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Tips and Tools

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How Instructors Can Enhance Biology Students' Motivation, Learning, and Grades through Brief Relevance Writing and Worked-Example Interventions

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INTRODUCTION

The high failure rate in American introductory undergraduate science, technology, engineering, and mathematics (STEM) courses poses a persistent challenge to students, instructors, and universities. These large introductory courses have been identified as "gateway courses" (1) and as a principal reason for students' loss of interest in, and eventual abandoning of, STEM degree paths, particularly among women and students from underrepresented groups (2). Researchers have investigated different approaches to improve achievement and retention in undergraduate STEM. Research suggests that major curricular changes to introductory biology (e.g., shifting from a single large lecture format to many hands-on small sections) can have positive effects on students' attitudes toward and learning of biology (3). Unfortunately, these changes often require laborious transformations of the existing curriculum and are expensive to implement. Here, we propose an alternative approach that aims to boost students' learning, motivation, and success with on-line supplemental modules to the existing course curriculum. The supplemental modules build on research that demonstrates the contribution of targeting specific learning mechanisms, such as problem solving and reflective studying (4). For example, research has highlighted the positive effects of demonstrating example problems on student learning, particularly during initial skill/knowledge acquisition (5, 6). However, learning course content requires student effort, and learning and applying effective cognitive strategies commonly require a greater investment of effort (7). Hence, the effect of course assignments that teach students study and problem-solving strategies can be expected to be higher if combined with features that enhance students' motivation in the course (8). For example, recent research has demonstrated the positive effect of interventions that promote students' perceived relevance of course materials on their grades in STEM classes (9, 10).

In this article, we describe a subset of a larger study that tested the effects of different combinations of cognitive and motivational interventions on undergraduate biology students' achievement, motivation, and intentions to remain in science (11, 12). Interested readers can find information on the effectiveness of the various interventions in articles published elsewhere (10–14). Specifically, we focus on how instructors can implement the intervention materials and improve student achievement in their course by including electronic assignments that ask students to watch worked-example videos that demonstrate biology problem-solving and briefly respond in writing to relevance writing prompts that ask them to connect the biology concepts to their lives (1).

PROCEDURE

Students (n = 350) from introductory biology courses (Organismal Diversity and Evolution and Cellular and Molecular Biology) at a large, urban, and racially diverse U.S. mid-Atlantic research university were given instructional supports as part of a set of experiments conducted over four academic years that tested combinations of one cognitive mechanism (either promoting cognitive processing

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TABLE 1
Worked-example types and sample questions

Worked-example	Sample question
Given a specific example of biological phenomenon (such as a plant or animal species in an environment), where the specific example had not been taught in class or textbook, explain how a particular biological principle applies.	Severe digestive problems (such as diarrhea, Crohn's disease, or anorexia) can lead to too little potassium in the body. Using what you have learned, explain at the cellular level how low potassium would affect nerve conduction.
Given an example of a (plant or animal) species in an environment, where the specific example had not been taught in class or textbook, compare and contrast two organisms observed in a particular environment and explain how these represent one or more biological principles.	A number of asters (flowers related to daisies) were recently reclassified from two genera with 5 species to one genus, *Gorteria*, and 8 species based on comparative DNA analyses. How does this show that taxonomy and phylogeny differ in important ways?
Given a true statement that requires inference(s) to be drawn from a biological principle(s) in the chapter, explain why the statement is true.	Net primary production is highest where rainfall is highest. Using what you have learned about ecosystems in biomes, explain why this is so.

using study strategy videos or teaching procedural knowledge using worked-example videos) with one motivational mechanism (either enhancing perceived relevance through relevance writing exercises, enhancing the student's beliefs in their ability to perform satisfactorily using individualized messages, or reduction of stress/costs of effort using videos). The larger study found numerous positive effects of combining cognitive and motivational mechanisms (13). Of these supports, the administration of a combination of worked-example videos and relevance writing prompts requires the least instructor investment during the semester and yields significant improvements in student grades (14). This research was completed with full participant consent and with the approval of the Temple University Institutional Review Board (22316).

Worked-examples

We developed worked-example videos focusing on the major topics of the courses. We worked with course instructors to write scripts specific to course content that followed one of three patterns (Table 1). The scripts posed a question similar to a medium-difficulty exam question followed by the process of reasoning through an answer. Students who had taken the class previously were videotaped reciting the script. These videos were deployed about twice a week during the semester via Blackboard course management software for student viewing.

Relevance writing

To encourage students to relate course concepts to their own lives, we created relevance writing prompts that asked students to engage in open-ended writing of about 300 words regarding the connection of a main course concept they were learning to any aspect of their lives (e.g., self-knowledge, career goals, social relationships, etc.) (Table 2). Prompts were administered in the middle of the unit concerned with the concept. Instructors may wish to read the open-ended responses to gain insight about student motivation and possible misconceptions. However,

TABLE 2
Relevance writing topics and prompt

Topics	Example open-ended prompt
Organismal diversity, evolution, animal physiology, ecology, chemistry of life and cellular organization, cell structure and metabolism, cellular and DNA replication, genetics and inheritance.	How might knowing about Organismal Diversity be interesting, or important, or useful for you? You can be creative and think of any connection that is meaningful to you. The more meaningful the connection is, the more likely it is to contribute to your learning and understanding of it and to your performance on assignments. In the space below, explain in as much detail as possible: (i) what aspect of the material in Organismal Diversity you chose to connect to your life, (ii) what in your life you connected it to, (iii) the connection between that aspect of organismal diversity and your own life, and (iv) why and how much the connection is meaningful to you.

detailed analysis of student responses is not required for the intervention to show a positive impact on student grades.

Interested instructors can access all worked-example videos at https://osf.io/saqh7/. The worked-example videos are available as mp4 files that can be directly imported into the instructor's course management software (Blackboard, Canvas, etc.) and negate the need to recruit volunteer actors or record new videos. All intervention materials from the larger study are also accessible for interested researchers and instructors (http://hdl.handle.net/2142/97878), together with a detailed "how-to" guide that explains how the materials were created and how to import the intervention materials into the course management software.

CONCLUSIONS

The grades of students who watched worked-example videos and completed relevance writing prompts were significantly higher than those of control group students who did not access these supports (+6.3%; $P = 0.05$). Moreover, the grades of students who completed only one of the supports (e.g., only watched worked-example videos) were not significantly different from those of control group students ($P = 0.53$). This highlights the interdependence between student learning and motivation (10). Therefore, we recommend that instructors assign the combination of worked-example videos and relevance writing prompts to promote student learning and success.

Worked-example and relevance writing supports are easy to implement and integrate with existing course content. Student engagement in these modules led to higher motivation, biology reasoning, and course grades (14), with effects occurring without additional instructor effort. In addition, instructors can gain valuable insight into students' understanding if they solicit student feedback about the worked-example videos and read the relevance writing responses. This can contribute to reflective improvements to the course that promote learning and motivation and address specific student misconceptions. These easily implemented supports can utilize online tools such as Blackboard, Canvas, and Moodle and can be implemented when a more comprehensive change to instruction in large introductory courses is not practical or possible.

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