as there were no extra credit assignments incentivizing students who were not already familiar with these techniques to try them out. The reason that no assignments were given for these assignments was mainly because it was difficult to collect artifacts. For example, elaboration refers to students conducting elaborate integration whenever they learn new materials, such as during a lecture, reading textbooks, etc. These mental activities were difficult to keep track of in the current study context.

As for the concept mapping technique, the reason that even though a weekly assignment was given, still no statistically significant results were generated may stem from that many students who attempted it were not very skillful at summarizing concepts. As a result, they have completed the concept mapping assignments by simply drawing random arrows between concepts without thinking, therefore gaining extra credits without improving their understanding. It is also possible that students considered concept mapping to be very similar to active recall and therefore repetitive, thus not putting in too much deep thought when completing the assignment. Also, it may be possible that there was not sufficient guidance and feedback for students to improve concept mapping skills, as the later extra credit assignments were graded for completion only. Other than that, it could also be possible that most students were already familiar with these above-mentioned learning techniques, so they couldn't become more familiar with a learning technique that they are already very familiar with.

R2. What are the student's overall self-reported learning behaviors throughout the Learn Smart training program?

Understanding how students' learning behaviors developed during the progression of the course will be helpful to better understand how the training program may have changed their learning. In the weekly learning journal (Appendix 2), students were promoted to report the learning strategies they used for the prior week to provide an open response.

We analyzed the open-ended responses from the Learning Journals for students' current week-reported strategies for the prompt: "Please describe the main learning activities you participated in and learning techniques you used, and roughly how much time you spent on them each." We also examined their planned strategies for the following week for the prompt "Plan for upcoming week's MAE 131A learning activities. Very briefly, describe what you expect to adjust to your learning activities and the techniques to use." A thematic analysis was conducted using ATLAS.ti software. We try to understand the trends by looking at their frequency in each week, comparing behaviors reported in the current week and those planned for the next, as well as the combined results. The first learning journal was due in week 2, and last one was due in week 10, always prompting the students to reflect on their previous week's learning strategies.

Table 2. Combined Learning Journal Table: The table shows the overall codes for select learning strategies during each learning journal, taking into account both reports for the current week as well as learning strategies planned for the following week. Numbers represent the number of students who would mention it during either question.

	LJ1	LJ2	LJ3	LJ4	LJ5	LJ6	LJ7	LJ8	LJ9	Total
Homework:With Notes/Unspecified	58	64	48	48	51	36	35	33	34	407
Practice Questions With Notes/Unspecified	58	46	35	31	31	32	38	46	48	365
Active Recall: After/Unspecified	11	13	16	65	52	36	35	44	36	308
Group Studying/Discussion	20	28	29	26	22	25	24	21	24	219
Later Week Review Notes	27	37	27	16	20	19	23	18	25	212
Read After Lecture/Unspecified	51	27	32	24	12	13	13	11	13	196
Textbook/Slides Read Before Lecture	32	26	29	30	18	17	13	10	12	187
Spaced Learning	29	17	23	17	24	8	17	12	6	153
Mind/Concept Mapping	2	4	5	17	32	23	21	23	23	150

Regarding the combined overall results, homework completion, practice questions, active recall, group studying, reviewing notes, reading the textbook, spaced learning, and concept mapping emerged as the dominant learning behaviors. While most of these strategies were relatively consistent throughout the quarter, active recall and concept mapping saw large increases during and following week four of the quarter. This could be attributed to the training program intervention, where students may have been made aware or reminded of the strategies and their usefulness. Other learning strategies with large frequencies not depicted in the table above include independent learning (85 codes), attending office hours (85), summarization (75), and reviewing problem solutions from textbooks and lectures.

Table 3. Current Week Table: The table shows the number of codes for select learning strategies students reported when asked to describe the strategies they used throughout the current week. The numbers represent the number of students who mentioned each strategy during each learning journal.

	LJ1	LJ2	LJ3	LJ4	LJ5	LJ6	LJ7	LJ8	LJ9	Total
Homework: With Notes/Unspecified	47	51	41	36	43	32	30	31	32	343
Practice Questions With Notes/Unspecified	27	23	22	12	15	12	22	26	20	179
Active Recall: After/Unspecified	8	7	10	36	29	23	21	31	27	192
Group Studying/Discussion	15	23	21	22	17	19	18	17	19	171
Later Week Review Notes	20	28	18	11	14	13	16	13	16	149
Read After Lecture/Unspecified	36	16	24	21	8	11	12	9	11	148
Textbook/Slides Read Before Lecture	19	13	18	19	14	12	8	7	12	122
Spaced Learning	4	1	4	4	5	0	2	2	1	23
Mind/Concept Mapping	2	2	2	2	21	15	12	14	11	81

Table 4. Planning for next week table: The table shows the number of codes for select learning strategies students reported when asked to plan learning strategies for the following week. Numbers represent the number of students who mentioned each strategy during each learning journal.

	LJ1	LJ2	LJ3	LJ4	LJ5	LJ6	LJ7	LJ8	LJ9	Total
Homework:With Notes/Unspecified	11	13	7	12	8	4	5	2	2	64
Practice Questions With Notes/Unspecified	31	23	13	19	16	20	16	20	28	186
Active Recall: After/Unspecified	3	6	6	29	23	13	14	13	9	116
Group Studying/Discussion	5	5	8	4	5	6	6	4	5	48
Later Week Review Notes	7	9	9	5	6	6	7	5	9	63
Read After Lecture/Unspecified	15	11	8	3	4	2	1	2	2	48
Textbook/Slides Read Before Lecture	13	13	11	11	4	5	5	3	0	65
Spaced Learning	25	16	19	13	19	8	15	10	5	130
Mind/Concept Mapping	0	2	3	15	11	8	9	9	12	69

When comparing the results from the individual questions regarding their current week and planned learning activities for the next week, some notable similarities and differences appear. In both questions, the coding showed that active recall and concept mapping both showed increased frequency following the training program intervention in week four. There exists some large differences in the frequency of coding between the reported learning behaviors during the week and planned for the next. These occur with the following strategies: homework (343 codes in the current week vs 64 in planning), group studying (171 vs 48), reviewing notes (149 vs 63), reading textbooks before the lecture (122 vs 65), and spaced learning (23 vs 130). These differences could indicate students are neglecting to mention their actual usage of a specific learning strategy, using strategies that they don't specifically plan for, or not following through with their intended plans.

R3. What is the correlation of the training program with students' learning outcomes?

We are also interested in understanding how participating in this program correlates to students' learning performance within the training time frame. One challenge to conducting such analysis is the various levels of participation in the many training components. For example, some students participated in x % of active recall, and y % concept mapping. With different activities and different participation rates, it was difficult to define participation. In addition, different assignments involve various levels of effort and time commitment, and it was challenging to precisely quantify the differences between the assignments. Thus, we assigned the same points to all learning strategies assignments, and calculated participation based on completion. We investigated the correlation between participation in a few important learning strategies and course learning outcomes, measured through delayed tests - quizzes, and final exams.

Active Recall

The effects of the active recall learning technique on students' performance were analyzed because students reported becoming more familiar with this learning technique by the end of the quarter, and there were submitted artifacts for the learning technique which allows for an effective measurement of how many students practiced it.

For active recall, students were given the opportunity to submit an artifact or create a brief summary of the new concept discussed in the lecture that day, and submit this summary for extra credit. Active recall is a format of retrieval practice. The core idea of active recall is to recall what has been recently learned without accessing the materials. Students could try to write down, draw concept maps, verbally paraphrase, or just mentally actively recall what they remember from the newly learned lesson. To overcome the forgetting curve, students were encouraged to conduct the active recall during the same day of the lecture within 12 hours, but the assignment was due at midnight the next day after the lecture. To meet the requirement for an assignment, students were required to write down a summary or draw a concept map from their active recall as an artifact to submit. There were 2 active recall assignments each week, a total of 12 for the pilot intervention quarter.

The correlation between the number of active recall assignments each student completed and their performance on quizzes and exams was studied. Correlation analysis showed a weak correlation between the number of active recalls completed and course grade, but showed no correlation between the number of active recalls completed and quiz or final exam scores, as shown in Figure 1. Additionally, the correlation coefficient seems to increase from quiz 1 to quiz 2 to the final exam, even though the coefficients are too small, and considered weak. Active recall was first introduced to students right after Quiz 1. This may suggest that active recall assignments benefit students' learning, although the benefit is small and takes some time to have effect on students' performance.

Active Recall vs Score Correlation Coefficient	
Quiz 1	-0.022
Quiz 2	0.102
Final Exam	0.135
Course Grade	0.333

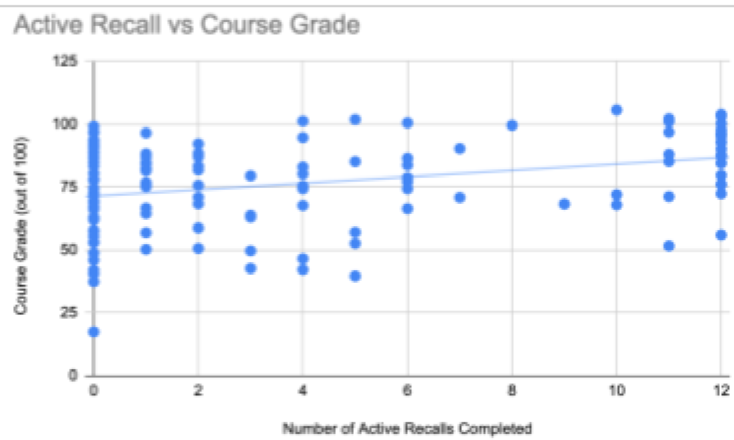

Figure 1: Correlation between active recall completion and grades

Students were also categorized into comparison groups by the number of active recall assignments completed to analyze whether active recall improves the time efficiency of studying. The groups were created somewhat arbitrarily to show the most extreme cases (0 and 12 active recalls completed) and to ensure a sufficient sample size for each group. Other features of these 4 comparison groups, such as GPA or hours that students reported to have worked for pay each week, were also analyzed to see if there are other explanations for the differences.

As shown in the table, the correlation between time spent and scores was still negative. Other features of these 4 comparison groups, such as GPA or hours that students reported to have worked for pay each week were also analyzed. It seems like the group who completed all 12 active recall assignments worked for pay for the longest hours each week, but still had a comparable GPA to the other groups that quarter. This may suggest that they were able to study more efficiently using active recall techniques, which allows them to learn well despite having to spend lots of time working for pay. However, this could also be caused by other features of this group such as motivation or prior knowledge about the subject.

Table 5: Comparison among groups that completed different number of active recall assignments

Separated by # Active Recall Completed (AR)		**0 AR**	**0< AR <6**	**6≤ AR <12**	**12 AR (all)**
Sample Size		**39**	**45**	**21**	**20**
Correlation Coefficients (time vs grade)	Quiz 1	-0.2625	-0.3626	-0.3083	-0.1955
	Quiz 2	-0.2190	-0.3775	-0.3576	-0.2865
	Final Exam	-0.1833	-0.4027	-0.5436	-0.3206
	Course Final Grade	-0.0778	-0.2210	-0.2334	-0.0178
GPA: Term		2.9	3.5	2.9	3.2
GPA: Cumulative		3.2	3.7	3.3	3.3
Hours Worked End of Quarter		4.2	3.5	6.5	6.9
Statics/Intro to Dynamics grade		85.2	91.4	88.5	90.1
Intro to Differential Eqs. grade		84.3	90.8	85.7	88.9

Conclusion and Limitations

In this study, a course-integrated approach to train students in metacognition and learning strategies was piloted in a solid mechanics class. The intervention successfully promoted students to use more effective learning strategies. The impact is especially significant for the learning strategies that were enhanced through extra credit assignments. Participation in active recall weakly positively correlates with course grade and enhances learning efficiency.

Both the qualitative and quantitative data obtained from the weekly Learning Journals used in this study required students to self-report information regarding their performance in class and their confidence in learning. As a result, the data itself inherently has limitations in its reliability. An example of this includes the potential for omission of information regarding their learning, whether intentional or not, due to a possible inclination for students to give a “correct answer” or the usage of a routine of learning strategies such that they are implied and therefore not reported. Furthermore, students can be inclined to be more or less specific with their responses overall due to fluctuations in interest or availability to complete the Learning Journals as the quarter progresses, causing the potential for variation in the responses between multiple students and in a chronological sense when looking at a particular student's progression.

While course, exam, and quiz grades were used alongside grade point averages to quantify a student’s performance and compare it to their learning strategies, this does not necessarily reflect a deep understanding of the course content. Grades could be influenced by various other outside factors including external commitments such as work, extracurriculars, or other hardships during the quarter. In addition, strategies such as cramming could result in a higher grade on quizzes or exams, but may not be helpful in a student's retention of information after the course.

In a similar vein, the structure and teaching style of the course or intervention method may be more effective for some students than others. Courses with other pedagogical techniques, such as choosing to offer the intervention as extra credit or being mandatory, the number of quizzes and examinations, the amount of homework, and more, may show different results as a result. Furthermore, the completion of the intervention does not directly cause an increase in effective learning strategy usage. This could be correlated to a difference in the effort put in by each student.

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Appendix 1

Questions in the Beginning of Quarter and End of Quarter Survey

Familiarity with Learning Strategy *Prompt*: Rate your familiarity of the following learning techniques: *6-point Scale*: Not familiar with this learning technique (0) - Know this learning technique but never done it (1) - Rarely (2) - Sometimes (3) - Often (4) - Very often (5)
Prepare for the lecture: Initial textbook reading or slide review before the lecture
Highlighting or underlining while reading text materials
Rereading textbook after an initial reading
Review notes after the lecture
Review problem solutions
Take notes from slides/textbook
Rewrite notes
Imagery for text: Attempting to form mental images of text materials while reading or listening
Mind/ concept mapping: rearrange and organize knowledge, find connections between concepts
Active recall
Active recall within the same day of the lecture
Take Verbatim (word by word) notes during the lecture
Elaboration: during the lecture or reading, try to relate the new information to my prior knowledge, ask questions like "What are the assumptions and conditions to use this principle, how does this apply to the xxx situation, how it relates to and differ from previous topics", etc.
Self-explanation: Explaining how new information is related to known information, or explaining steps taken during problem-solving
Teach others/ explain the concepts/ problem-solving strategies to others
Summarization: summarize what has been learned in the past week and consolidate the knowledge
Rehearse and memorize: Rehearse important facts to memorize them.
Use mnemonics (e.g., acronyms, keyword method)
Generate or construct real-life examples
Practice questions/quiz yourself: Answer practice questions without notes.
Review graded work/tests: For wrong answers, try to understand what I missed and why
Spaced learning over a few days

Study a big chunk of time before exams/assignments due time
Interleaved practice: alternate practice between different concepts, instead of just focus on one single concept
Ensure sufficient sleep
[Free-response] Are there any other techniques you have utilized when trying to succeed in your courses?
Self-evaluation and confidence about Learning Strategies
From 1 (not knowledgeable at all) to 7 (very knowledgeable), rate your knowledge about effective learning strategies.
From 1 (not confident at all) to 7 (very knowledgeable), rate your confidence using effective strategies properly based on the course content.
Growth Mindset (Adapted from Dweck, 1999)
Rate the following statements on a scale of 1 (strongly agree) to 6 (Strongly disagree) [I have a certain amount of intelligence, and I can't really do much to change it.]
Rate the following statements on a scale of 1 (strongly agree) to 6 (Strongly disagree) [My intelligence is something that I can't change very much.]
Rate the following statements on a scale of 1 (strongly agree) to 6 (Strongly disagree) [I can learn new things, but I can't really change my basic intelligence.]
Learning Motivation Questionnaire (Adapted from MSLQ, Pintrich, 1991) *Prompt*: Use the scale below to answer the question. Answer your questions based on the [Course Name]. *7-point Scale*: 1 (not at all true of me) - 2 - 3 - 4 - 5- 6 - 7 (very true of me).
The most satisfying thing for me in this course is trying to understand the content as thoroughly as possible.
When I have the opportunity in this class, I choose course assignments that I can learn from, even if they don't guarantee a good grade.
The most important thing for me right now is improving my overall grade point average, so my main concern in this class is getting a good grade.
In a class like this, I prefer course material that really changes me so I can learn new things.
If I can, I want to get better grades in this class than most of the other students.
Getting a good grade in this is the most satisfying thing for me right now.
In a class like this, I prefer course material that arouses my curiosity.
I want to do well in this class because it is important to show my ability to my family, friends, employer, or others.

Appendix 2

Learning Journal Questions

Weekly Learning Journal Questions
How many hours did you spend on all the learning activities for [Course Name] outside the lecture and discussion session?
Please describe the main learning activities you participated in and learning techniques you used, and roughly how much time you spent on them each.
From 1 (lowest) to 10 (highest), rate your confidence level for understanding and using knowledge covered in weeks 1 to [previous week] to solve problems.
Plan for upcoming week's [Course Name] learning activities. Very briefly, describe what you expect to adjust to your learning activities.
Additional Questions For Weeks 4-9
From 1 (lowest) to 7 (highest), rate your confidence level on the content covered in weeks 1 to [previous week] at different learning outcome levels. [Recall (remembering)]
From 1 (lowest) to 7 (highest), rate your confidence level on the content covered in weeks 1 to [previous week] at different learning outcome levels. [Understand (be able to explain)]
From 1 (lowest) to 7 (highest), rate your confidence level on the content covered in weeks 1 to [previous week] at different learning outcome levels. [Apply many related concepts together to solve problems]
In the past week, what learning techniques did you use that were found to be helpful to remember fundamental concept learned from class?
In the past week, what learning techniques did you use that were found to be helpful to use the knowledge to solve problems that require higher order thinking and a good understanding of interconnection of knowledge?