Tracing Metacognitive Self-Regulation in an Introductory Physics Course

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Abstract: Many students’ beliefs about physics knowledge can impede their development as a learner in introductory physics courses. Thus, physics classrooms must offer an environment in which students can make mistakes, recognize them, and resolve inconsistencies. Such a thought process is metacognitive by nature, and requires students to actively monitor and modify their academic progress. This assessment of oneself as a learner is called self-regulation, and takes behavioral forms such as setting appropriate learning goals, retaining intrinsic motivation, and choosing the appropriate learning strategies in a given situation. In this paper, we describe a study in which students write weekly self-reflections in an objective-based, introductory physics course. Examining the responses of the highest and lowest performers, we found that students increased, decreased, or remained the same in terms of their ability to reflect metacognitively over the course of the quarter. From these results, we discuss ways in which self-regulation may be integrated into additional components of the introductory physics curriculum, specifically in Tutorial sessions.

I. INTRODUCTION

In general, a classroom is a space susceptible to a complex combination of factors that may influence learning. When analyzing an academic environment, one must consider aspects such as the distinct learning styles of individual students, the dynamic between students and instructors, and the instructor’s implementation of the curriculum, in addition to the interplay of the discipline content itself with the ways that students reason. Physics classrooms in particular are home to a vast array of student difficulties and prior intuitions that must be transformed into formal conceptual knowledge, and thus present a need for scientific studies to guide instruction.

In the rising field of Physics Education Research (PER), experts trained in the domain of physics study the teaching and learning of physics mostly at the college level, with the goal of identifying prominent student difficulties and developing instructional methods that rebuild and correct these intuitive perceptions. Since its origins, PER has expanded from focusing on student reasoning issues to applying epistemological and cognitive approaches to guide physics education.

Most introductory physics courses follow a fairly standard combination of lecture, lab, and recitation sessions; as such, there are a multitude of people, activities, and assessments that contribute to a student’s overall learning experience. Students must successfully synthesize all of the activities and information presented to them in order to understand the physics content, and this necessitates an ability to monitor one’s academic progress and use of learning strategies.

The goal of the present study is to explore one method by which students can monitor their own recognition and correction of misunderstandings in physics: metacognitive self-reflection. During this process, students cognitively take a step back and think about what they do and do not understand, and identify how and why their thinking changes as a result of certain tasks and activities. In this way, learners monitor and modify their comprehension of material in a process known as self-regulation.

This paper describes a cognitive approach to analyzing student perceptions of physics concepts as indicated on weekly self-reflections written throughout an objective-based introductory mechanics course. By investigating survey data and reflections of the highest and lowest performing students, we trace patterns of metacognitive thought processes in a preliminary attempt to relate self-regulation to academic performance.

We compare this lecture section to a control section that did not reflect at all. Further, we use our findings to create instructional developments that foster self-regulatory skills.

We begin by outlining the existing literature and theoretical background of self-regulated learning. This is followed by a description of the experimental methods used in this study, as well as a dissemination and analysis of our results. We conclude with a discussion on how we may further incorporate metacognitive thinking in the physics learning environment.

II. BACKGROUND

A. Components of Self-Regulation

As mentioned above, the physics classroom is a complex learning environment in terms of both interpersonal dynamics and diverse mindsets. The involved nature of the subject’s content in itself often presents a challenge for students: many physics problems necessitate the connection between qualitative concepts and quantitative approaches, including the ability to apply the correct explanations, graphs, and diagrams to a given situation [1]. Nonetheless, it is very common for students to perceive the subject as strictly requiring
the algebraic manipulation of given formulas [2]. Thus, a main focus of PER is to guide students’ physics approach to problem-solving and troubleshooting and to help students become active, motivated learners.

To facilitate the synthesis of the diverse information sources of an introductory physics course, students may need to become more aware of and hold more control over their learning environment. This skill, called self-regulation, has been shown to contribute to effective learning [3]. Self-regulation more specifically refers to a student’s ability to plan, monitor, and regulate his or her cognitive behaviors in the pursuit of successfully completing academic tasks. This mainly involves an individual learner’s ability to identify what he or she does not understand, and to adapt his or her learning processes accordingly. Self-regulated learning behaviors include the following: setting appropriate goals, retaining intrinsic motivation, and using appropriate strategies in a given situation [4]. These three skills are explained in more detail below.

a. Setting Appropriate Goals. The first of these skills specifies that students effectively engaging in self-regulation set goals for themselves that are challenging, yet attainable. With knowledge of what one does and does not know, one must be able to gauge and achieve fitting academic goals. Previous work suggests that self-monitoring becomes more manageable when students set specific, short-term objectives – subgoals, instead of generic, long-term goals [5]. This provides more structure to a student’s learning procedure and focuses his or her attention on particular skills.

b. Maintaining Intrinsic Motivation. Intrinsic motivation refers to a personal desire to complete an activity or excel academically. This contrasts with extrinsic motivation, which is one’s commitment to a task based on superficial outcomes such as recognition among peers and high grades. Students intrinsically motivated by intellectual interest and self-development are more likely to engage in better learning strategies than those who are extrinsically motivated by rewards. Young (2005) found that intrinsic motivation in marketing courses is directly related to self-regulatory processes such as monitoring, planning, and regulating, whereas extrinsically motivated students likely use surface level skills such as memorization [6].

c. Applying Appropriate Learning Strategies. As mentioned earlier, the complex nature of problem-solving in physics makes it essential that students access the correct methods at the appropriate times [7]. Since internal feedback is generated during self-regulation, a learner’s engagement with and approach toward activities evolve over time as different learning tactics are accessed and applied [8]. Students must determine the qualitative and quantitative implications of given problems, and then access the appropriate tools – formulas, explanations, diagrams, etc. – to reach a solution. To promote effective implementation of learning methods in certain situations, previous work advocates that instructors of content-area courses directly teach students such strategies [9].

B. Prior Research

Self-regulatory learning skills in general have been empirically shown to increase conceptual knowledge gains and improve student performance of tasks. In a study of the verbal self-monitoring of students as they learned a specific computer language, those who were taught self-explanation and self-regulation strategies had higher performance gains [12]. Higher performing students are cognitively aware of what they do not understand and ask themselves more specific questions during self-regulated learning processes than lower performing students [13]. Accordingly, it may be of value to not only assign self-regulatory activities, but to teach students how to successfully employ such self-monitoring techniques on their own. We discuss this proposition further in section V.

The primary focus of the present study is students’ metacognitive monitoring of self-regulated skills. Metacognition is the act of cognitively reflecting upon and being aware of one’s own thought processes. The understanding of one’s own cognition is important because it allows learners to regulate their thinking processes as they focus on achieving certain goals [10]. For physics students in particular, it is important that learners monitor, reflect on, and adapt these processes as they occur during the course of solving problems and learning new material. Van De Bogart et al. (2015) showed that troubleshooting via metacognition in an upper level electronics course helped students strengthen their conceptual understanding and apply effective troubleshooting techniques when repairing defective circuits [11].

A student’s ability to recognize and critically reflect upon his or her errors in understanding concepts is a crucial aspect of metacognitive self-monitoring. In one previous study, students in an honors introductory physics course reflected weekly on what they learned and how they learned it. Higher performing students were found to hold more favorable epistemological beliefs and practice more self-regulatory behaviors, as seen in their written responses [14]. Thus, reflective practices may elicit metacognitive self-regulation by helping students identify and focus on strengthening conceptual knowledge gaps.

In addition to the presence of self-regulation in previous PER work, the literature also demonstrates that there are advantages for both students and instructors when a course is designed around specific learning goals [15]. Focusing on a set of learning objectives, particularly in the domain of physics, helps students organize the presented information and monitor what they do and do not know as the course progresses. In other words, learning goals can provide a structure around which students can self-regulate.

To combine these two previously studied concepts of
self-regulation and learning objectives while drawing on prior research to influence our experimental method, we designed a course around learning objectives and incorporated reflection assignments. We compared two lecture sections of the course – one in which students reflected weekly (experimental section) and one in which students did not reflect at all (control section) – based on results from the Colorado Learning Attitudes about Science Survey (CLASS), long response exam solutions, and written self-reflections [16].

C. Research Questions

Our research questions are the following:

1. What differences are there in CLASS and final exam long answer problem responses between the two sections and between the highest and lowest performers?

2. What kinds of metacognitive and self-regulatory thoughts are present in weekly reflections, and how do they change over a 10 week quarter?

3. How can instructors integrate self-regulation into additional course components?

To address the first question, we analyzed the CLASS responses by section and by quartile (based on final course grade) both numerically and graphically. We also created histograms of the final exam question grades and examined the written responses to this problem. To answer the second question, we looked at the responses of individual students in the experimental session over the course of the quarter and determined common patterns among the reflections. We discerned evidence of metacognition, characterized how each student’s reflections change over time, and began to develop a coding scheme that can be applied to all of the data. Finally, we explored how instructors may implement elements of self-regulation and metacognitive thinking in coursework other than reflection assignments.

III. METHOD

Our study focuses on two lecture sections of an introductory, calculus-based physics course at the University of Washington during a 10 week quarter (Spring 2018). The course covers topics in mechanics and is primarily comprised of engineering, computer science, and physics majors. Each week, students attend three 50 minute lectures, a two hour laboratory session, and a 50 minute Tutorial session. Tutorials take place within smaller sections of students and serve as an interactive supplement to lecture and lab instruction. Using materials developed by the University of Washington Physics Education Group, students work in groups and use reasoning and inquiry skills to construct conceptual knowledge and relate formalism in physics to the real world [17].

Two different instructors – both female – taught the two lecture sections, but both designed their courses and assessments around the same learning objectives. The same free response homework questions were assigned and graded in Mastering Physics in both sections. In the experimental section (N=193 students), students wrote reflections each week. These were assigned as an additional question on the weekly online homework problems for the lecture component of the class. The reflections were graded in a pass/fail manner such that students either got full credit or zero credit for responding adequately. In the control section (N=147 students), the students did not complete any reflection assignments.

It is important to note the underlying assumption that these two sections of an introductory physics course at UW are comparable. Heron (2015) investigated the impact of variables that may seem to distinguish two lecture sections of a course – time of day of the lecture, class size, etc. [18]. She determined that only about 10% of variation in student performance before and after lecture has occurred can be explained by lecture instruction. From this study, we are able to compare our two sections of introductory mechanics without considering these variables that may differentiate the lecture sections.

Making this assumption that the two sections being compared are academically identical, we present the method and analysis of the three forms of data we collected from the two sections: the CLASS, long answer solutions from a final exam problem, and weekly reflections.

1. CLASS

The CLASS was designed to measure student perceptions and attitudes toward learning physics, and serves as a basis for how students’ beliefs change after completing a physics course. Students respond to 42 Likert-Scale questions that cover a variety of categories related to learning physics, including problem solving skills, real world connections, and sense-making. As such, the CLASS allows us to gain a general outlook on how the students in our two sections perceive physics.

The CLASS analysis is based on whether students give favorable responses to the survey statements, indicative of expert-like thinking, or unfavorable responses, indicative of novice thinking. The creators of the survey tested and validated which question and answer combinations are favorable or unfavorable. For example, agreement with the following statement from the survey indicates expert-like thinking: “When I solve a physics problem, I explicitly think about which physics ideas apply the problem.” Of course instructors aim to
increase students’ ability to think like experts, but gaining favorable responses from students is very rare in practice. The expected result is a slight decrease in favorable responses between the pre and post administration of the survey. The national average for this shift in favorable responses is about -4%.

We administered the CLASS to both the experimental and control sections, once at the beginning of the quarter and once at the end of the quarter. By generating numerical and graphical representations of student responses, we compared the students in each section before and after the course on the basis of attitudes toward physics. We also analyzed the survey responses when each course is broken down into quartiles of students based on final course grades to compare the beliefs of the highest and lowest performers.

2. Final Exam Long Response

Both sections were assigned a very similar long answer problem on the final exam. Students in the control section answered the following question, and students in the experimental section answered the following question with the hoop replaced by a solid cylinder:

“A bullet of mass \( m \) moving with velocity \( v_i \) grazes the top of a hoop of mass \( M \) and radius \( R \) resting on a rough surface. The bullet leaves with velocity \( v_f \) along (approximately) the same path as shown (see Figure 1). The hoop rolls without slipping. Find the kinetic energy of the hoop after it starts to roll. Express your answer in terms of \( m, M, R, v_f, v_i \), and any constants. Justify your work and simplify your answer as much as possible.”

![FIG. 1. The above diagram was provided with the long answer question on the final exam.](image)

This question requires students to apply standard mechanics concepts: conservation of angular momentum about a particular point in the system and combining translational and rotational kinetic energy. We created histograms of student grades for this problem in the two separate sections in order to compare the control group and experimental group in terms of conceptual knowledge at the end of the course. We also looked through the students’ written responses to these problems, focusing on the highest and lowest scoring answers within each section, to find common mistakes and any signs of students using self-regulatory strategies in their approach.

3. Weekly Reflections

Students in the control section were not assigned reflection questions. Students in the experimental section reflected each week about their personal progress toward meeting the instructor’s learning objectives. The reflections were assigned at nine times during the course, and students were asked to write about the material and course activities from the previous week. Students responded to the following prompt:

“Select one course Weekly Objective on which you’ve made progress over the past week. Briefly describe an activity you engaged in over the past week during which you made progress on one of the Learning Objectives you selected. Finally, describe how your thinking changed as a result.”

The goal of assigning such a prompt was to elicit a metacognitive awareness of one’s prior conceptual misunderstanding being transformed into correct formal knowledge. In order to help students write acceptable reflections, substantial feedback was given during the first few weeks of the assignment, and some guidance was provided during the remainder of the quarter. Feedback comments were intended to get students to reflect metacognitively, and pushed students to explicitly state their previous thinking about a topic, how any activity or problem changed that thinking, and their new line of reasoning.

We first went through the responses and discerned which reflections included these three components and were thus metacognitive. We then organized the reflection data by students’ final grade in the course and focused on the top and bottom quartiles. Reading each student’s written reflections, we traced trends of metacognitive thought over time. Such patterns yielded a preliminary coding scheme and a motivation to develop instruction.

IV. RESULTS AND ANALYSIS

For each of the three types of data collected, we describe our analysis and interpretation of the results.

1. CLASS

For our comparison analysis of CLASS responses, we only considered those students who took the survey at both points in the quarter, \( N=138 \) in the experimental section and \( N=100 \) in the control section. Figures 2 and 3 show the pre and post CLASS responses of the experimental and control sections, respectively, broken down
by categorical clusters of questions. From left to right, the clusters are applied conceptual understanding, conceptual understanding, personal understanding, problem solving confidence, problem solving general, problem solving sophistication, real world connection, and sense-making/effort. These categories were determined through factor analysis, and then named, by the CLASS designers.

A general look at the plots reveals little difference between the the pre and post performances of the two lecture sections. We see very little measurable differences between the two groups based on our measures. However, we see that the control group started with higher favorable response percentages, so these samples are not identical in this regard. In what follows, we discuss interesting trends that will require further study in order to determine if they are indeed real effects.

Numerically, the experimental section resulted in an overall decrease in favorable responses by $6.9 \pm 1.5\%$, while the control section resulted in an overall decrease in favorable responses by $5.9 \pm 1.7\%$. The statistical difference in overall shift in favorable responses between the experimental and control section is not significant by a two-tailed t-test ($p > 0.05$).

One may notice that these two sections experienced shifts in favorable responses worse than the national average (-4%). A potential explanation for this is instructor gender. Both sections had female lecturers, to whom students respond differently than to male instructors. To compare, the third lecture section of this same course from Spring 2018 had a male instructor, and covered the same content with the same assignments and assessments as the two sections we are investigating. This third section had an overall decrease in favorable responses on the CLASS of about -4.2%, which is more in line with the expected value.

From our plots and our analysis, we see that there is little variation between the two groups in terms of how their attitudes and beliefs towards physics changed between the beginning and end of the quarter when all students and all questions are considered. From a broad perspective, there seems to be a lot of similarity in beliefs between these two lecture sections; however, further analysis yields deeper insight.

To determine whether there were more noticeable differences between the higher and lower performing students, we created plots of CLASS results organized by quartiles of overall course grades. In prior research, Finkelstein and Pollock (2005) broke down the CLASS results by quartiles of Tutorial homework grades and found that the top quartile increased in favorable responses and the bottom quartile decreased in favorable responses [19]. In both lecture sections of our study, the top quartile experienced a smaller overall decrease in favorable responses than the bottom quartile, as shown in Figure 4. The top quartile of the experimental section had a decrease in favorable responses of about 4%; the bottom quartile, about 8%. The top quartile of the control section had a decrease in favorable responses of about 5%; the bottom quartile, about 11%. Both top quartiles' shifts are comparable to the national average.
(about a 4% decrease) within error, while the bottom quartiles’ favorable response rates decrease more than the national average, including error. This trend suggests that the bottom quartile may be a viable target for our instructional developments and self-regulation analysis, for these students experienced much heavier reductions in expert-like thinking.

More specifically, one CLASS question that relates to self-regulation asks students to indicate their agreement with the following statement: “If I get stuck on a physics problem on my first try, I usually try to figure out a different way that works.” This statement reflects qualities of intrinsic motivation (internal persistence through multiple attempts) and self-regulation (applying and monitoring different methods in pursuit of completing the task). When broken down by quartile, responses to this question indicate mixed results. In the experimental section, the top quartile’s percentage of favorable responses to this statement increased by about 7% and the bottom quartile’s decreased by about 20%. In the control section, the top quartile’s percentage of favorable responses to this statement decreased by about 10% and the bottom quartile’s decreased by about 9%. So, the section that engaged in reflection activities experienced an increase in favorable cognitive opinion for the top quartile, but a large decrease for the low performers. Both high and low performers of the section in which students did not reflect experienced negative shifts in favorable responses to this statement; however, the bottom quartile’s negative shift was much less than that of the experimental section. It seems that, in regards to this particular question, the implementation of reflection assignments benefitted the cognitive approaches of high performers, but worsened the cognitive approaches of low performers.

2. Final Exam Long Response

To determine whether the two sections differed on content knowledge by the end of the quarter, both sections were assigned very similar free response questions on the final exam. Figures 5 and 6 display the grade distributions of the experimental section (N=193) and control section (N=147), respectively. Students could earn a maximum of 32 points on the question.

From the figures, we see that both sections resulted in fairly similar, bimodal score distributions. There were no perfect scores because almost every student neglected to state to which axis of rotation their calculations corresponded. The mean score of the experimental section was 19.7 ± 0.7 and the mean score of the control section was 19.3 ± 0.8. The difference between these two means is not statistically significant by a two-tailed t-test (p>0.05); thus, the experimental and control sections did not display a significant difference in conceptual knowledge on this final exam long response problem.

It is interesting to note that the most prevalent error in the responses to this question was related to dimensional analysis: about 45% of the students scoring between 0 and 10 points in each of the two class sections provided answers in terms of variables that did not have overall units of energy. We believe that a lot of students could have checked their answer by quickly analyzing the units and knowing they were incorrect. This self-assessment may have led students to reconsider their approach and reflect on why their thinking was flawed. Since both classes had similar percentages of students making a mistake in dimensional analysis, the integration of self-reflection in the experimental group may not have been very influential in teaching students to think about their learning strategies, at least within an exam environment. Other common errors included applications of conservation of linear momentum and conservation of total energy.

Interestingly, we noticed a few cases of student recognition of mistakes in the control section’s long answer responses. One student, who scored 30 points on the problem, had initially applied the incorrect idea that translational kinetic energy was conserved in this situation. Upon reconsideration, he or she crossed out that section of work and wrote out the words “Whoops, I
don’t think it is.” Although we do not have insight into this student’s exact thought process, it seems that he or she took the time to think about the applied learning approach, evaluate that the strategy was incorrect, and then work through the problem again to apply the correct method. This student’s written response may be indicative of self-monitoring, and his or her high score on the question may suggest that self-regulation enhances student performance. This is an isolated case however, so no definitive result can be concluded – the above is just one interpretation made by the researcher.

Another student in the control section, who scored 18 points on the problem, applied the conservation of both angular momentum and energy. He or she also questioned the effect of friction and did some side calculations involving torque. The student wrote out the following statement on the exam: “This doesn’t make sense since there’s some energy lost to friction and it doesn’t seem right.” Here, we again see some written evidence of a student monitoring his or her approach to the problem. Although this student ultimately did not arrive at the correct answer, he or she seems to have been aware that his or her strategy was inappropriate. Perhaps unrestrained by exam time, this student could have engaged in more metacognitive processes and worked out the right solution. Again, however, this is simply an interesting, single case from the control section that can at most lead to qualitative interpretations by the researcher.

An explanation for why these cases may have come up is that the control section instructor emphasized before the final exam that students be clear in their explanations and justify all of their answers. In this way, students in the control section may have been more attentive to providing their thought processes when responding to the problem than those in the experimental section.

### 3. Weekly Reflections

Both the CLASS and final exam problem yield a fairly general perspective toward how students in these two sections think about learning physics. Written reflections offer much richer insights into student thinking and therefore embody the most important part of our data.

As stated earlier, we determined that fully metacognitive statements were those in which students clearly identified three elements: their prior erroneous thinking in regard to a specific learning objective, an activity or problem that changed this way of thinking, and their new, modified thinking. An example of a student’s response containing these components of metacognition is the following:

“When I was solving this problem, I initially thought that the quadrant of the graph the line was in showed which direction the car was headed in. After working through it and messing up a couple times, I learned that this direction the car is headed in is shown by the direction the line is headed in. If the slope at that point is in a negative direction, it is moving back, if it is positive, it is moving forward.”

This student clearly explains his or her thinking both before and after a certain activity, and also demonstrates a common trend seen in the reflections: admittance of making mistakes and not completely understanding a concept initially. This process is important in self-regulation, as students must identify where they struggle to comprehend material in order to modify their learning approach in pursuit of the correct line of reasoning.

Once we agreed upon and labeled which reflections contained evidence of metacognitive thought, we examined how the reflections of individual students changed over time. We found a few general trends in how students’ responses evolve: some students improved their ability to identify and correct their erroneous thinking, some students did not change their metacognitive thoughts, and still other students became worse at metacognitively reflecting as the course progressed. Thus, we began to create a coding scheme to identify the type of progress, or lack thereof, a student made over the nine weeks of reflection. A coding scheme is a qualitative data analysis method in which the researchers determine and define trends in the data such that each individual piece of data can be labeled with a code. This makes the data more readily available and easier to analyze.

Table 1 explains the details of our preliminary codes. Below are sequences of student responses that exemplify each of the codes, taken from the bottom quartile of the experimental section. Phrases or statements that are evidence of metacognition are italicized.
As indicated by the code, this student initially includes the three elements of metacognitive thought in his or her reflections, and this remains consistent throughout the quarter. This is also visible due to the consistent presence of italicized statements.

Flat (not metacognitive)

Week 1: “I practiced drawing those dot diagrams in response to certain descriptions of velocity and acceleration of an object. Now my thinking is more in tune with how to visualize a word problem.”

Week 5: “By studying and understanding the relationships between the quantities associated with power, I can now more reliably and fluidly solve problems coupled with an understanding of kinematics.”

Week 8: “By understanding how forces apply in linear situations, I can understand torque is similar in a rotational situation as a sort of twisting force, as a vector magnitude, the dot product of a linear force vector, position vector, and the sine of the angle created by the two mentioned.”

In none of these reflections taken from different times throughout the course is the student able to display metacognition. Our desired metacognitive elements never emerge and even by the end of the course, the student simply states conceptual facts instead of reflecting upon his or her understanding of material.

Decreased

Week 1: “Before, it [was] hard for me to interpret graphs because I was not too sure the actual meaning behind the graphs. Also the conceptual ideas were not very clear to me because I haven’t done physics for awhile. However, after practicing with professor in class, I [got] to know how to read graphs in terms of slowing down and speeding up in the velocity versus time graph.”

Week 4: “For this week, I [learned] how to draw the free body diagrams. Before, I thought the net force should be drawing from the same origin. However, after the lecture, I figured out that different types of forces are not all from the same origin.”

Week 8: “This week I [learned] that the angular momentum is conserved the same way the momentum we [learned] previously is conserved, which can be calculated using formula L=Iω.”

At the beginning of the course, this student is fully able to reflect metacognitively, but this decreases by the middle of the course and entirely vanishes by the end. This student’s initially self-regulatory thinking reduces to factual statements.

These examples and explanations are intended to make the definitions of the codes clear. Although we established these generic patterns, we need to refine and re-characterize the trends such that the code is applicable to all statements and exposes more qualities within the reflections. Once a final coding scheme is de-
thing round that is rolling without slipping. After dis-
stand the direction and magnitude of vectors of some-
derstanding of this concept. Before I did not under-
friend from another lecture section, I have a better un-
tial velocity, not just tangential velocity. Once I under-
ting to final grades in the course, so this environment
may provide a good opportunity in which instructors
can promote metacognitive reflection and improve un-
derstanding. Further, it seems that students in both
the top and bottom quartiles have thinking changes as
a result of Tutorials, so modifying this course compo-
ent may have the opportunity to impact students of
differing academic performance.

An example of a reflection from a student in the top
quartile who identified Tutorial as the means of trans-
forming his or her thinking is the following:

“Last week’s tutorial on the topic of rolling without
slipping helped me a lot with fully understanding the
topic and the kinematics associated with it. In the tuto-
rial, we were told to draw velocity vectors for points on
a rolling wheel in different reference frames. At first,
I didn’t fully understand why the velocity of a point in
contact with the ground was zero, but after completing
about a page of the tutorial I soon realized that the veloc-
ity was a sum of the center of mass velocity and tangen-
tial velocity, not just tangential velocity. Once I under-
stood how the vector sum of these two quantities could
end up being exactly zero, I was able to complete rolling
without slipping problems with a better understanding of
the motion of an object under these conditions.”

An example of a reflection from a student in the bot-
tom quartile who identified Tutorial as the means of trans-
forming his or her thinking is the following:

“After working on the tutorial homework with a
friend from another lecture section, I have a better un-
derstanding of this concept. Before I did not under-
stand the direction and magnitude of vectors of some-
thing round that is rolling without slipping. After dis-

V. IMPLICATIONS FOR RESEARCH AND
INSTRUCTION

Although what we have seen up to this point is not
statistically significant, we use this work to inform fu-
ture research design. We believe that students in the
lowest quartile likely need more human interaction than
is provided by a weekly online lecture assignment. We
also believe that lecture is not the most conducive learn-
ing environment for mentoring students’ self-regulation.
We intend to implement these strategies in the context
of the smaller group meeting aspects of this course, and
repeat the study.

The reflection prompt was intentionally very open-
ended; as such, students could choose any activity ei-
ther within or outside of the classroom that altered their
way of thinking about a certain physics concept. Since
a handful of reflections already indicated that Tutorials
are a place in which self-regulation occurs, we focused
on the impact of Tutorial sessions. The work done in
these sessions are fairly low stakes in terms of contribut-
ing to final grades in the course, so this environment
may provide a good opportunity in which instructors
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“After working on the tutorial homework with a
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derstanding of this concept. Before I did not under-
stand the direction and magnitude of vectors of some-
thing round that is rolling without slipping. After dis-

Both reflections indicate that the collaborative
problem-solving environment of Tutorials, and the cor-
responding homework assignments, clarified and im-
proved the student’s understanding of course content.
Thus, Tutorials are our primary focus for curriculum
development. The process of improving instruction in
Tutorial is cyclical and involves the following, as shown
in figure 7: research on student understanding of con-
cepts, use of these results to guide curriculum develop-
ment, and assessment of student learning [20].

![FIG. 7. The above diagram displays the cyclical procedure
developing the Tutorial curriculum.]

Tutorials consist of pre-tests (completed before Tu-
orial session, but usually after lecture instruction),
worksheets (completed in small groups during Tutorial),
home assignments, and post-tests (completed af-
ter Tutorial). As such, there are multiple aspects in
which we can implement elements of metacognitive self-
regulation. We would like to focus our discussion on the
Tutorial pre-tests. The goals of assigning students these
questions before they attend Tutorial are to inform stu-
dents of what they need to learn and to notify course
instructors and TAs about the current state of students’
knowledge.

It is important to note that pre-test results are never
returned to students. As such, we propose that stu-
dents enter Tutorial without proper recognition of what
concepts they need to focus and improve on during
the session. It may be beneficial to give feedback on
the pre-test responses such that students can monitor
their progress toward understanding the course objec-
tives by the time they take the post-test. Butler and
Winne (1995) proposed a model of self-regulation in
which external feedback contributes additional informa-
tion to the learner and influences the student’s learn-
ing procedure. Thus, we suggest that informing stu-
dents about their pre-test performance may facilitate
their self-regulation of misunderstandings during Tuto-
rial and improve post-test performance. As indicated
by the cycle of curriculum development, this is an idea
that must be implemented, assessed, and modified in future work in order to determine its effectiveness.

VI. CONCLUSION

In this paper, we have discussed an experiment in which students in an introductory, objective-based physics course reflected weekly in regards to how their thinking changed. We sought to answer the following research questions:

1. What differences are there in CLASS and final exam long answer problem responses between the two sections and between the highest and lowest performers?

2. What kinds of metacognitive and self-regulatory thoughts are present in weekly reflections, and how do they change over a 10 week quarter?

3. How can instructors integrate self-regulation into additional course components?

In response to the first question, we have displayed both graphically and numerically the results of CLASS and exam problem responses. We saw that the CLASS responses were similar between the two sections as a whole, but differed among the top and bottom quartiles. We also illustrated the similar grade distributions for the final exam question and described some isolated cases of student thinking from the control section. In response to the second question, we started to develop a coding scheme that characterizes a student’s ability to use metacognition in reflections as improved, decreased, or remained the same over time. We have started to answer the third question by proposing one way – Tutorial pre-test feedback – in which self-regulation may be incorporated in the curriculum of introductory physics courses. However, implementation, assessment, and modification of this idea is needed. Largely, we have highlighted the benefits and potential outcomes of self-regulation via metacognitive self-reflection, specifically in an objective-based physics environment.

The most important element of future work with this project is to answer the following question of interest: What, if any, traits and patterns distinguish the reflections of higher performing students from lower performers? To address this question, we must code all of the reflections based on a definitive coding scheme that characterizes a student’s ability to subgoals in private study. Journal of Educational Psychology, 77(6), 623.


study and use examples in learning to solve problems. 
*Cognitive science*, 13(2), 145-182.


