Adding self-regulated learning instruction to an introductory physics class

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Self-regulated learning (SRL) is an essential factor in academic success. Self-regulated learning is a process where learners set clear goals, monitor progress toward attainment of those goals, and adapt their strategies to improve their learning. Because SRL is often not explicitly integrated into the classroom, students struggle to identify and use learning techniques empirically proven to be more successful than others. SRL is a learned skill students can develop over time that has been found to be related to high achievement and self-efficacy. This paper examines the effects of introducing SRL strategies into an undergraduate introductory physics classroom. The degree to which the students were self-regulated learners was correlated with their test averages ($r = 0.23$, $p < 0.05$). Students reported that they found the SRL instruction helpful (3.5 out of 5.0 on a 5-point scale) and 86% of the students felt the time spent on the instruction was generally appropriate. Students' preferred study methods changed over the course of the semester, indicating that students applied SRL by adapting their learning processes based on which methods were most effective in helping them study for an upcoming exam and opting not to use techniques no longer perceived as useful. Higher achieving students were more likely to settle on highly effective techniques by the end of the semester, while lower achieving students continued to modify their learning processes.

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I. INTRODUCTION

Self-regulated learning (SRL) is a skill that learners develop to direct their cognition, metacognition, behaviors, and performance to achieve their academic goals [1]. While there are many theoretical models for self-regulated learning, several share a few common features. First, goal-setting begins the self-regulated learning process by outlining the objectives of the learning period [2]. This includes choosing learning strategies dependent on their effectiveness at achieving the desired learning outcomes. Next, self-regulated learning is a cyclical process involving feedback loops that inform learners on how to proceed toward their goals [3]. Learners metacognitively monitor the effectiveness of their chosen strategies, distractions from internal or external sources such as the environment, and motivation levels throughout the learning period. Finally, self-regulated learners reflect on the successes and failures of their learning processes [4]. This includes identifying successful or unsuccessful learning strategies and measuring the attainment of their previously set goals. Self-regulated learners determine the strengths and weaknesses in their learning regimens, make necessary changes toward goal achievement, and the cycle continues.

In a study on self-regulatory processes, 93% of students were correctly classified as higher achieving or lower achieving based on their knowledge of self-regulated processes; the use of SRL strategies predicted their standardized test scores after controlling for non-cognitive variables [5]. However, in another study, when asked to rank the general effectiveness of learning strategies, undergraduates were unable to identify the methods which have been empirically determined to be more effective [6]. SRL is a learned process that helps students develop effective study strategies [7] and has been previously implemented in physics courses with a positive effect [8]. Because the use of SRL strategies has been shown to increase student grade point averages [9] and be correlated with academic achievement in the natural sciences [10], it is likely that students would benefit from instructors incorporating SRL instruction into their classrooms.

This study presents initial results of the implementation of SRL instruction in undergraduate physics classrooms. The following research questions will be explored: *RQ1: Does the self-regulated learning intervention produce positive student results? RQ2: How do students' preferred study strategies and behaviors change over time when exposed to self-regulated learning instruction?*

II. METHODS

This study was conducted at a R1 university with greater than 18,000 undergraduate students as of Fall 2021. The institution's undergraduate population was 81% White, 6% two or more races, 4% Hispanic/Latinx, 3% Black or African American, 3% non-resident alien, 2% Asian, and other groups less than 1% [11]. The intervention program was administered over two semesters from Fall 2022 to Spring 2023 in the introductory, calculus-based electromagnetism course taken by physical scientists and engineers. The class features three 50-minute lectures each week which use Peer Instruction [12] and group problem solving and one 170-minute lab each week which implements a number of active learning strategies. Students were presented with ten SRL and metacognition techniques during the lecture segment of the course as well as a general discussion of SRL and metacognition and why it was important in learning physics. One new technique was presented each lecture through the first half of the class using one to three powerpoint slides with discussion occupying approximately two to three minutes of class time.

The theoretical model for the study was based on models developed by Zimmerman [13] and Pintrich [14]. The SRL program was developed around a cyclic application of "Plan," "Monitor," and "Reflect." Students were exposed to new learning techniques they may not have been familiar with and encouraged to experiment with implementing these strategies into their study routines. The strategies presented included six SRL techniques: (1) Take Care of Yourself, (2) It's Never Too Early, (3) Study A Little A Lot, (4) Don't Rote Memorize, (5) Quiz Yourself, and (6) If At First You Don't Succeed, Try Something Else. These strategies were chosen based on previous work by Lineweaver on the memorability and perceived positive influence of the techniques [15]. Additionally, students were presented with four metacognition techniques: (1) Concept Maps, (2) Take Notes From Memory, (3) Think Out Loud, and (4) Identify the Muddiest Point [16, 17].

To encourage the key reflection and planning parts of the SRL cycle, all students were sent four online surveys; they received a small amount of course credit for completing each survey (10 total bonus points out of 1000 total class points). Only students consenting to participate in this research study (99.1% of students taking the surveys) are included in the following analysis. The first survey was sent the week before the first exam and asked the students to select the techniques they planned to use on the upcoming exam and to rate their expected effectiveness of the study techniques. A large list of possible study methods were presented; a subset of that list is shown in Fig. 1. The last three surveys were given one week after the first three in-semester exams. These surveys asked the students to reflect on their previous exam performance and rate the study methods by effectiveness. The students reported the most and least effective techniques through open-response answers as well as which techniques they would add or remove from their study plan.

On the last survey, students were asked about the effectiveness of the SRL instruction overall to measure the students' perceived value of the program. In Spring 2023, Survey 4 also included additional questions measuring the perceived effectiveness of specific SRL and metacognitive techniques. In Spring 2023, Survey 4 also contained 17 questions to assess the degree to which students were "self-regulated learners." These Likert-scale questions were developed from items in the Motivated Strategies for Learning Questionnaire (MSLQ)

[18]. The items measured a number of constructs important to SRL including goal setting, environment and time management, cognitive/metacognitive strategies, help-seeking, and evaluation.

III. RESULTS

Table I presents the descriptive statistics for the two semesters: the overall class enrollment (N), the number of students who completed each survey (n), and the test average of the 3 in-semester examinations. The average survey response rate was 81% rate in the fall and 76% in the spring. While response rates decreased for later surveys, they remained high throughout the semester.

TABLE I. Descriptive Statistics. N represents the total class enrollment; test average is presented as mean $\pm$ standard deviation.

Semester	Fall 2022	Spring 2023
N = Total	239	136
n = Survey 1	196	121
n = Survey 2	203	104
n = Survey 3	192	95
n = Survey 4	186	95
Test Average (1 - 3)	74.6 ± 17.8	73.2 ± 19.1
DFW Rate	14%	15%

A. Intervention Efficacy

To provide evidence for the value of SRL instruction and its potential benefits for students, we measured the degree to which students implemented self-regulated learning behaviors late in the course using the items developed from the MSLQ [18]. The degree to which students were self-regulated learners by Survey 4 was positively correlated with their average on Exams 1 to 3 with correlation $r = 0.23$, $p < 0.05$. This represents a small to medium effect by Cohen's criteria [19]. This correlation represents a stronger association between a non-cognitive variable and academic achievement than a number of other constructs thought to influence achievement, such as test anxiety, the student's personality, or their goal commitment [20]. The correlation is weaker than that of self-efficacy or cognitive measures such as ACT scores with academic achievement.

The DFW rate – the fraction of students earning grades of D or F or withdrawing from the course – was lower in the semesters implementing SRL instruction than in the two semesters prior to introducing SRL instruction. The DFW rate in Fall 2021 was $16.5\% \pm 7\%$, which decreased to 14.0% in Fall 2022. The DFW rate in Spring 2022 was $22.5\% \pm 6\%$, which decreased to 15% in Spring 2023. Historically, the DFW rate for the class is smaller in the fall which is taken by more on-sequence students.

TABLE II. Overall SRL technique effectiveness (5-point Likert scale with extremely effective as 5).

Technique	Mean	SE
Take Care of Yourself	3.48	0.08
Start Things Earlier	3.38	0.08
Think Out Loud	3.30	0.08
Identify the Muddiest Point	3.25	0.09
If At First You Don't Succeed	3.11	0.08
Study A Little A Lot	3.00	0.07
Quiz Yourself	2.93	0.09
Don't Rote Memorize	2.38	0.08
Concept Maps	2.22	0.09
Take Notes From Memory	1.90	0.09

The students were asked to rate the effectiveness of the SRL and metacognitive techniques presented on a 5-point scale ($5 =$ most effective) as shown in Table II. Of the 10 tips presented, reminding students to Take Care of Themselves was reported as the most effective. This may suggest that simple messages promoting mental and physical health and well-being can be productive when included in physics classes. Students also reported that the advice to start their assignments and exam study sessions earlier, as opposed to cramming, was beneficial. This result was supported by a qualitative analysis of the open-response answers; the most common strategies students wished to add to their study regime included starting earlier and improving time management (Table IV).

The students rated the helpfulness of the in-class SRL discussion as 3.52 ± 1.0 on a 5-point scale; 57% of participating students felt that in-class discussion was somewhat or very helpful. The helpfulness of the reflection into past study habits provided by the surveys was rated 3.55 ± 1.1; 59.8% found the reflection as somewhat or very helpful.

TABLE III. Student feedback on the presentation of self-regulation, metacognition, and study habits in lectures.

	Fall 2022	Spring 2023	Total
Eliminate entirely	8	3	3.93%
Reduce substantially	12	6	6.43%
Reduce slightly	26	16	15.00%
Keep same	98	51	53.21%
Increase slightly	34	15	17.50%
Increase substantially	7	4	3.93%

The time spent discussing SRL reduced the time spent discussing physics content. The most direct measure of the student's perceived value was whether they thought the time was well used. Table III shows the results of a question asking how the time used by SRL instruction should be modified for

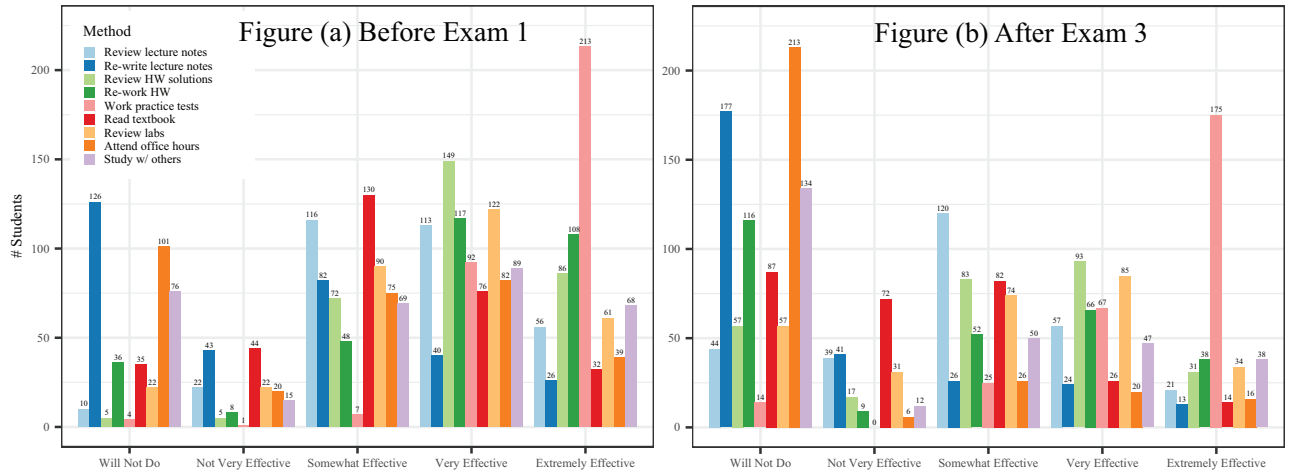

FIG. 1. Figure (a) Study methods and their perceived effectiveness students thought they would use to study for Exam 1 ($n = 317$); Figure (b) methods and their perceived effectiveness students did use to prepare for Exam 3 ($n = 281$).

next semester. The overwhelming majority, 86%, of the students felt the SRL instruction used about the right amount of time (Table III either keep the same, reduce slightly, or increase slightly).

B. Patterns of self-regulation

The survey items asking students to reflect on their study habits allowed the investigation of how student perceived their habits to have changed through the semester and gave some indication of what level of self-regulation could be expected.

Figure 1(a) presents student responses to the question, "Select all the study methods you plan to use for Test 1 and how effective you think they will be. If you don't plan to use the method, select Will not do." Students were asked about many methods, a subset of those methods are presented in the figure. These include "Review lecture notes," "Rewrite lecture notes," "Review homework solutions," "Rework homework," "Work practice tests," "Read textbook," "Review labs," "Attend office hours," and "Study with others." Students had access to their instructor's class lecture notes and three practice tests for each exam.

Before Exam 1, students reported that most of the study methods presented would be effective to some degree in their studying and indicated they would use those methods. About 67% of participants (213 of 317) believed that completing the practice tests would be "extremely effective," while other methods such as reviewing homework solutions and reading the textbook were more often perceived as "very effective" or "somewhat effective." While some methods stood out as likely to not be utilized by students, overall, most methods were viewed as likely to be effective prior to the first exam of the course.

Figure 1(b) presents student responses to the question, "Select all the study methods you used for Test 3 and how effective you think they were. If you didn't use the method, select Did not use." The figure shows a dramatic shift in habits and their perceived effectiveness from those in Fig. 1(a). Working through practice exams remained the most favored method by students for the third exam, but there were several more techniques than previously that students were opting not to include in their studying. 48% of students (134 of 281) would not study with others, 63% (177 of 281) would not rewrite lecture notes, and 76% (213 of 281) would not attend office hours. Students continued to utilize the course textbook throughout the semester; however, it was often viewed as a less effective tool compared to other study techniques. This agreed with students' qualitative open responses that frequently listed using the textbook as the "least effective" study method (Table IV). The change from Fig. 1(a) to (b) happened over the semester; Surveys 2 and 3 showed a progressive change in study methods suggesting students were reflecting on their past performance and modifying study behavior accordingly.

The prior analysis aggregated all students, but one might expect students who are doing well in the class to modify their study behaviors less than students who are struggling. To analyze the differences between higher achieving and lower achieving students, participants were asked to report their most effective and least effective study method in an open-response question and asked to identify any strategies they intended to add or remove from their study plan. Higher achieving students were students with a test average above the 75th percentile after Exam 3, while lower achieving students were those with a test average lower than the 25th percentile. A qualitative analysis of these responses is presented in Table IV. Both groups of students reported that reviewing the instructor-provided practice exams and home-

TABLE IV. Study strategies of higher and lower achieving participants after Exam 3.

Study Strategies of Higher Achieving Participants (75th Percentile) after Exam 3			
Most Effective	Least Effective	Add Strategy	Remove Strategy
51 - Practice exams	23 - None	69 - None	70 - None
23 - Reviewing HWs	15 - Readings	1 - Focus on free-response	
11 - Readings	12 - Reviewing notes		
9 - Reviewing labs	(+20 responses / 10 strategies)		
7 - Reviewing notes			
(+15 responses / 9 strategies)			
Study Strategies of Lower Achieving Participants (25th Percentile) after Exam 3			
Most Effective	Least Effective	Add Strategy	Remove Strategy
42 - Practice exams	22 - Readings	55 - None	3 - Procrastination
11 - Reviewing HWs	15 - Not studying enough	5 - More practice problems	2 - Remove distractions
8 - Reviewing labs	7 - Reviewing notes	4 - More time studying	2 - Readings
5 - Readings	7 - None	2 - YouTube videos	1 - Reviewing notes
5 - Studying w/ others	6 - Lectures, lecture slides	(+ 12 responses / 10 strategies)	
5 - None	(+9 responses / 7 strategies)		
(+16 responses / 6 strategies)			

work were the most effective study methods. Both groups also agreed that reading the textbook was the least effective. 23 of 70 high-achieving students reported that none of their study methods were least effective. No higher achieving student said they would remove any methods from their studying, and only one noted they would add to their study plan. In contrast, lower achieving students listed a variety of methods they would add or remove from their processes, including spending more time on studying and removing distractions and cramming.

IV. DISCUSSION AND CONCLUSIONS

RQ1: Does the self-regulated learning intervention produce positive student results? Students found the SRL instruction was helpful and felt the 2-3 minutes per lecture spent on the instruction was appropriate. "The study habits helped me because I knew physics was a hard subject for me and I didn't really understand how to study for it," one student commented. Higher levels of self-regulating behaviors were correlated with higher exam scores ($r = 0.23$, a small to medium effect), which agrees with past work on SRL and achievement [5, 9, 10]. The DFW rate in the semesters implementing SRL instruction was lower – substantially lower in the spring semester – than in the prior year's offering of the class. The participation rate for students was high from 75% to 80% with small incentivization in the form of course credit. As such, SRL instruction is a promising, low-cost method to help students succeed in introductory physics.

RQ2: How do students' preferred study strategies and behaviors change over time when exposed to self-regulated learning instruction? Throughout the semester, students self-regulated by actively modifying their study habits and choice of techniques between each exam. Figure 1 shows a dramatic shift from students' planned behavior and its expected effectiveness before Exam 1 to their actual behavior and its perceived effectiveness when reflecting on Exam 3. This suggests students are practicing SRL by planning to employ a study method, monitoring its usefulness, and reflecting on its effectiveness. Beyond methods reported in Fig. 1, students were also asked to rate the effectiveness of reading online physics material, watching online physics videos, and using tutoring sites. Before Exam 1, approximately 61% of students reported using these online sources to some degree. By the end of the semester, only about 25% of students reported using these resources, suggesting students recognized that using the materials provided by the class, particularly the practice tests, were more useful. The patterns of self-regulation differed for higher achieving and lower achieving students. Higher achieving students established a study regime using methods they found effective by the end of a semester, while lower achieving students struggled to develop stable study plans and continued to make modifications late in the semester.

This study has potential limitations. No control group was available for the study. The data were collected at one institution with predominantly white students. Demographic variables such as gender and race were not collected; therefore, it is unknown if the program served different students to different degrees.

A program of SRL instruction supported by online surveys to promote reflection and planning represents a low instructional time-cost method to help students develop self-regulation skills. This work is supported in part by National Science Foundation grant DUE-1833694.

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