International Journal for the Scholarship of Teaching and Learning

Volume 1 | Number 2 Article 10

7-2007

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Recommended Citation
Chaplin, Susan (2007) "A Model of Student Success: Coaching Students to Develop Critical Thinking Skills in Introductory Biology Courses," *International Journal for the Scholarship of Teaching and Learning*: Vol. 1: No. 2, Article 10.
Available at: https://doi.org/10.20429/ijsotl.2007.010210

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Keywords
Critical thinking skills, Introductory biology courses

A Model of Student Success: Coaching Students to Develop Critical Thinking Skills in Introductory Biology Courses

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Abstract

Science students who perform poorly in introductory science classes often don't know how to do better because they "don't know that they don't know", and they have poor critical thinking and problem solving skills. The current study describes how modeling and coaching students in "active study" improves higher order thinking skills. The data show that students who received such coaching performed significantly better on exams by the end of the semester compared to control groups. Modeling and coaching "active study" behavior is essential to ensure that students build confidence in their ability to study science and remain in the science pipeline.

Introduction

Introductory college courses are a first step in the process of a student's development of critical, reading, thinking, and writing skills. More than just mastering basic content knowledge of a specific area of study, one goal of introductory courses is for students to "learn", or understand and use course content to demonstrate higher order thinking skills like, analysis, synthesis, and evaluation of problems (according to Bloom's taxonomy of critical thinking skills, Bloom 1964). This problem is more difficult in the sciences for a variety of reasons. There is an increasingly complex volume of "content" (i.e. facts) to be mastered, and lecture periods often proceed at a much more rapid pace than high school science classes on similar subjects. Although college instructors may use a variety of active learning techniques in their introductory science courses, there may still be a significant portion of class time devoted to lecture. First year college students often have poor listening, note taking, and synthesizing skills (Erickson and Strommer 1991) which hinders their learning in the classroom. Poorly developed study skills combined with poor time management and poor self-discipline in first year college students may result in them feeling so lost and overwhelmed that they give up easily on courses they otherwise profess great interest in and should be able to master. This is the point at which instructors need to intervene and provide support and direction for helping students "learn how to learn."

There are a wealth of science education resources that provide strategies for encouraging interaction in the classroom and promoting deeper levels of intellectual engagement of students (e.g., Angelo and Cross, 1993). Many of these pedagogical strategies address the problem of the poorly performing student that needs to adopt new study skills that improve critical thinking, that stress understanding rather than rote memorization, that help students move beyond the level of simple recognition of vocabulary that they mastered in high school to using that vocabulary to solve problems. Multiple publications, with suggestions specifically for improving critical thinking skills of students, abound in the literature (a few recent examples: Lauer 2005; Yuretich 2003/2004; Svinicki 2004; but see also texts on the subject by Stice 1987 and Halpern 2003). For example, Halpern (1998) proposed a four-part process involving: an attitudinal component, instruction and practice in critical thinking skills, activities that enhance transfer of these skills across a variety of contexts, and development of metacognitive processes to monitor progress. Similarly, Svinicki (2004) has developed a survey instrument (GAMES©) in which students are introduced to different techniques for good study behavior; in the process of evaluating what they do when they study, they learn other, perhaps more efficient ways of learning and monitoring their success. Broadbear (2003) suggests that "ill-structured problems" (those with more than one right answer, arrived at through sound reasoning), some criteria for assessing critical thinking, (especially that done by the students themselves), and demonstration of improvement of thinking (e.g., portfolios) are the key elements to improving critical thinking ability.

All of these methods have a common strategy, to engage students in metacognitive effort, that is, to improve self awareness of their learning, and similar outcomes, that of increasing students' reflection on and engagement with the subject material. Despite the quantity of publications describing the methods for improvement of critical thinking skills and exam performance in college students, the quantitative assessment of the efficacy of the methodology lags behind. The purpose of this report is to quantify the impact of a particular instructional intervention (modeling and coaching "active" studying) on a group of "at-risk" students in an introductory level biology course for biology majors.

Methods

In order to learn something about the level of awareness that students of varying academic ability have about their own learning, students enrolled in a large introductory biology course at University of St. Thomas, St. Paul, Minnesota (88 % freshmen, n=90 students) were asked to predict their performance on every exam immediately after turning it in. Their actual scores were then compared with their predictions for each of four exams during the semester in order to determine longitudinal trends in their performance and their ability to predict their performance.

To investigate techniques that might help "at-risk" introductory students reform their study strategies to improve both their actual performance and their ability to predict performance, students in the same introductory course (n=126) during a subsequent year were grouped voluntarily according to the type of interaction they had with the instructor: 1) 15 students who sought help from the instructor on several occasions during the semester (coached group), 2) 12 students who interacted with the same instructor during the laboratory portion of the course (lab contact group), and 3) 15 students who did not seek help from the instructor during the semester (no contact group). Students in the coached group scored between 50% and 80% on the first exam and voluntarily sought help to improve their exam performance. The third group of no contact students was selected by matching their first exam scores ($\pm$ 2%) with those of the students in the coached group, thus making it possible to compare improvement in performance as a function of the coaching technique used by the instructor. Students in the lab contact group of 12 students not only interacted with the instructor on a more personal level in the small laboratory section weekly, but were also the instructor's freshman advisees. These students were concurrently enrolled in an advanced English literature course that was paired with the freshman biology lab, and thus tended to be better than average students.

Students in the coached group received assistance from the instructor in a number of ways: exam analysis, demonstration of active study techniques, and Q and A on sample upcoming exam questions. Exam analysis consisted of looking for patterns of missed questions, misread questions and/or answers, voids in content knowledge, and misconceptions or incorrect notes. Students were asked to group the exam questions into easy, medium, and hard difficulty levels for them, and then assign one of three critical thinking categories (knowledge, application, analysis) to the questions to determine which categories of questions they were answering incorrectly. Modeling and coaching methods of "active studying" provided students with several new techniques for learning. For example, one "active" studying approach modeled was building concept maps using the same flash cards students had created to study vocabulary. Students were asked to state why they drew the concept maps they way they did and to describe the nature of the relationship between the items. Another technique was to have students write an explanatory paragraph about a figure from the text that utilized new vocabulary or flash-card concepts, or conversely, to draw a figure based on a descriptive paragraph of bold-faced words from the text. Students in the "coached" group asked to be pre-tested on upcoming exam material by providing them with practice test questions. However, the instructor felt it was more beneficial for the students to write and critique test questions of their own construction. Students were urged to write and share questions with each other, occasionally in groups, and usually with the instructor present for guidance. Further, they were encouraged to write questions that illustrated knowledge-, application-, or analysis-type levels of thinking, as practice for what they might see on the actual exam.

Results

Low achievers on individual exams (scoring less than 60% on an exam) consistently overestimated their performance by an average of 22%, while high achievers (scoring at least 90% on the exam) were either very accurate or slightly underestimated by 5% their actual performance. Although students improved slightly in their ability to predict their exam performance over the course of the semester, students who performed poorly still over-predicted their performance by an average of 17% on the third exam (Fig. 1).

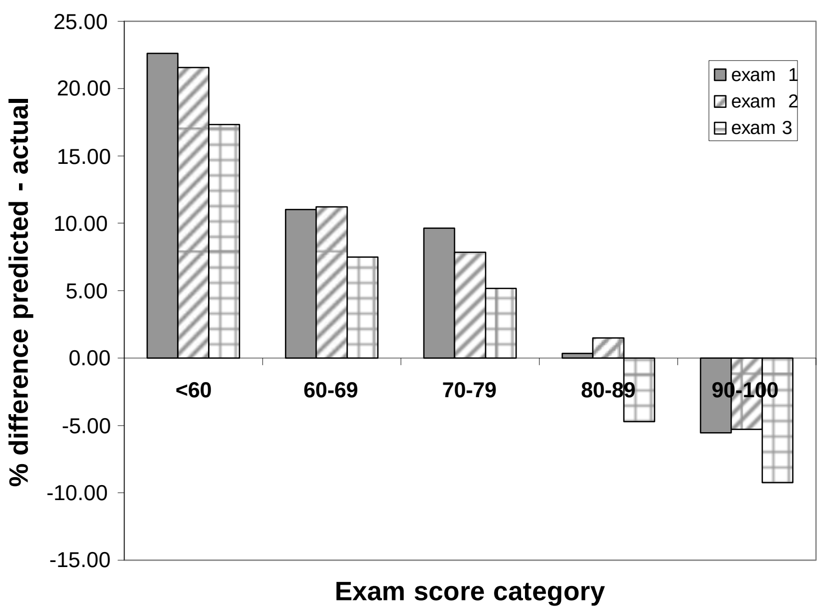

Figure 1. Longitudinal (over the semester) changes in the mean percent difference between predicted and actual exam score for 90 introductory biology students scoring in specific grade categories A (90-100%), B (80-89%), C (70-79%), D (60-69%) and F (<60%) on each exam.

There was a surprisingly significant inverse linear correlation between the mean difference between predicted and actual exam score and the mean score of the grade category on an exam:

$$\% \text{ difference} = -0.66 * (\text{mean score of grade category}) + 56.20;$$
$$R^2 = 0.98;\ P = 0.001.$$

There was a significant and positive impact of the modeling and coaching strategy on exam performance of students in the coached group (Table 1). There was no significant difference between coached and no-contact groups on their first exam, as expected, because these students were matched for first exam performance. Both coached and no-contact groups scored significantly lower than the lab-contact group on the first exam, most likely because the lab-contact group was composed of strong students enrolled in this particular lab section because it was paired with an advanced Freshman literature course. However, there was a highly significant difference between the coached and no-contact groups on the last exam. Further, there was no significant difference between the coached group and the lab contact group on the last exam (Table 1), as the coached group had increased their mean exam score almost 21 points from first to last exam of the semester. In contrast, the no-contact and lab-contact groups showed significantly less change from first to last exam scores (Table 1).

Table 1. Comparison of means and standard errors (in parentheses) of first and last (final) exam scores and difference between last and first exam scores of introductory biology students. All exams were 100 points. See methods for definition of groups. Students in the coached and no-contact groups were matched for first exam performance. Groups were compared by one-way ANOVA with post-hoc comparison of means by the Tukey test. Significant differences between means within the ANOVA are indicated by different alphabetic superscripts following the means.

PARAMETER	COACHED	NO CONTACT	LAB CONTACT	ANOVA P
Mean score first exam (S.E.)	66.1^{A} (2.41)	67.5^{A} (2.55)	82.6^{B} (2.71)	<0.0001
Mean score last exam (S.E.)	87.0^{A} (2.22)	73.9^{B} (2.33)	88.1^{A} (1.84)	<0.0001
Difference in exam scores, last to first (S.E.)	$+20.9^{A}$ (2.4)	$+6.4^{B}$ (2.1)	$+5.5^{B}$ (2.2)	<0.0001
Number of students	15	15	12	

Coached students were surprised at how much the exams revealed about the gaps in their study preparation and about how much carelessness and inaccuracy had contributed to wrong answers. Further, when they were able to (correctly) identify the levels of critical thinking involved in each question, they could evaluate the types of questions that were more frequently missed on the exam and modify their method of study preparation accordingly. This type of exam analysis seemed to be as beneficial in stimulating a change in study habits as the coaching of "active studying".

Asking students to write (and share with each other) their own questions that illustrated the knowledge, application, or analysis level of thinking proved far more helpful as a study aid than the flash card memorization technique, and it encouraged development of their critical thinking skills. In reviewing the construction of student-written exam questions with the instructor, students began to adopt a more metacognitive approach to their learning, assessing what they did or did not know in order to construct a good question. By writing sample test questions themselves students were forced to focus on the central content of a particular unit and to learn to distinguish core ideas to be mastered from the tangential examples or illustrations.

Discussion

The strong negative correlation (Fig. 1) between the magnitude of error in predicting exam score and the actual exam performance indicates that low achieving students not only lack the content knowledge or critical thinking skills required to answer exam questions correctly, but they also do not recognize whether the answer they give may, in fact, be wrong. That is, students who perform poorly don't know that they don't know, and students who perform poorly don't know how to change their method of studying. This is not a new finding in the education or cognitive psychology literature (Kruger and Dunning 1999; Kennedy et al. 2002). However, what was unusual about these data was the goodness of fit of the data to a linear relationship between predictive error and exam performance ($R^2 = 0.98$).

Although there was some improvement in the degree of predictive accuracy about exam performance of all groups of achievers (Fig. 1) over the course of the semester, this could simply be explained by student realization that they never performed as well as they thought, and should therefore predict a lower score for themselves on each successive exam. Thus, this is not good evidence that students get better at realistically assessing their level of learning throughout the semester.

Low achievers typically complain that "I studied harder for this test than any other, and still got an F"; or "The problems were completely different than the homework"; or "The questions were tricky"; or "You never talked about this in class". They label questions as "tricky" or assume it was "not covered" in class because they are not able to apply or analyze content knowledge to solve problems that require a higher level of critical thinking than simple recall and recognition type questions they have mastered in the past. The challenge is to provide these students with a different approach to studying "hard".

In this study, there was a marked (and significant) increase in exam performance of coached students who engaged in "active" studying tutorials, compared to the other two groups (Table 1). One might argue that students who seek help and have more personal contact with the instructor in a large class are bound to do better on exams, and that it is not the active studying method that is making a difference. However, in this study, the instructor spent as much or more informal time with the lab-contact group of students than the coached students. Thus, personal contact alone with an instructor is not enough to get students engaged in their own learning process.

Positive effects of critical thinking exercises on exam performance have been reported by others, as well. Osborne (2000) reported that students who enrolled in a critical thinking laboratory received higher grades in their introductory psychology course, received fewer D, F, or withdrawal grades, and had higher overall GPA than students who enrolled in the introductory psychology course alone. Similarly, Yuretich (2003/2004) measured progressive and significant improvement in performance of geology students on exams, following implementation of critical thinking exercises in the classroom.

Educational Implications

For students whose exam preparation formerly consisted of reading notes many times and making flash cards of definitions of concepts or vocabulary, "active studying" is both foreign and laborious. Modeling the process of "active studying" alone is not sufficient because introductory students are novices with the use of most pedagogical techniques and may, in fact, use them incorrectly, thus contributing to their frustration when these "new" techniques fail them. For example, the concept map technique requires not only modeling examples for the student, but careful critique of the content and accuracy of the map. As Bransford et al. (1999) point out, novices, such as introductory students, may build maps with missing (essential) content and with incorrect relationships, and in studying this, may gain erroneous misconceptions. The concept map technique does not work well unless the instructor goes over the map with the student, listening carefully to their explanations and correcting their misconceptions (coaching). Similarly, writing sample test questions encourages deeper learning and thoughtful analysis in students who might otherwise have resorted to simply memorizing terms. However, instructor guidance is essential in this task to ensure that students' questions (and answers) stretch beyond the simple knowledge recall level of thinking.

What can instructors do to reach struggling students who don't voluntarily seek help from the instructor? Coached students made the greatest gains in metacognitive processing by reviewing the reasons for missed questions on exams and by analyzing the cognitive level of the test questions themselves. This is an activity from which all students can profit and takes little time for the instructor to demonstrate after the exam, or even after every exam. Although it seems obvious to instructors that gaps in knowledge may lead to lower exam scores, it is not apparent to students how much of an impact that knowledge gap actually has on their test score. When students realize the number of missed questions that result from one of these gaps, they may make more of an effort to fill in gaps in their notes or their understanding of the material before the exam. Another exercise that may help all students to improve exam scores is having them assign a Bloom category to the exam questions: recognition-recall, comprehension, application, analysis, etc., and then try to write questions like those for study on the next exam. There is often a mismatch between the types of questions that students expect to see on an exam or may write when they study (recognition-recall type questions) and the actual exam questions themselves that may require higher order processing than simple recognition. The more practice students have with writing and answering questions that require higher order thinking, the better they will do on exams.

Modeling and coaching learning in the classroom, and then reviewing the students' progress are all essential to changing study habits and encouraging new methods of learning. For "coached" students in this study, the rewards were not only a marked increase in exam score, especially in the lower achieving students, but an increased self-confidence in their ability to "do" science. This is especially important in introductory science courses, from which there is typically a high attrition rate, due to large class size, and a lower level of student-instructor interaction and greater fear of failure than some humanities courses. Although there is no guarantee that we can reach these students before they decide to give up on a science career, taking proactive steps to ensure that introductory science students "learn how to learn" seems to be imperative for a continued flow of talent into the science pipeline.

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