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Teaching Engineering Students How to Learn Through Course-Integrated Self-Regulated Learning Interventions: A Case Study for Engineering Mechanics Courses

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Introduction and Literature Review

Effective self-regulated learning (SRL), the process through which learners take active control of their learning by planning, monitoring, and reflecting on their progress toward academic goals, is a critical skill for both academic achievement and lifelong professional success in engineering. Engineers must continuously adapt to emerging technologies, tools, and methodologies, yet many undergraduates progress through engineering programs without mastering the skills needed to learn effectively and independently. Research consistently shows that engineering students frequently rely on inefficient learning strategies such as rereading, highlighting, repetition, and rote memorization, which undermine conceptual understanding, long-term retention, and knowledge transfer (Dattathreya & Shillingford, 2017). Such 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.

Although the importance of SRL for student success is widely recognized, effective approaches for helping students develop this skill remain insufficiently understood. Learning support is often offered outside the classroom through learning-to-learn courses, supplemental instruction, remedial programs, or learning assistance centers (Simpson et al., 1997). While valuable, these approaches are typically extracurricular (i.e., not embedded within the core curriculum) and generic (i.e., not discipline-specific). When learning strategies are taught in overly broad contexts, students frequently struggle to apply them effectively in discipline-specific situations (Mayer & Wittrock, 2006). Prior studies indicate that SRL interventions are most impactful when situated within the learning context; Prior studies have indicated that SRL interventions were most effective when situated in a context, and when fostering a high amount of student activities and metacognitive awareness. Such “embedded” instruction allows students to bring the application of metacognitive strategies in line with task demands by deciding which activity needs to be performed when in the context of a specific task.

In engineering education, common pedagogical approaches, such as project-based learning, formative assessment design, exam wrappers, and flipped classrooms, implicitly encourage students to plan, monitor, and evaluate their learning. However, these approaches often embed learning strategies without explicitly explaining how or why they work. While this implicit integration may help students recognize the relevance of learning strategies in specific contexts, it often fails to support transfer to novel situations. Successful transfer requires the development of reflective expertise (van Merriënboer et al., 1992), a form of metacognitive skill that enables learners not only to execute strategies but also to understand their underlying principles. Reflective expertise involves constructing explicit knowledge and schemas that allow learners to decontextualize and adapt strategies beyond the original training environment (Hesketh, 1997; Reeves & Weisberg, 1994). Research suggests that indirect activation of SRL alone, while beneficial, is often insufficient to cultivate metacognitive awareness or promote the transfer of SRL skills across contexts. Recent work therefore highlights the importance of explicit SRL instruction to support students in intentionally and effectively integrating evidence-based learning strategies into their learning processes.

In this paper, we investigate the implementation and outcomes of course-integrated SRL intervention in two foundational mechanical engineering courses series: ***Course #1– MAE 30A Statics and Introduction to Dynamics*** **and** ***Course #2 – MAE 131A Solid Mechanics I.*** This course-integrated SRL Intervention leverages the *synergy* between explicit instruction and deep-integrated effective learning strategies assignments in engineering courses. The explicit component teaches evidence-based learning strategies, such as active recall, concept mapping, elaboration, self-explanation, and spaced or interleaved practice, as well as growth mindset and metacognitive regulation. The indirect component embeds these strategies within authentic engineering coursework through evidence-based learning strategies assignments, projects, and post-exam reflections, prompting students to plan, monitor, and regulate their learning as part of disciplinary problem-solving.

A multi-methods research method combining quantitative and qualitative data, including students self-reports, artifact, learning behaviors logs, and performance, was used to examine the feasibility, student engagement, perceptions, and preliminary impact of integrating SRL instruction directly into core engineering courses, with particular attention to changes in students' motivation, use of effective learning strategies, and course performance. The study also identified key design characteristics, including task relevance, scaffolding, feedback, and incentive structure, that most strongly influenced participation, offering valuable guidance for refining engagement strategies and improving scalability.

Method

Classes Overview

The self-regulated learning strategies intervention we described in this paper, which we introduced as "Learn Smart Program" to the students, were implemented in two ***Statics*** **and Introduction to Dynamics (MAE 30A)** class sections and a subsequent course - ***Solid Mechanics*** **(MAE 131A)** class section in the winter and spring 2025 quarters at a public research university in the United States.

These two classes were chosen for the self-regulated learning intervention for its timing in the student's academic career and the nature of the content. Both courses are lower-division foundational classes that many students find to be one of the first a few challenging engineering courses to learn. Training students on how to learn effectively in these courses is particularly meaningful. It is hoped the students will apply the learning skills in later courses.

Both courses were 10-week long, with similar logistics structure: 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. For MAE 30A in winter 2025, there were two 50-minute long quizzes, in week 3 and week 8, and a 3-hour long final exam. For MAE 131A in spring 2025, there was one 50-minute long midterm exam in week 5, and a 3-hour long final exam.

Participants

The class enrollment for the three class sections studied in this paper are MAE 30A Section A in Winter 2025 (107 students); MAE 30A Section B in Winter 2025 (101 students); MAE 131A in spring 2025 (143 students). Students' data who consent to the reserach were included in this study.

The Intervention Design

This course-integrated SRL Intervention leverages the *synergy* between explicit instruction and deep-integrated effective learning strategies assignments in engineering courses. The explicit component teaches evidence-based learning strategies, such as active recall, concept mapping, elaboration, self-explanation, and spaced or interleaved practice, as well as growth mindset and metacognitive regulation. The indirect component embeds these strategies within authentic engineering coursework through evidence-based learning strategies assignments, projects, and post-exam reflections, prompting students to plan, monitor, and regulate their learning as part of disciplinary problem-solving.

Explicit instruction

The explicit introduction of effective self-regulated learning was mainly completed through a 80-minute long lecture “ how to learn effectively - learn in harmony with your brain”. In MAE 30A the lecture was given in week 2, at the beginning 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. The main goal of the lecture is to increase students’ belief that there are more effective learning strategies, as well as their knowledge about these learning strategies - what they are and why they work better (McDaniel & Einstein, 2023). To provide students a “hands-on” opportunity to witness how human cognition and memory can be affected by different learning approaches and conditions, several psychological experiments were given during the lecture. For example, to illustrate elaboration as an important effective learning strategy, “ Men Sentence” elaboration demonstration was given to the class (Pressley, etal, 1987).

Deep-integrated Effective Learning Strategies Assignments and Implicit Promotion of SRL

Another key component of the SRL intervention focused on fostering students’ commitment to and self-regulated planning and adjustment of effective learning strategies. To support this goal, a series of supplemental learning-strategy training materials and assignments were distributed throughout the remainder of the quarter. Following the introductory lecture, optional extra-credit assignments were used to encourage the practice of active recall, concept mapping, and spaced learning. In addition, textbook pre-reading assignments and group peer-discussion videos were offered as extra-credit opportunities throughout the course.

Formative feedback was provided on the first two active recall, concept mapping, and weekly scheduling assignments, while subsequent submissions were graded for completion. Course exams were intentionally redesigned to promote metacognition by explicitly aligning questions with different levels of Bloom’s taxonomy (remember, understand, apply, analyze, evaluate, and create). Due to time constraints in in-person exams, only the first four levels were assessed. Both quizzes and final exams were closed-book and closed-notes; however, students were provided with the necessary equations.

Table 1 summarizes the class overview, participants and Intervention.

Table 1. Summary of the class overview, participants and Intervention

	MAE 30A **Statics and Introduction to Dynamics**		**MAE 131A** **Solid Mechanics I**
Class Level	Sophomore		Sophomore
Main topics	Engineering Mechanics - Statics and Introduction to Dynamics		Stress and strain analysis
Implementation quarter	Winter 2025 Section A	Winter 2025 Section B	Spring 2025
Class enrollment Size	107	101	143
Students participated the study	95	92	116
The overall estimated intervention participation rate	90%	90% for the intro lecture 35% for most assignments	35% for most of the assignments
Targeted enhanced learning strategies	Elaboration, retrieval practice, spaced learning, interleaved practice, self-care for overall health		
Introduction lecture, timing, and duration	Week 2 (80 minutes)		None, Recorded video provided
Metacognition	Yes		
Growth Mindset	Yes		
Assignments and activities	None	Video modules: metacognition modules, growth mindset modules. Weekly assignments: Post-lecture active recall, concept mapping, schedule planning, and learning reflection.	
Feedback format	None	The first 3 assignments, graded with comments	

Data Collection

Multi-faceted data were collected and analyzed in this study: course assignments and assessment grades (pre-quiz, two midterm quizzes and final exam), learning strategies completion status, responses to Beginning-of Quarter and End-of-Quarter surveys, and learning behavior logs. The 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 behavior logs were captured through the online learning management system. For example, the student's first log-in time to access the homework, duration they spent, how many attempts they made for each question, and the time they submitted the assignment were recorded. In the study, cramming was defined as a student's first log in to access homework on the day of homework due date.

Data Analysis and Research Methods

The research questions this study aims to answer are:

R1. How did students experience and engage with the course-integrated learning strategies intervention?

> *RQ1.1 What factors motivated students to participate in and sustain engagement with the intervention?*
>
> *RQ1.2 What challenges and barriers did students encounter when engaging with the learning strategies?*

R2. What impact did the course-integrated learning strategies intervention have on students' learning behaviors, attitudes toward learning, and growth mindset?

R3. How did the intervention affect students' learning performance, as measured by course assessments and examinations?

This study employed mixed -research methods to answer these research questions.

For the quantitative part, a quasi-experimental design was employed to examine the relationships among student engagement in self-regulated learning strategies, perceptions of learning effectiveness, and course performance across multiple offerings of undergraduate engineering courses. The data source includes surveys, reflection reports, course performance records for assignments and exams, and behavior data including assignment submission, assignment submission time, and learning activity engagement. Likert-scale survey items were coded into numerical values ranging from 1-5 or 1-7, depending on the question, consistent with common practice treating multi-point Likert responses as approximately continuous for parametric analysis.

The analysis employed a combination of tests to examine outcomes in students. Descriptive statistics were used to summarize participation rates and student perceptions.Paired t-tests were used to assess changes in students' attitude towards learning, growth mindset, and self-reported knowledge and confidence related to learning strategies. Independent-sample t-tests were performed to evaluate differences in exam performance based on students' completion rates of learning activities. Multiple regression analyses were used to examine relationships between study behaviors and academic performance, including whether the adoption of particular learning strategies served as a significant predictor of increased exam scores. Pearson correlation coefficients were additionally calculated to assess relationships among reported learning strategy usage. Statistical significance was evaluated at an alpha level of 0.05.

The study also employed a qualitative thematic analysis to examine students' experiences with self-regulated learning strategies. Qualitative data drawn from the open-ended responses from the end-of-quarter surveys. Data consisted of structured written reflection reports completed at the end of the term. Prompts asked students to reflect on their learning strategies, their experience participating in the learning strategies intervention program, challenges that prevent them from participating in the program.

A hybrid inductive and deductive thematic analysis was employed. Initial deductive codes were informed by self-regulated learning and motivation frameworks (e.g., metacognition, self-regulated learning, and self-determination theory), while inductive coding allowed for emergent themes grounded in students' reflections.

Four researchers independently coded an initial subset of reflection reports to develop a preliminary codebook. Through iterative discussion and refinement, codes were clarified and consolidated. The refined codebook was then applied to the full dataset, with regular meetings to resolve discrepancies and ensure consistent interpretation. Once codes were applied throughout, a cross-checking process was applied to ensure consistency in code applications. Each coder reviewed 20% of the codes applied by the other three researchers. Upon discussing coding differences, code definitions were further refined and re-coded into student responses. This coding process allowed for a consistent and reliable dataset to review students' motivations and barriers.The researchers used Atlas.ti software.

This study was approved by the institution's IRB. Student participation was voluntary, and all data were anonymized prior to analysis.

Results and Discussion

This section presents the results addressing the three research questions.

R1. How did students experience and engage with a course-integrated learning strategies intervention?

Across all offerings, approximately 85–90% of students attended the introductory lecture, which is named "How to Learn More Effectively." Submission rates for learning-strategy assignments (e.g., active recall, concept mapping) were consistently around 35–40%.

RQ1.1 What factors motivated students to participate in and sustain engagement with the intervention?

Analysis of open-ended responses from the end-of-quarter survey from both MAE 30A and MAE 131A revealed primary themes related to the factors that motivated the students to participate in and sustain engagement with the Learn Smart Program, as well as the challenges/ barriers for those who did not participate in the program. A variety of factors played into a student's decision on whether to start and sustain engagement with the Learn Smart program: (1)Identified Value; (2)Self-Improvement Goals; (3) Intrinsic Interest; (4) Extra Credit Incentives; (5) Witnessing Notable Improvement.

Identified Value

The most prominent reason students mentioned for participating was the perceived value of the intervention to their learning (82 codes). Students were drawn to participate from the pitched opportunity to study more effectively, as exemplified by this comment: *"What motivated me to participate in the effective learning strategies was knowing that it was going to help me overall and provide a way for me to get a deeper understanding of things, all while trying a new strategy that will help me in other classes down the line."*

One key selling point of the program that students found valuable was its emphasis on studying efficiently, and how using strong learning strategies can be more beneficial than studying longer using less effective techniques. Students would say: *"I participated in the effective learning skills activities to introduce myself to smarter learning strategies. With an* *interest in learning how to 'work smarter not harder' and to make efforts to improve my intelligence, I believed it was worth giving these strategies a try…"*

A significant number of students were drawn to this idea of efficient studying, motivated by the concept of learning more in less time. Several students expressed a desire to save time, as commented by this student: *"What motivated me to engage was the possibility of being more effective in studying and having some free time again while making studying less stressful."* With how valuable time can be for college students, the program's expectation for efficient learning proved to be a major point of entry to participation.

Self-Improvement

Self-improvement goals were another recurring reason for engaging with the program (38 codes). This set of students held growth mindsets and were motivated to improve their own understanding and learning abilities, with an emphasis of continuous improvement towards their future goals. As one student described, "*I think I can always improve my studying/learning habits so any change I get to improve I will make my best effort to do so…"*

Many of these students reflected on previous quarters and were motivated by the belief that changing their learning methods could improve their performance. One student stated: *"I wanted to prove I could learn more than previous quarters."* Students like these appear to be very motivated by competency, wanting to improve themselves and become competent with regards to the material.

Students who had struggled in previous classes also saw the learn Smart program as an opportunity to improve information retention, rather than learning for a current class and forgetting immediately after. One student described their desire to apply their learning to future classes: "*The biggest thing was actually just wanting to improve myself. I think classes and workload will only increase in the future and I want to grow with my learning so this was a great opportunity."*

Given the fast-paced nature of college courses, students would be motivated to improve their own long-term retention. One student explained engaging in order to retain their knowledge and apply it to future courses: *"It's pretty hard to retain everything you learn due to the fast-paced nature of the quarter system, so the activities I did were in hopes of better understanding the content and retaining it for the future…"*

Intrinsic Interest

Many students also mentioned being motivated to engage because of an intrinsic interest in learning. The learn Smart introduction lecture played a large role in encouraging exploration of learning strategies through presentations on learning science and introducing students to the effective learning strategies. Many students appreciated this cognitive-science backed introduction, saying, *"...Seeing that these learning strategies were backed by cognitive psychology studies inspired me, as I believed they could scientifically make a difference in the way I learned."*

This interest in learning science was further enhanced by a hands-on demonstration approach to the lectures. During the introduction lecture, students participated in activities in which they put the learning strategies to the test. Some of these activities included "experiments" in which students used strategies such as elaboration and knowledge organization and observed an improvement in their ability to remember words. Many students were engaged by this, such as one student who described how these motivated them to participate: *"The moments where we* *were invited to join in and do a (psychology) experiment (on memory) to represent how the learning works. It was interesting to be engaged."* These psychological explanations and the opportunity to witness their effect appears to have motivated many students to engage

Beyond the presentation itself, many students were motivated by the opportunity to try something new. One student claimed: *"One of the primary motives for me was to try something new to see how it can change my perspective on studying or learning."* Another similarly noted, *"I was engaged because it was something new for me and I enjoy trying new things and try to step out of my comfort zone as much as possible."* Students like these show very autonomous motivation, as they perceive the learning process as interesting and enjoyable, and are motivated by their own interest.

Extra Credit

Besides intrinsic and self-improvement motivations, many students were motivated to engage in pursuit of the extra credit awarded (75 codes). While some students only participated the bare minimum to receive extra credit, for many other students, the exposure allowed them to discover alternative motives for continuing their SRL activities, enriching their experience in the course. Many of the students who participated for extra credit then also identified the strategies as valuable for their learning. One student explained, *"The extra credit was definitely the motivating factor at first, but I also saw the activities as a way I could consistently study the course materials."* These students came to value the program, not only because of the boost to their grade, but also as a useful method of improving their learning practices.

Extra credit also helped students persist in using the strategies. Many students expressed interest in learning and implementing the strategies, and how whenever their motivation was low, the extra credit would encourage them to continue engaging. As one student commented, *"Learning the topics thoroughly and understanding them was my main motivation, and when I felt lazy, the extra credit motivated me."* This way, extra credit acted as a support for students to persist in their efforts to become better learners.

Witnessing Notable Improvement

Beyond initial motivations, students also reflected on how the Learn Smart program encouraged them to continue engaging after trying the strategies. Upon trying these strategies, many students would comment on how much these strategies would help their learning, and would be motivated to continue participating. One student mentioned a noticeable difference from implementing effective learning strategies: *"The aspect of the activities that motivated me the most to engage was seeing the improvement in my abilities to do homework problems with less help from notes, becoming more confident in quizzes, and feeling more knowledgeable about MAE 30A topics."*

Another student commented on how this notable improvement also helped him continue engaging: *"The relation between doing the learning skills activities and the midterm exam scores was striking to me. I started doing the activities more once I saw how much of a difference they can make."* Students who are able to notice visible upwards trends in their current course performance, while most importantly, correlating performance to learning strategies, are most likely to continue utilizing the learning strategies. This quote also demonstrates how participating in these activities helps students lessen their doubts about the strategies' effectiveness. Another student complemented this, commenting: *"I saw an enrichment and increase in my recall and learning capabilities."* These findings are promising, as we can see students who engaged with the program, found the strategies useful, and indicated a desire to continue using them.

RQ1.2 What are the challenges, barriers and reasons for resistance that prevent students from engaging with the learning strategies?

As appealing and beneficial as the program was intended to be for the students, multiple barriers deterred some students from participating in or sustaining efforts with the program:

(1) Time constraints; (2) Fatigue and Insufficient Energy; (3) Low Utility Value;

In addition to these time constraints, we also observed the role of the timing of the intervention.

Time Constraints and Fatigue

Time constraints stood as a common barrier for participation in the learn Smart program, as students chose to not engage in or forgo program participation in efforts to keep up with their already busy and demanding schedules. Those who felt they did not have enough time to engage with the program were categorized under two separate barriers.

One of which was that students had competing priorities that they could not cut back from (29 codes); one student explained, "*...I would have loved to try out different learning methods… Unfortunately, I just did not have that kind of time since the concrete and mandatory assignments of this class and my other three classes obviously took precedence...*" Though the benefits of the program were acknowledged and understood, students still felt that they could not afford to dedicate time to completing SRL activities at the risk of their performance faltering in other classes or responsibilities.

In tandem with competing priorities that deterred students from participating in the program, other students found ***difficulty with having sufficient energy*** to have meaningful engagement with the SRL activities, feeling fatigued and overwhelmed from outside factors (22 codes). The program is meant to instill new habits, strategies, and levels of understanding that a student possesses when learning new material. In many cases, it leads to students having to completely recode their mindset through consistent and meaningful work through the SRL activities, requiring significant cognitive energy to achieve. One mentioned that, "*when choosing between extra school and leisure activities I decided this quarter I would focus on what makes me happy.*" Other studies show the positive correlation of free time management for leisure and quality of life in university students and how they would avoid this program, attributing the additional work needed to adopt this program as a potential cognitive overload and a burden to their mental health (Terzi et al, 2024).

In the United States, at the university this study took place or similar, full-time engineering college students take a minimum of 12 to 16 units of major required classes, typically equivalent to three to four courses, along with additional general-education courses. Aside from school work, students will also have personal obligations, such as jobs or research projects, that inevitably takes precedence over participating in the learn Smart program. One student mentioned, "*...I work 2 hours away… I am also part of triton robotics and recently joined research under a professor which also took up most of my time. In addition I also took MAE 3 (another major-required course) which is a major time commitment.*"

Low Perceived Value and Resistance to Change

Many other students didn't participate simply because they ***did not perceive the program adds additional value to their learning*** (18 codes). It is hoped the SRL intervention program could engage all students either high-performance or lower-performance, but particularly those who have struggled with courses or did not achieve their performance goals. However, some students perceived the intervention as less valuable to their learning and consequently acted as a barrier. Some of these students gave answers that simply ruled out any attempt at intervention, mostly following the structure of *"I don't think there's anything that would've motivated me to engage."*

This type of student can be contrasted to another set of students whose criticisms are addressable,*"Something that would've motivated me to engage was if it began with motivating yourself to study and work harder even for classes you feel more confident in. While I am interested in how the brain works and how to study more effectively, I personally have learned many strategies and already found what works for me, where I struggle is studying when I feel like I don't need to in order to succeed, when I am confident in material through only doing homework and taking lecture notes I find it really difficult to do any more work outside of that for a class and promoting the learn smart program to deal with this problem would've gotten my interest."* This student's reflection aligns with a broader trend in which increased course difficulty motivates some students to find value in engaging with more rigorous material.

Some students found that the course material difficulty level was not worth the additional effort, especially noticed in the engineering statics course. *"I would have been more motivated to participate if I was struggling with concepts more."* This seems to demonstrate how some students will not feel the need to improve their learning strategies if the content feels easy to them.

Many students would similarly exhibit resistance to changing their learning strategies and would *prefer sticking to past strategies they were used to* (19 codes). When students are already able to find value in their current learning strategies and often-times are already finding success, they do not recognize the need for newer strategies that may take time and further cognitive burden to sufficiently learn. One such student claimed: *"Over the years I have developed a system that facilitates my study, so a study skills workshop doesn't appeal to me…"*

Some students mentioned not engaging with the program because of ***low utility value in terms of grades***. In other words, *they did not perceive it as something that would influence their grades directly*. One student explained that, although the program supported deeper understanding, academic pressure related to grades prevented proper engagement: *"Unfortunately we live in a world where the grade is all that matters, and true deep understanding of the concept is less important. Given all the time in the world and no stress, I would love to experiment with the learning strategies and see what works best for truly understanding and remembering all the concepts. But I am inclined to care most about the grade, so I will just learn as fast as possible and get the grade I want and not focus on the *way* I learned it, if that makes sense."* It is worth noting that the courses in which the SRL intervention was implemented employed carefully designed assessment approaches aligned with ABET Student Outcomes (ABET, 2023). These assessments emphasized multiple levels of learning, particularly higher-order outcomes such as the transfer and application of knowledge, rather than simple factual recall. Although this emphasis was communicated explicitly and repeatedly throughout the course, some students still failed to recognize the connection between performing well on these assessments and the use of effective learning strategies. Furthermore, the student has not yet realized the real and potential value of the course content, specifically within certain subjects reappearing in industry and in future curriculum.

Effective self-regulated learning is inherently individualized, shaped by students' preferences, prior preparation, schedules, and a range of contextual factors. Although cognitive psychology research provides general principles for effective learning, the specific strategies that work best can vary across students. To maximize flexibility and allow students to select approaches that align with their needs and preferences, a wide range of learning strategies was introduced and highlighted throughout the course, with the intention that students would adopt those they found most valuable for achieving their desired learning outcomes.

However, offering a broad set of weekly assignment options also introduced logistical challenges. In particular, students reported difficulty navigating the course website (Canvas), where the volume of materials and activities created a sense of clutter. As one student noted, "It was just very hard to navigate the whole Canvas page—I wasn't sure where to even find the workshops… They should be more visible to encourage students who aren't actively looking for them." The large number of learning strategies and associated assignments resulted in a dense organization within the calendar and module structure, making it harder for students to locate and engage with relevant resources.

These findings highlight an important design trade-off: while variety supports personalization and autonomy, excessive options may increase cognitive and logistical burden. This suggests the existence of an optimal range of strategies introduced at any given time, particularly in the context of students' existing course loads, to balance flexibility with usability and sustained engagement.

The Impact of Course Timing and Difficulty

The timing of the intervention also appears to play a role in the motivation and barriers students face when deciding to engage with the program. Ideally, students would enter college equipped with effective learning strategies. Students' decision to engage or not engage with SRL intervention can vary a lot depending on where they are in their academic trajectory. On one hand, we observe how in the MAE 30A course, the course's lower difficulty may make students feel like the learning strategies are unnecessary. Previous research shows how many students prefer to stick to their current learning strategies, and how when information is easier to encode, students will tend to overestimate their current knowledge while underestimating how much more they could learn with better studying (Bjork et al, 2013). This tendency can be understood through the lens of perceptual narrowing, where repeated success with existing strategies reinforces their perceived effectiveness, reducing openness to alternative approaches. (Lewkowicz, Ghazanfar, 2009)

This trend showed up in the data, with more students reporting wanting to stick with their old strategies in the earlier course. Amongst the students who did not engage with the program, a preference to stick with old strategies was more often mentioned in the earlier course than the advanced course (20% in Statics vs 15% in MAE 131A Solid Mechanics). Similarly, students in the earlier course were more likely to report that a lack of challenge made changing their strategies feel unnecessary (6% in MAE 30A vs 3% in MAE 131A). This suggests that lower difficulty courses may make it more difficult for students to feel the need to engage with the program and change their learning habits.

On the other hand, we observe how time constraints and fatigue barriers can be a prevalent barrier in more difficult courses. Time constraint and fatigue barriers were observed significantly more in the advanced course (34% in MAE 131A vs 13% in MAE 30A), as were time constraint barriers (34% vs 20%). With MAE 131A being an upper division course, students likely took it alongside other complex upper division courses. Students from this course also more frequently mentioned other responsibilities affecting how much time they had available. As one of the MAE 131A Solid Mechanics students explained: *"... I simply don't have the time when balancing 3 other upper division eng classes and a leadership role in an engineering team."* Not only does the difficult course likely take up more time, but upper division students likely also have other difficult classes and other responsibilities."

As students progress in their engineering curriculum, they become more selective in how they evaluate the usefulness of academic interventions. And on many occasions, the usefulness is defined by reflection on their short-term test scores. This increased selectivity can have mixed effects, while students become efficient in problem solving, they lose the flexibility in changes to overall learning methods and strategies.

These findings raise the possibility that introducing effective learning strategies earlier in students' educational journeys could help prevent the formation and adoption of study habits. However, implementing such interventions at earlier stages presents its own challenges. Not all students intend to pursue engineering or similar disciplines, and may not immediately perceive the relevance of these strategies. As a result, a more broadly applicable approach may be to frame these interventions in terms of general critical thinking and learning skills, which can transfer across disciplines. By emphasizing adaptable skills rather than engineering-specific strategies, early interventions may provide benefits that extend beyond any single field of study.

Together, this suggests that engagement with the program is very influenced by students' academic context. Earlier course students might face more barriers in terms of questioning the need for these strategies, while later course students might face more time constraint barriers. Designing interventions that account for students' academic context can make them more impactful by either emphasizing the need for these strategies, or time management, depending on the context. Future studies could also look into whether introducing the strategies throughout multiple courses could help address this issue.

R2. What impact did the course-integrated learning strategies intervention have on students' self-evaluation of learning skills, self-reported learning strategies use, and growth mindset?

Quantitative analyses were performed to understand the impact of the course-integrated SRL intervention on students' self-evaluation of learning skills, self-reported learning strategies use, and growth mindset. These analyses were conducted for the two MAE 30A two sections for comparison purposes.

Self-evaluation of Learning Skills

In order to compare students' perceived change in learning skills across the academic quarter, dependent paired sample t-tests were used and Cohen's d was calculated to review beginning-of-quarter (BOQ) and end-of-quarter (EOQ) self-reported scores on (1) Their knowledge of effective learning strategies and (2) confidence in using those strategies in class environments. Analysis was conducted separately for students in MAE 30A class section A00 (light intervention) and B00 (intense intervention). The light intervention group had a sample size of 86 students, and the intense intervention group had a sample size of 83 students.

Students answered two survey items, each on a 7-point Likert scale. The first question asked, ("From 1 [not knowledgeable at all] to 7 [very knowledgeable], rate your knowledge about effective learning strategies"). The second question asked, ("From 1 [not confident at all] to 7 [very confident], rate your confidence using effective strategies properly based on the course content"). Both questions were identical, and asked in the BOQ and EOQ.

Knowledge of Effective Learning Strategies

From Table 2, students from class B00 demonstrated a statistically significant increase in reported knowledge from BOQ (M = 4.494, SD = 1.253) to EOQ (M = 5.241, SD = 0.905), p = 2.42 x 10-7, with a medium effect size (Cohen's d = 0.6183).

Students in class A00 also showed a statistically significant increase in reported knowledge from BOQ (M = 4.930, SD = 1.049) to EOQ (M = 5.302, SD = 1.179), p = 4.38 x 10-3. However, the effect size was smaller (Cohen's d = 0.31568), indicating a small effect.

These results point to the fact that while both sections demonstrated gains in perceived knowledge of learning strategies, the more intense intervention was associated with a larger effect size.

Confidence in Using Effective Learning Strategies

From Table 3, students in the B00 section showed a statistically significant increase in reported confidence from BOQ (M = 4.530, SD = 1.291) to EOQ (M = 4.783, SD = 1.169), p = 0.046. The effect size was small (Cohen's d = 0.22286).

On the other hand, the students in the A00 section did not have a statistically significant change in confidence from BOQ (M = 4.837, SD = 1.094) to EOQ (M = 4.756, SD = 1.487), p = 0.61, with a negligible effect size (Cohen's d = -0.081).

Table 2. MAE 30A Paired Sample T-Test Results for Self Reported Knowledge by Intervention Group

	BOQ Mean (SD)	**EOQ Mean (SD)**	***p*-value**	**Cohen's d**
A00 (Light intervention)	4.930 (1.049)	5.302 (1.179)	0.004	0.31568
B00 (Intense Intervention)	4.494 (1.253)	5.241 (0.905)	<0.001	0.6183

Table 3. MAE 30A Paired Sample T-Test Results for Self Reported Confidence by Intervention Group

	BOQ Mean (SD)	**EOQ Mean (SD)**	***p*-value**	**Cohen's d**
A00 (Light intervention)	4.837 (1.094)	4.756 (1.487)	0.610	-0.081
B00 (Intense Intervention)	4.530 (1.291)	4.783 (1.169)	0.046	0.22286

Growth Mindset

In the same surveys, students answered questions about growth mindset. This set of three questions was a subset of questions from the standard Growth Mindset Survey (Dweck,1999) They were answered on a scale of 1 (strongly agree) to 6 (strongly disagree).

Table 4. Growth Mindset Question Set

Question 1	"I have a certain amount of intelligence, and I can't really do much to change it."
Question 2	"My intelligence is something that I can't change very much."
Question 3	"I can learn new things, but I can't really change my basic intelligence."

From Table 5, only question 2 from the non-intervention group showed statistically significant results from BOQ (M = 4.988, SD = 1.068) to EOQ (M = 4.605, SD = 1.374), p = 0.0077 with a small effect size (Cohen's d = -0.29447). The other two questions showed a negative mean change, however they were insignificant.

Similarly for the intervention group (See Table 6), none of the three questions had statistically significant results, although they all had negative mean change. This negative mean change should be interpreted as a shift from a growth mindset to a fixed mindset across the course of the quarter.

While these results do not suggest improvement in growth mindset, it is important to understand the factors that influence how a student views themselves and their learning experiences. The results suggest that the intervention did not effectively improve the student's growth mindset. The negative trend, although not statistically significant, may suggest that.

Growth mindset is a complex construct, and shifts toward a growth mindset are influenced by multiple factors and may require extended periods of development. These factors include students' experiences both within and beyond the classroom, such as their stage in the academic program, learning experiences in other courses, and academic performance. Future research should further investigate the factors that contribute to the development of students' growth mindset and explore how course-integrated interventions can be designed to maximize positive impact. In addition, students' self-reported growth mindset may be influenced by the timing of data collection. Because the end-of-quarter survey was administered immediately after the final exam, students may have conflated their recent performance with their perceived ability to learn, potentially affecting their responses.

Table 5. Non-Intervention Group Growth Mindset Trends

	BOQ Mean (SD)	**EOQ Mean (SD)**	***p*-value**	**Cohen's d**
Question 1	4.779 (1.131)	4.512 (1.361)	0.071	-
Question 2	4.988 (1.068)	4.605 (1.374)	0.008	-0.29447
Question 3	4.512 (1.361)	4.267 (1.537)	0.123	-

Table 6. Intervention Group Growth Mindset Trends

	BOQ Mean (SD)	EOQ Mean (SD)	*p*-value	Cohen's d
Question 1	4.639 (1.185)	4.482 (1.119)	0.266	-
Question 2	4.771 (1.262)	4.578 (1.159)	0.202	-
Question 3	4.506 (1.253)	4.277 (1.243)	0.135	-

R3. How did the intervention affect students' learning performance, as measured by course assessments and examinations?

To understand the impact of the intervention on students' learning performance, exam and quiz scores were compared across levels of participation in course-integrated learning activities for MAE 131A. Participation in learning strategies related assignments measures the amount leading up to the examination. Performance was evaluated through midterm examination (maximum score: 50), and final examination (maximum score: 100) in MAE 131A and analyses were conducted using *independent t-tests.*

To rule out the prior knowledge effect on learning, we conducted an independent t-test between the students on their pre-quiz scores. The pre-quiz, given in week 1 of the class, measures students' proficiency in the prerequisite knowledge needed for the class. Among all the groups, there was no statistically significant difference between the students' pre-quiz scores.

Through an independent t-test, a statistically significant difference ($p = 0.032$) was found on the final exam between students completing 3 or more learning strategies related assignments (mean = 70.57, standard deviation = 15.22) outperforming those with lower participation (mean = 63.58, standard deviation = 20.76), as illustrated in Figure 1 where the y-axis represents the mean final exam scores while the x-axis categorizes students by their levels of participation with the intervention. Although the difference was statistically significant, the effect size suggests a modest practical difference ($d = 0.384$).

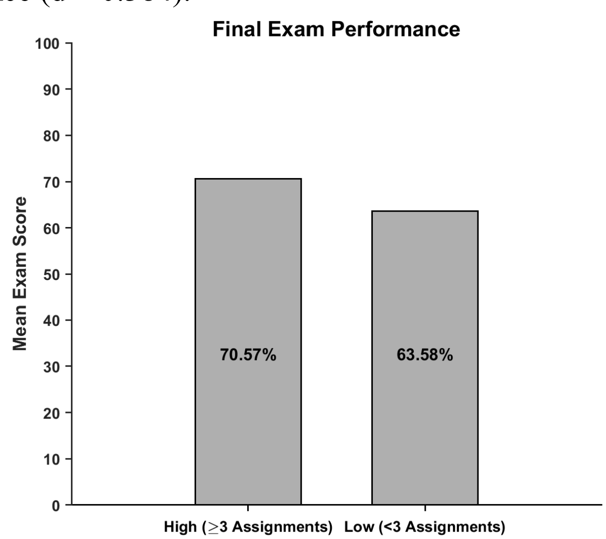

Figure 1. MAE 131A Final Exam Performance between Participation Levels

Similarly, for the midterm exam, students who participated in at least one learning activity prior to the midterm examination scored significantly higher on the examination compared to non-participants (p = 0.032, d = 0.368).

Exam	Groups	Mean (SD)	*p*-value	Effect Size
Midterm	≥1 activity vs. None	37.17 (7.85) vs. 34.00 (9.32)	0.032	0.368
Final	≥3 assignments vs. <3	70.57 (15.22) vs. 63.58 (20.76)	0.032	0.384

Conclusion and Limitations

Trends in student motivational devices demonstrate how the Learn Smart program was effective in engaging students to attempt and adopt new learning strategies. Multiple factors highlighted and introduced by the program helped engage students, including a focus on efficient learning, encouraging students' growth mindset, and further engagement in activities. Many students who engaged found it very helpful and suggested they would continue using strategies in future classes. Extra credit was found to be a useful tool in motivating students to begin engaging. Although some students participated in the program for extra credit, others were observed to initially engage for extra credit and eventually found meaningful value from the intervention. Extra credit also proved useful in supporting students to sustain practice of strategies.

In terms of barriers to engagement, we observe a main trend of students having limited time and energy, and so they often have other priorities that prevent them from engaging. Workload is an important consideration when designing a program like this, keeping in mind students have many time constraints and too many assignments can make them overwhelmed. Additionally, many students showed resistance to change, not seeing the need to change their current strategies if not necessary. While the Learn Smart program highlights the need to replace less effective strategies with more effective ones, the additional effort or the perceived additional efforts it takes to make such a change did seem to drive students away. One important note is that although these learning strategies involve an initial learning curve, once students master their effective use, both learning effectiveness and efficiency are likely to improve. In many cases, this improvement occurs not through increased study time, but through more even distribution of study efforts over time rather than last-minute cramming. But many students, either did not give it a try, or did not sustain their efforts until they could effectively use these learning strategies to reduce study time.

Overall, the intervention with learning strategies related assignments generated greater gains in their reported knowledge and confidence compared to only giving an effective learning strategies introduction lecture. While students in both groups reported increasing their knowledge over the course of the quarter, only students in the intervention section showed a significant result in their confidence to use these strategies. This would suggest that the intervention supported both student's awareness of these strategies, as well as their attitude toward the learning process. The growth mindset questions may suggest that the intervention did not improve the student's growth mindset. It is important to view this in context, this shift to a fixed mindset may have come as a result of a student's attitude and mindset during finals week. Students answered this survey right after finals week, and may have felt discouraged. In order to investigate this further, it would be important to ask students again in a delayed timeframe to cool down their self perception of intelligence demoralized from the final exam, when they are given a chance for a mental reset, however due to limitations with the class structure this was not possible. The Spearman correlation matrix suggests that the intervention may have caused students to experiment with different learning strategies and try some out in tandem.

Participation in a course with integrated learning activities are shown to broaden the changes in students' self-reported learning strategy usage. Students in the intervention section reported increased use of a wider range of strategies by the end of the quarter including many strategies associated with deeper engagement, while changes in the section with no intervention were more limited in their scope. Rather than reflecting a shift to any specific learning strategy, the results suggest an expansion of the students' study habits over time.

Findings indicate that course-integrated learning activities are related to students' learning performance in ways that are complex and mediated by patterns of preparation and study behavior.

Several limitations should be considered when interpreting the learning performance and self reported learning strategy use results. Participation in course-integrated learning activities was not randomly assigned and thus introduced the possibility of self-selection effects. Due to the observational nature of the study, causal conclusions regarding the impact of participation of learning activities on examination performance are precluded. Assessment outcomes varied in scope and format, with early examinations having less content to cover and thus less optimally aligned with the intended outcome of the intervention which limits the assessments capability of detecting differences that might result from participation in the intervention. The survey captures changes over a single academic quarter, limiting conclusions about long term effects of reported strategy use and performance.

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Appendix 1

Questions in the Beginning of Quarter and End of Quarter Survey

Use of Learning Strategy *Prompt*: Rate your use 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.