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BOARD # 271: NSF IUSE 2315777: Training engineering students to be better learners: a course-integrated approach

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Project motivation and background

Learning is a lifelong process exercised within and beyond the classroom and a vital professional skill. Engineers, in particular, must adjust to rapidly evolving technologies and practices that require continuous learning and adaptation long after their initial formal training and transition into their professional careers.

Education research emphasizes the need for engineering students to hone these lifelong learning skills. Effective learning requires them to adopt self-regulated learning strategies to synthesize and apply knowledge, and evaluate problems using engineering principles effectively (Zimmerman, 2000). However, students often default to ineffective learning strategies such as rereading, highlighting, repetition, and rote memorization (Blasiman et al., 2017; Dattathreya, & Shillingford, 2017), and do not exercise the higher-order thinking required to solve difficult engineering problems and reach conceptual mastery. As a result, students often struggle in their courses, which may negatively affect their curricular progress and ability to adjust to university life.

However, despite the critical role of effective learning skills in their academic and professional success, engineering students receive minimal guidance on how to become effective learners. The engineering curriculum has traditionally emphasized teaching the content while assuming that students are equipped to manage their own learning. Although recently more efforts were made in delivering evidence-based learning strategies to engineering students (Blasiman et al., 2017; Santangelo et al., 2021), most of the training was delivered in extra-curricular format. This includes stand-alone learn-how-to-learn classes or workshops delivered by student success centers, or one-time learning-strategies lectures delivered in a course context (McGuire, 2015). However, these interventions were not found to result in the desired transfer of skills. While they did raise their awareness of effective learning, students still found it difficult to transfer these learning strategies to their own learning context within their engineering courses. To address such a challenge, interventions on effective learning strategies could be integrated in the discipline context itself (Wingate, 2007). This project examines how to successfully design and implement a scaffolded and course-integrated intervention on learning strategies. We investigate how the intervention impacts students' knowledge, belief, commitment, planning, and attitude of using effective learning strategies and their course performance.

Project details

The aim of this project (NSF IUSE #2315777) is to develop, implement, and evaluate course-integrated learning interventions and their impact on student learning in engineering classrooms. The project has two primary objectives. The first objective is to develop discipline-specific training modules that are grounded in the framework of self-regulated learning (the process of goal setting, planning, self-monitoring, and reflection) (Santangelo etal, 2022). These modules focus on evidence-based learning strategies such as active recall, concept mapping, summarizing, self-explaining, and self-testing. A key innovation of this project is the alignment of course content with the application of learning strategies to ensure there is a direct connection between student learning practices and the technical material being taught. This project includes close collaboration among faculty, our campus teaching and learning center and a student success unit to ensure that modules are adaptable to a range of engineering disciplines and include practices that are transferable to both current and subsequent courses. The second objective involves the implementation of these training modules across both lower-division and upper-division courses in the Mechanical and Aerospace Engineering and

Electrical and Computer Engineering departments. Once implemented, students' short-term and long-term academic performance, attitudes toward our interventions, learning habits, and self-efficacy are measured to evaluate the effectiveness, transferability, and impact of the training interventions. By embedding the developed training practices into the curriculum, our approach ensures that learning strategies are perceived not as supplemental activities, but as a core part of engineering education. This paper presents our first-year results on this project and our plans for future studies and improvements.

Methodology

Our course-integrated intervention project on self-regulated learning strategies is built on three pillars: (1) supporting students' cognitive development by teaching effective learning strategies, (2) fostering students' affective development by encouraging a growth mindset, and (3) promoting students' metacognitive development by providing structured feedback and reflection opportunities. This approach to encouraging the adoption of effective learning strategies is informed by the knowledge, belief, commitment, and planning (KPCP) framework for learning strategy training (McDaniel & Einstein, 2020), integrated with principles of self-regulated learning [ref]. In each target course, students' adoption of effective learning strategies will be supported by interventions aiming to enhance students': (1) knowledge about these strategies, through explicit instruction on target learning strategies with engineering-specific examples, (2) belief in the effectiveness of the strategies, through in-class demonstrations and guided practice, allowing students to experience the benefits firsthand, (3) commitment to using the strategies, through the integration of utility-value interventions, and (4) implementation planning, through structured assignments and activities that direct students on when and how to apply specific strategies to their engineering studies.

The components are being implemented across multiple mechanical and electrical engineering courses and involve training materials, new and redesigned assignments, adjusted assessments promoting deep learning, and specialized TA training. To evaluate the effectiveness of this intervention, we are using pre- and post-course surveys, quasi-experimental designs comparing intervention and non-intervention course sections, and longitudinal tracking of strategy transfer to subsequent courses. Data collection methods include surveys, focus groups, tracking course performance metrics, and analysis of student work.

Results

Overview

In the first year and a half of the project, the research team implemented a pilot intervention four times in three unique Mechanical and Aerospace Engineering (MAE), and Electrical and Computer Engineering (ECE) courses: MAE 131A - solid Mechanics, ECE 100-Linear Electronic Systems, and ECE 35 - Introduction to Analog Design. All the courses are lower division foundational courses, and students have historically reported the class to be difficult, which made the classes ideal candidates for the learning strategies intervention. The pilot implementation uses the same intervention design KBCP framework while maintaining some flexibility in terms of the specific targeted learning strategies, format of the learning strategies, introduction lecture, method for feedback, format, and incentives for student participation, etc. All the pilot interventions were implemented in a research university, in a 10-week-long quarter. The key characteristics of the intervention for each course have been summarized in Table 1.

Table 1. Overview of the class context of the courses in which the learning strategies intervention was implemented

	MAE 131A **Solid Mechanics**	**ECE 100** **Linear Electronic Systems**	**ECE 35** **Introduction to Analog Design**

Class Level	Sophomore	Junior		Sophomore
Main topics	Stress and strain analysis	Active and passive electrical circuits, such as filters, integrators, differentiators, and oscillator circuits		Basics of electronics
Implementation quarter	Spring 2024	Spring 2024	Fall 2024	Fall 2024
Class Size	n=129	n=118	n=123	n=267
The overall estimated intervention participation rate	About 33% for most assignments	31%	30%	10%
Targeted enhanced learning strategies	Elaboration, retrieval practice, space learning, interleaved practice, self-care for overall health	Mind map		Elaboration, concept maps, Feynman technique, retrieval practice, spaced practice, interleaved practice, environmental strategies, behavioral strategies
Introduction lecture timing and duration	Week 4 (80 minutes)	Week 4 (20 minutes)	Week 2 (20 minutes)	Week 1, 2, and 3 (50 minutes each)
Metacognition	Yes	Yes, as integrated into the activity		Yes
Growth Mindset	Yes	No		Yes
Assignments and activities	Video modules: metacognition modules, growth mindset modules. Weekly assignments: Post-lecture active recall, concept mapping schedule planning, earning reflection.	Weekly mind map submissions starting at the end of the introduction week		Group discussions during the lecture sessions (ungraded, voluntary)
Feedback format	The first 3 assignments, graded with comments	Yes		N/A

In the following section, we briefly describe the preliminary results for each class.

1. MAE 131A Spring 2024

In spring 2024, a series of self-regulation learning strategies intervention was implemented as extra-credit activities in MAE 31A, including an 80-minute introduction lecture, additional video-based learning modules and learning reflection assignments, assignments for post-lecture active recall, concept mapping and weekly time management plan submitted on Canvas and/or google form. In addition, students were given a weekly learning journal to reflect on the utility value of the learning strategies they have used in each week. Detailed feedback was given to the first two active recall, concept mapping and weekly time planning assignments. About 90% of the students attended the introductory lecture, while 35% of the students participated in the assignments. Students' self-reported learning strategies usage and growth mindset status information have been collected both pre-and-post interventions through Google Form survey.

There was a statistically significant improvement in the following areas: students self-report increased use of effective learning strategies - active recall, and concept mapping and decreased use of ineffective learning strategies- highlighting and rereading; an increase of growth mindset. However, there are some other targeted learning strategies that were taught in the introduction lecture but did not generate a statistical difference.

The majority of the students highly valued the learning strategies training. In particular, they found active recall a very helpful learning technique. Most students found the organization and implementation very helpful and accessible. The only concern is the learning strategy training generates an additional workload.

2. ECE 100 Spring 2024 and Fall 2024

In Spring and Fall 2024, a "mind map" activity was introduced as an optional extra credit assignment in the course. During the first lecture, the instructor highlighted the value of effective learning strategies and mind mapping for deeper understanding. Participating students created weekly mind maps, submitted them via a Google Form, and reported time spent and perceived effectiveness.

To foster collaboration and feedback, a Discord server was set up for submissions, where the instructor and tutor provided guidance on improving connections and correcting errors. A sample mind map based on ECE 100 content and recommended tools (e.g., Freeform app, Microsoft Whiteboard, LucidChart, MindMeister) were shared with the class.

Participation rates were consistent across offerings, with 37 students participating out of 118 in Spring 2024 and 37 out of 123 in Fall 2024. The activity began in Week 4 during Spring but was introduced earlier in Week 2 in Fall, following a Week 1 orientation. Surveys conducted before and after each quarter gathered feedback on the activity's impact.

Cluster analysis of Spring 2024 survey data revealed performance-based differences in engagement. High-performing students (Cluster 1) showed the strongest participation (18/28), utilizing advanced strategies like elaboration and metacognitive self-regulation. Moderate performers (Cluster 2) engaged moderately (9/18), while lower performers (Cluster 3) had minimal involvement (5/17), missing the opportunity to benefit from mind mapping.

Overall, students reported a slight but positive increase in confidence with basic and complex concepts, with participation in the mind map activity correlating with this growth. These findings suggest that mind mapping is a valuable metacognitive tool for enhancing learning in technical courses, particularly when supported by feedback and early engagement.

3. ECE 35 Fall 2024

In Fall 2024, a dedicated learning strategies workshop was integrated into the course. The workshop included three 50-minute sessions during the first three weeks of discussion sections, covering: Week 1: Growth mindset and Bloom's taxonomy; Week 2: Grit and self-regulated learning; Week 3: Effective learning strategies. These topics were supplemented with group discussions, videos, written resources, and session recordings. Participation was optional and ungraded, with in-person attendance ranging from 20 to 42 students out of 267 total enrollees. Evening scheduling (6:00–6:50 PM) and the availability of asynchronous materials likely contributed to low attendance. However, survey data showed that nearly twice as many students engaged with the recordings and resources.

The workshop aimed to refine materials and gather student feedback through surveys administered at the start and end of the quarter. Among post-survey respondents, 65 students reported attending synchronously or watching recordings. Most participants found the workshops valuable, with perceived usefulness of topics grouped as follows:

- **Tier 1 (80–90% useful)**: Growth mindset, Bloom's taxonomy, grit, self-regulated learning, self-reflection, elaboration, Feynman technique, time management,

help-seeking, and study environment
- **Tier 2 (65–77% useful)**: Retrieval practice, spaced practice, interleaved practice, group work, exercise, and breaks/sleep
- **Tier 3 (45–50% useful)**: Concept mapping

Students applied most strategies but found concept mapping less useful, likely due to limited familiarity and lack of explicit practice. Future iterations will include graded assignments and explicit feedback on concept mapping to enhance its perceived utility. Additionally, strategies to boost participation and adoption will be explored.

Next steps

Our initial implementations have highlighted the need for refinements, including more targeted survey questions. A key takeaway is that making learning strategy activities optional resulted in low engagement, particularly among students who might benefit most. To address this, we are now integrating learning strategies into required course components, aiming to establish them as a fundamental aspect of engineering education. Moving forward, we plan to conduct quasi-experimental studies to compare intervention and non-intervention courses and develop protocols for investigating long-term strategy transfer and adoption in students' engineering coursework.

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