Can Self-Regulated Learning Practices Shift Without Intervention? An Exploratory Study of Calculus I and II Students

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This study examines changes in self-regulated learning (SRL) skills among undergraduate Calculus I and II students, without explicit interventions. Using pre- and post-surveys aligned with Zimmerman's SRL model, we identified both improvement and decline across items assessing various SRL practices. Calculus II students showed significant improvements in planning, self-control, and information management, which appear to be supported by student maturity, conceptual course content, and collaborative instruction. In contrast, Calculus I students exhibited a decline in performance-phase strategies, reflecting challenges from large lectures, formulaic content, and first-year adjustment. The researchers' hypotheses on potential reasons for the observed results were corroborated by the course instructor and teaching assistants. However, more research is needed to understand these patterns and their underlying causes. Our findings suggest that while some SRL skills may develop naturally in more advanced contexts, first-year students may require targeted support to become more effective learners.

Keywords: Calculus, Self-Regulated Learning (SRL), Study Skills

Calculus courses play a critical role in university education, particularly for STEM majors, as they often serve as gateway or gatekeeper courses. Success in these courses can significantly influence students' trajectories in STEM fields, while difficulties can create barriers to persistence. Due to their central role, improving student learning and success in Calculus has been a priority for both instructors and education researchers. Understanding not only what is taught but also how students approach learning is essential for designing effective instructional reforms. In particular, it is important to understand students' use of self-regulated learning (SRL) skills, which encompass cognitive, metacognitive, behavioral, motivational, and affective aspects of learning (Panadero, 2017).

This study was conducted within the context of a larger initiative aimed at improving teaching and learning in the Calculus sequence at a large public university in the northeast of the USA. The larger reform effort at this university encompassed Precalculus, Calculus I, and Calculus II. While all courses use a lecture–recitation format, the primary focus of the reform was on recitations. In these sessions, students engaged in conceptually rich activities and collaborative group work, supported by Learning Assistants (LAs) alongside Graduate Teaching Assistants (GTAs). After several years of applying these reforms, students often continued to use unproductive study methods despite instructional changes. Motivated by this, we sought to investigate the learning strategies of students in Calculus I and II and examine how these strategies "naturally" change over the semester without any particular intervention. To this end, we administered a 64-item Likert survey at both the beginning and the end of the semester.

In this paper, we report on survey items that showed statistically significant changes, whether positive (improvement) or negative (decline), in specific SRL skills. We focus on items where the direction of change differed between Calculus I and Calculus II students. To explore possible explanations for the observed changes, we enlisted interpretations from the course instructors, TAs, and LAs, and included them in this report. Our research question is: *How do undergraduate*

Calculus students' SRL skills change over a semester without formal intervention, and how do these changes compare between Calculus I and Calculus II students?

Literature Review and Theoretical Background

Calculus Reform

Undergraduate calculus courses function as critical gateways, affecting students' success and persistence in STEM. National data show that while many students enter calculus with prior high-school exposure, fewer than 60% earn an A or B, and confidence and enjoyment often decline (Bressoud, 2015). Across institutions, about 11–20% of STEM-intending students do not continue, with women's attrition roughly 1.5 times that of men, even controlling for prior achievement (Ellis et al., 2016; Rasmussen & Ellis, 2013).

To address these issues, many institutions reform introductory courses by integrating active learning and student-centered pedagogies to reduce attrition and promote deeper learning. Courses emphasizing collaborative problem solving, conceptual tasks, and real-world applications yield higher concept-inventory gains, improved exams, and reduced equity gaps (Kramer et al., 2023; Rasmussen & Ellis, 2013). Scaling these practices remains challenging: only 23% of Precalculus–Calculus II courses use active-learning strategies, with usage declining in higher-level courses (Rasmussen et al., 2019).

Metacognitive and study-skill development is another critical factor for student success or lack thereof. Structured study routines, including problem sets, review tasks, and guided reflection, improve performance and engagement (Boelkins & Pfaff, 1998; Khan, 2020). These practices support consistent study habits, conceptual understanding, and monitoring of learning – core self-regulated learning (SRL) skills. Despite their importance, SRL practices are rarely made explicit in traditional courses, leaving students to develop them independently.

Self-Regulated Learning (SRL)

Self-regulated learning (SRL) includes cognitive, metacognitive, behavioral, motivational, and affective aspects of learning (Panadero, 2017). Students with strong SRL skills set goals and actively select, monitor, and adjust strategies to achieve them. They also demonstrate more expert-like thinking individually and in groups (Stanton et al., 2021; Van De Bogart et al., 2017), which correlates with higher achievement, motivation, and lifelong learning (de Boer et al., 2018; Donker et al., 2014; Richardson et al., 2012; Rosário et al., 2019; Theobald, 2021).

Metacognition, a core SRL component, refers to awareness and control of one's thinking and learning (Stanton et al., 2021). Students with strong metacognitive skills assess understanding, identify gaps, select strategies, and evaluate outcomes. In mathematics, metacognition supports problem-solving and abstraction (Desoete & De Craene, 2019; Pólya, 1945/2014; Schoenfeld, 1992). Research shows SRL skills can be taught through explicit interventions (de Boer et al., 2018; Donker et al., 2014; Richardson et al., 2012). Yet, college instructors often prioritize content over SRL scaffolding (Moos & Ringdal, 2012), and secondary-level opportunities are often implicit (Dignath & Büttner, 2008). As a result, undergraduates enter with limited metacognitive knowledge and SRL skills (Pintrich, 2002). This gap is especially consequential in mathematics, where first-year calculus requires shifts in thinking, strategies, and time management. Research on SRL at the undergraduate math level remains sparse, even though its discipline-specific nature underscores its relevance for early STEM courses (Panadero, 2017).

Cyclical Phases SRL Model

This project uses Zimmerman's (2000) Cyclical Phases Model of SRL, involving three phases: forethought, performance, and self-reflection. In forethought, students analyze tasks, set goals, and plan strategies guided by motivation. In performance, they execute tasks and monitor progress. In self-reflection, they evaluate outcomes and attributes, shaping future learning. Zimmerman's model, grounded in social-cognitive theory, is widely used in STEM SRL research (Panadero, 2017; Gamby & Bauer, 2022; Jin et al., 2023; Layco, 2020; Marchis, 2012).

SRL is closely linked to motivation influencing learning performance (Zimmerman & Schunk, 2011). Expectancy-Value Theory frames motivation as learners' expectations for success and task value (Wigfield & Eccles, 2000). Within the SRL model, motivational beliefs affect goal setting, strategy selection, and engagement during forethought, while reflection shapes future expectations. Effective SRL enhances control, mastery, autonomy, and confidence, supporting intrinsic motivation (McCombs, 2013; Reeve et al., 2012). Framing this project with Zimmerman's SRL model allows analysis of how calculus students plan, enact, and reflect on their learning. The framework was used to both develop the survey and to interpret survey data on strategy use, motivation, and metacognitive engagement.

Methods

Setting and Participants

This study is part of a broader NSF-funded initiative to transform STEM gateway courses, focusing on the calculus sequence at a large public university in the northeastern United States. Calculus recitations were redesigned with conceptually rich activities and active learning, including collaborative problem-solving in small groups (CBMS, 2016). Calculus courses follow a lecture-recitation format: large lectures (~ 120 students) led by a faculty instructor three times a week, and recitation sections (~ 20 students), led by GTAs supported by LAs twice a week.

Data came from Spring 2025 students in Calculus I and II, who are predominantly STEM majors (89% and 99%, respectively), and share similar demographics, reflecting the university's predominantly white population. In Spring 2025, the same experienced instructor taught both Calculus I and II courses. There are minor but meaningful distinctions in the prior preparation of the two groups. Spring Calculus I students had not reached the mathematics proficiency threshold and were placed in Precalculus in the Fall. Spring Calculus II students usually completed Calculus I in the Fall, indicating their initial stronger mathematical preparation. Additionally, the instructor of both courses in Spring 2025 had taught Calculus I in the Fall. Thus, students in Calculus II experienced continuity of instructional style, whereas Spring Calculus I students had a different instructor for their prerequisite Precalculus course.

Instrument and Data Collection

Students' SRL skills were assessed with a 64-item survey. Items are measured on a 4-point Likert scale ranging from "1 (disagree)" to " 4 (agree)." The survey is theoretically grounded with items aligned with Zimmerman's (2000) SRL phases – forethought, performance, and self-reflection – and capture a range of skills (e.g., planning in forethought, task analysis in performance, and evaluation in self-reflection). Due to space constraints, examples of survey items will appear in the results section. Many items were drawn from well-established SRL instruments, such as Schraw and Dennison's (1994) Metacognitive Awareness Inventory, and Marchis' (2012) SRL inventory, and modified to the context of college-level calculus. The initial survey was piloted in Fall 2024 with 299 calculus students and revised following statistical and qualitative analyses. The revised instrument used in Spring 2025 had good to excellent reliability (Cronbach's Alpha values ranging from 0.87 to 0.94) of the three SRL subscales.

The same survey was administered at the beginning and at the end of the semester. Students completed the survey online via Qualtrics, which took approximately 15 minutes. Only data from consenting students were included in the analysis. The final sample comprised of 74 (out of 181) students in the Calculus I course and 78 (out of 193) students in the Calculus II course, who completed both pre- and post-surveys.

Data Analysis

Quantitative analysis involved descriptive statistics for all survey items and assessing internal consistency using Cronbach's alpha. Although Likert-scale survey data are ordinal, parametric methods, such as paired *t*-tests, are widely accepted in educational research when sample sizes are adequate and data approximate normality (Norman, 2010; Chen & Liu, 2020). Given the size of the current study and alignment with these established practices, paired two-tailed *t*-tests were conducted on pre–post differences within each course, and effect sizes were calculated. The survey was not anonymous, allowing for matching pre- and post-responses. Although we initially did not intend to compare across the courses, course-specific analyses revealed notable differences between the Calculus I and Calculus II cohorts, which were further explored.

To contextualize the quantitative results, particularly the statistically significant changes observed on certain SRL items, we reached out to the course instructional staff, shared with them the statistical analysis, and asked them to comment on these findings and suggest possible explanations based on their classroom experiences. Responses were received from one instructor, two GTAs, and three LAs. We incorporated the background information and the insights they provided into possible interpretations and explanations for the observed findings.

Results

Across all three SRL phases, the average student response was "somewhat agree," showing moderate use of SRL strategies in both Calculus I and II. This suggests that students in both courses engage in SRL strategies frequently, though not consistently at the highest level. Considering pre–post course changes, on average, Calculus I students' SRL scores decreased from 3.034 (SD = 0.688) to 2.935 (SD = 0.782), which is statistically significant ($t = -2.141$, $p < .036$, Cohen's $d = -0.315$). Calculus II students' scores increased slightly from 2.948 (SD = 0.741) to 2.990 (SD = 0.778). Furthermore, when examining pre-to-post semester shifts in overall SRL scores, a distinct pattern emerged: Calculus I students' responses declined on most SRL items, whereas Calculus II students' responses increased on most items (Table 1).

Table 1: Counts of Items by Average Change in Calculus I and II

	Declined	No Change	Improved
Calculus I	47	1	16
Calculus II	18	2	44

At the item level, 20 survey items showed a statistically significant change over the semester. Of these, several items reflected significant declines in Calculus I students' responses, while many indicated significant gains for Calculus II students. These differences between Calculus I and II students warranted further examination of how their SRL habits change.

Items with Statistically Significant Changes in Both Calculus I and Calculus II

Three survey items, seen in Table 2, demonstrated statistically significant change for both Calculus I and II. Importantly, these items followed opposite trends: Calculus I students reported declines, whereas Calculus II students reported improvements.

Table 2: Items with Statistically Significant Changes for Calculus I and II

Item	Class	Pre-Mean	Post-Mean	p-value	Effect Size
18: I try to understand the reasons behind mathematical formulas and concepts.	Calc I	2.946	2.703	0.0407*	-0.405
	Calc II	2.782	2.974	0.0348*	0.323
31: I ask questions during lectures or recitation sessions when I don't understand something.	Calc I	2.919	2.649	0.0101*	-0.401
	Calc II	2.641	3.026	0.0010**	0.611
57: When I need to solve a mathematical problem, I think of several ways to solve it and choose one that makes the most sense for me.	Calc I	3.054	2.824	0.0428*	-0.38
	Calc II	2.756	3.000	0.0109*	0.403

Item 18: "I try to understand the reasons behind mathematical formulas and concepts." Table 2 shows that Item 18 was statistically significant for both Calculus I and II, but in opposite directions. Calculus I students showed a significant decrease in this SRL skill, with mean scores declining from 2.946 on the pre- to 2.703 on the post-survey ($p < .0407$). Conversely, Calculus II students showed a significant increase, with mean scores rising from 2.782 to 2.974 ($p < .0348$). This item falls within the Performance Phase of Zimmerman's (2000) SRL model and is categorized under Information Management Strategies. One possible explanation for the difference in the direction of change in responses between Calculus I and II is the course content. Calculus I emphasizes limits and derivatives, often in procedural, formula-driven ways, potentially discouraging deep engagement with mathematical reasoning. By contrast, Calculus II introduces integrals, sequences, and series, which are conceptually complex and allow multiple solution strategies, fostering motivation to understand the reasons behind computational strategies. Reflections from the instructor, GTAs, and LAs provide additional perspective. The instructor noted many Calculus I students were "pretty focused on just getting through," contributing to reliance on procedural strategies. In Calculus II, instructional staff emphasized the "why" behind concepts, theory, applications, and deeper understanding, discouraging "plug and chug" approaches. Taken together, these results suggest both course content and instructional practices shape students' development of information management strategies.

Item 31: "I ask questions during lectures or recitation sessions when I don't understand something." As seen in Table 2, Item 31 revealed notable differences in help-seeking approaches between Calculus I and Calculus II. In Calculus I, mean scores significantly declined from 2.919 on the pre- to 2.649 on the post-survey ($p < .0101$). In contrast, Calculus II students reported significant growth in this area, with mean scores rising from 2.641 to 3.026 ($p < .0010$). This item is in the Performance Phase of Zimmerman's (2000) SRL model and is categorized under Help-Seeking. The contrasting outcomes between Calculus I and II may be partially explained by the differences in classroom climate and familiarity with instructional staff. The course instructor for both Calculus I and II noted that "Calc I was a huge lecture," which may have discouraged students from asking questions. On the other hand, many of the Calculus II students had the same instructor throughout the year in both courses, which may have fostered a stronger rapport and comfort. A Calculus II GTA and LA in different recitations described deliberate efforts to encourage questions and create a supportive environment. One GTA reflected, “I was very happy with the learning environment my LA and I created along with all of our students.” Collectively, these perspectives suggest that differences in classroom climate, continuity of instructional practices, and explicit encouragement of questioning likely contributed to the increase in those practices among Calculus II students.

Item 57: “When I need to solve a mathematical problem, I think of several ways to solve it and choose one that makes the most sense for me.” Comparisons of planning skills in Calculus I and II, measured by Item 57, revealed opposite trends in student development over the course of the semester. As shown in Table 2, Item 57 was statistically significant for both Calculus I and Calculus II. Calculus I students’ mean scores significantly decreased from 3.054 on the pre- to 2.824 on the post-survey ($p < .0428$), whereas Calculus II students’ scores significantly increased from 2.756 to 3.000 ($p < .0109$). Within Zimmerman’s (2000) SRL model, Item 57 belongs to the Forethought Phase and is categorized under Planning. Similar types of differences in course content and instructional practices, as described for Item 18, likely influenced students’ planning skills. Calculus II’s focus on integration techniques, and sequences and series, where there are multiple solution strategies, may be more conducive to seeking various solution paths, compared to Calculus I, which focused more on procedures for finding limits and derivatives. The instructor noted that planning skills may have improved in Calculus II because students must evaluate “all the paths we can go down to solve” a problem, whereas Calculus I problems follow a straightforward path. A GTA emphasized recitations highlighting multiple solution strategies, and an LA noted that peer collaboration exposed students to alternative approaches. Together, these factors support the development of planning skills in Calculus II, while the more linear nature of Calculus I may limit growth.

Course Specific Significant Changes

In addition to the items discussed above, several other survey items showed statistically significant changes for either Calculus I or Calculus II, though not both. Due to space constraints, we summarize the results here and focus on a select few items.

Calculus I students demonstrated significant improvement in two areas of self-regulated learning: Item 42, reflecting careful reading of instructions before starting a task (Forethought Phase/Planning Category), and Item 52, highlighting self-control in exam preparation (Performance Phase/Self-Control Category). These gains suggest that students were increasingly attentive and deliberate in their problem-solving approaches and exam strategies. Eleven other items showed decline, including Item 49 (Performance Phase/Help-Seeking Category), which measures help-seeking from instructors or GTAs. This decrease aligns with findings for Item 31, suggesting that Calculus I students were generally less comfortable seeking support from the instructional team. These results reflect areas for growth and provide valuable insight into where additional encouragement or support could further strengthen students’ SRL skills.

For Calculus II, four items showed statistically significant changes. Students improved on two items, which reflected enhanced skills across all three SRL phases, but declined on Item 8: “I can motivate myself to learn mathematics when I need to” (Forethought Phase/Conditional Knowledge). Interestingly, this item had a slight, non-significant increase for Calculus I, but a significant decrease for Calculus II students ($p < .019$), making it the only item with a reversed direction of change between the two courses. The instructional team was unsure why motivation decreased for Calculus II students, indicating a need for further research to better understand the factors contributing to this decline.

These results indicate that both courses can foster growth in students' SRL skills. Calculus I students showed improvements in self-control, while Calculus II students generally improved across several categories. These patterns highlight the potential for targeted instructional strategies to support continued development of self-regulated learning in both courses.

Discussion and Scientific Significance of the Study

This study examined changes in self-regulated learning (SRL) skills among Calculus I and II students that occurred without SRL interventions. The analysis revealed contrasting patterns across the two courses, despite their similar pedagogical approach and being taught by the same instructor, which we found surprising and tried to explore further. Calculus II students showed measurable gains in SRL skills, including planning, self-control, and information management, whereas Calculus I students exhibited declines across most SRL skills. Prior research on SRL demonstrated that students often struggle to develop self-regulatory skills independently and that explicit scaffolding or intervention is typically required for meaningful growth (Panadero, 2017; de Boer et al., 2018; Dignath & Büttner, 2008). Our findings regarding Calculus I students align with these previously observed results, but not for Calculus II students.

Calculus II students showed notable increases in many of their SRL skills. Several factors may explain this pattern. Improved instructional practices through a larger reform effort fostered opportunities for students to practice SRL skills. One GTA noted that her students "were very active participants in recitation and also seemed to develop good relations amongst each other," illustrating how a supportive, interactive environment can encourage self-regulated behaviors. Student maturity and prior experience with college-level mathematics also likely contributed to increased capacity for planning, monitoring, and reflecting on learning. Finally, course content that offered multiple solution strategies and encouraged deeper engagement may have supported intrinsic motivation and skill development.

In contrast, Calculus I students showed declines in several SRL skills, consistent with both SRL research and literature on challenges in introductory calculus. Students were less likely to seek help and engaged less in performance-phase strategies, reflecting the difficulties of large, formula-focused lectures and the cognitive and emotional demands of first-year calculus (Bressoud, 2015; Ellis et al., 2016). Instructional team members noted that many students were still adjusting to college-level study habits and heavier course loads, suggesting that SRL skills may not develop automatically (cf. de Boer et al., 2018). These findings underscore the importance of supporting SRL skill development, particularly in university STEM gateway courses where students may lack experience and confidence.

The results have several implications for calculus instruction and undergraduate mathematics education. They highlight the potential for instructional practices and course design to promote SRL even without formal interventions, while reinforcing the need to target first-year students with explicit scaffolding. SRL remains under-researched in undergraduate mathematics despite its role in promoting persistence, motivation, and conceptual understanding (Panadero, 2017). There is a clear need for research-based interventions, and we are currently designing one tailored for calculus students. Overall, supporting SRL must complement curriculum reform, as improving teaching alone cannot equip students with the skills to regulate their own learning.

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