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Avi Kaplan
Temple University

Jennifer G. Cromley
University of Illinois at Urbana-Champaign

Tony Perez
Old Dominion University, acperez@odu.edu

Ting Dai
University of Illinois at Chicago

Kyle R. Mara
University of Southern Indiana

See next page for additional authors

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Authors
Avi Kaplan, Jennifer G. Cromley, Tony Perez, Ting Dai, Kyle R. Mara, and Michael Balsai

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Author(s) Avi Kaplan, Temple University; Jennifer G. Cromley, University of Illinois at Urbana-Champaign; Tony Perez, Old Dominion University; Ting Dai, University of Illinois at Chicago; Kyle R Mara, University of Southern Indiana; Michael Balsai

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Avi Kaplan[1], Jennifer Cromley[2], Tony Perez[3], Ting Dai[4], Kyle Mara[5], & Michael Balsai[1]
[1]Temple University
[2]University of Illinois at Urbana-Champaign
[3]Old Dominion University
[4]University of Illinois at Chicago
[5]University of Southern Indiana

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Please send correspondence about this manuscript to Avi Kaplan, Temple University, at: akaplan@temple.edu

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Researchers acknowledge that students' learning and achievement requires both effective cognition and the motivation to apply it (NAS, 2018). In addition, both cognition and motivation are multidimensional, each involving different processes that may be less or more salient to different people in different contexts. However, most basic research and intervention studies focus on either cognition OR motivation, and commonly only target findings concerning one process in these categories (e.g., strategy strategies in cognition, utility value in motivation). To address some of these limitations, we designed a series of studies to investigate the effects of combining a cognitive intervention and a motivational intervention in first-year undergraduate introductory biology courses, and tested different combinations of one cognitive and one motivational interventions among four cognitive and three motivational processes.

Cognitive Interventions to Improve Undergraduates' Learning and Achievement

Cognitive interventions aim to enhance students' learning and achievement through improving attention, encoding, processing, and retrieval of the content being learned. Different cognitive interventions can aim at different phases of learning (e.g., eliciting prior knowledge to facilitate attention and effective encoding, supporting organization to improve processing, promoting analogical thinking to facilitate effective retrieval). The interventions should also match the nature of learning expected (e.g., memory strategies for learning facts, problem-solving strategies for learning how to solve problems). In the current study, we selected four cognitive processes relevant to learning and achievement in large undergraduate biology survey courses: (1) Eliciting prior knowledge for attention and effective encoding; (2) Enhancing organization of the material to facilitate effective encoding and processing; (3) Demonstrating worked examples to facilitate effective learning of problem-solving strategies; and (4) Demonstrating the use of study strategies for effective processing and retrieval (see NAS, 2018 for review of these learning mechanisms).

Eliciting prior knowledge. Eliciting prior knowledge constitutes an important strategy that improves effective encoding and processing of new material into existing knowledge structures (Gurlitt & Renkl, 2010). For our study, we developed brief videos that were posted to Blackboard with a link e-mailed to students before beginning a new unit, in which a presenter who was a former student in the course reminded the current student about content that they learned in high school biology that is relevant for the upcoming unit.

Enhancing organization of the material. Organization of new material can provide scaffolds for its effective processing. For our study, we facilitate organizing the content through sending students links to videos of the lecture they attended in which the lecture was segmented by relevant content themes.

Demonstrating worked examples. One challenge in biology learning is that while exams include many questions that require transfer of learning, biology instruction rarely includes extended, full demonstrations of problem solving. A widely-used instructional technique in STEM education research is self-explanation, or prompting students to explain (to themselves or to another person) why a phenomenon works the way it does (Baars, Leopold, & Paas, 2018). Self-explanation is a complex cognitive activity that includes summarizing, drawing inferences, activating prior knowledge, and metacognitive monitoring. Effective approaches to teaching problem-solving strategies for transfer provide an explicit illustration of every step in the problem solving of specific problems of different types (Renkl, 1997; Sweller & Cooper, 1985) and point out how the example is related to "big ideas" in the discipline (Perfetto, Bransford, & Franks, 1983). This contributes to in-depth understanding of how to reason in the domain. Thus, one of our cognitive components was providing students with worked examples of medium-difficulty exam-type questions. For our study, we developed brief videos in which a former student in the course demonstrated working through problems similar to those students were asked to solve in the course.

Demonstrating the use of study strategies. Study or learning strategies constitute crucial mechanisms of effective learning and achievement. Experimental research on study strategies has often considered effects on achievement of one strategy at a time, such as systematic note-taking, self-explanation, or summarizing the content. Such research found, for example, that training students in self-explaining the material, or giving reasons for why scientific processes work as they do, significantly improves undergraduate students' comprehension of passages about mitosis (McNamara, 2004) as well as understanding of mathematical proofs (Hodds, Alcock, & Inglis, 2014). Similar results have been found with undergraduate students in psychology for instruction in summarizing text on fallacies in reasoning (Bednall & Kehoe, 2011), prompting to sketch in biology (Hoskins & Stevens, 2014; Cromley & Mara, 2018), prompting comparing-and-contrasting for learning geology (Jee et al., 2013), and teaching mnemonics for learning statistics (Mocko, Lesser, Wagler, & Francis, 2017). Although general "study skills" courses are offered at many American universities, the literature is clear that much larger effects are found when strategy instruction is embedded in the specific content that students are studying (Weinstein, Husman, & Dierking, 2000). We implemented the strategies instruction principles of Pressley and Harris (2006) in delivering study strategies instruction to introductory undergraduate biology students using their own course content. For our study, we posted to Blackboard and emailed students a link to brief videos where a presenter described and then demonstrated the use of an effective learning strategy relevant to students' tasks in the course (e.g., a strategy for learning from scientific diagrams).

Preparing the cognitive intervention modules. For each of the cognitive support modules except for the class lectures recordings, we wrote scripts specific to each of 11 weekly biology course topics, videotaped the scripts (5 minutes per video), and made video links available to participating students (rather than the actual video, to prevent participants from sharing materials across conditions). In the scripts activating students' relevant prior knowledge, we reminded students of information they learned in high school biology class that the college textbook and instructor built on. In the worked examples videos, we posed an application question similar to a medium-difficulty exam question (i.e., of sufficient difficulty), followed by the process of reasoning through an answer and checking the completeness of the answer (i.e., the actor engaging in self-explanation of the question). The study strategies instruction videos modeled different effective strategies, including comparing-and-contrasting within diagrams, using sketching to enhance understanding, making concept maps, effective summarizing, and using mnemonics and etymology for learning new terms.

Each study strategy instruction video used modeling with that week's course content to demonstrate the strategy, together with explanations of the usefulness of the strategy, attributions of success to strategy use, and an invitation for the learner to pause the video and practice the strategy on a specific segment of the textbook. Comparing-and-contrasting within diagrams comprised modeling the process of looking for similarities and differences within multi-part diagrams; we used screen capture to create a video from the scanned image on the screen, the mouse pointer controlled by the narrator, and the voice narration. Using sketching to enhance understanding comprised drawing a diagram from text information (diagram covered with adhesive notes) with pen and paper under a document camera, also with narration. Making concept maps comprised making word, bubble, and arrow concept maps, also on a document camera, also with narration. Effective summarizing comprised typing summaries from textbook, PowerPoint, and personal notes, captured with screen capture and narration. Using mnemonics and etymology for learning new terms comprised brief text-based videos introducing these strategies.

Motivational Interventions to Promote Undergraduates' Engagement and Learning

Motivation concerns the processes that underlie initiation, maintenance, and quality of engagement in a task. As such, motivation is necessary for students to apply the behaviors required for learning: paying attention, harnessing effort, and employing the strategies that facilitate effective encoding, processing, and retrieval (NAS, 2018; Pintrich, 1989). Therefore, interventions that teach students effective study strategies can be expected to be more successful if combined with interventions that enhance students' motivation to invest effort in use of these strategies (e.g., self-efficacy enhancement, Guthrie et al., 2004). Likewise, motivational supports such as promoting students' perceived relevance and value of the course content are likely to be more effective if the enhanced investment involves applying effective study strategies. Indeed, the synergistic effects of cognitive strategies and motivation are at the heart of most theories of self-regulated learning that explicate the desirable processes by which students self-direct and manage their learning and performance (e.g., Boekaerts, 1996; Pintrich, 2000; Zimmerman & Moylan, 2009). Whereas there is a wide range of motivational processes in the literature, we focused on three processes emanating from Expectancy-Value Theory (EVT; Wigfield & Eccles 2000). (1) Expectancies for success, or self-efficacy; (2) Perceived self-relevance, or task value of the content; and (3) Perceived cost of engaging in the course. Many studies investigating the role of motivation in STEM achievement and retention have pointed to task values as underlying students' choice and persistence in a course, and to expectancies for success as related to students' academic success (e.g., Lynch, 2010). Recent work has also investigated and demonstrated the role of perceived costs in students' intentions to drop out from undergraduate STEM majors (Perez, Cromley, & Kaplan, 2014).

Promoting expectancies for success, or self-efficacy. Expectancies for success, or self-efficacy for graded assignments, is one of the most robust motivational processes in the literature on undergraduate learning and achievement (Richardson, Abraham, & Bond, 2012). Expectancies for success emerge from different sources, primary among them are the students' previous success on similar tasks. However, another important contributor to positive expectancies for success is the student's attribution of achievement to modifiable and controllable causes, such as effort and strategies (Weiner, 2010). For our study, following within-semester exams, we delivered students a personal message with specific feedback on their performance combined with an encouragement to consider the effort and strategies that they might use, either to maintain their high performance or to pursue higher performance in future exams.

Facilitating perceived self-relevance of the content. Perceived relevance of task value of the task is recognized as an important motivational factor by researchers, educators, and students alike (NAS, 2017, 2018). One of the most frequently evaluated motivational interventions tested for effects on undergraduate achievement aims to increase students' task value through relevance writing—asking students to write brief statements about the relevance of course content to their lives (Hulleman & Harackiewicz, 2009). In our study, we delivered students' prompts at different times during the semester to generate their own perceived self-relevance of the major concepts in the material (e.g., evolution, biodiversity, ecology).

Ameliorating perceived cost of engaging in the course. An important de-motivating process involves believing that engagement in the task is too costly. Expectancy-value theory emphasizes the non-monetary costs that students perceive they incur because of engagement, including the requirement to invest high effort, to give up on other valued activities, to risk failure and loss of self-esteem, and to suffer hindrance or even loss of important relationships (Wigfield & Cambria, 2010). For our study, we emailed students brief videos in which a former student in the course discussed their personal perceived cost and how they contended with it successfully to maintain their motivation in the course.

Preparing the Motivational intervention modules. Preparing the motivational support modules included writing prompts for students to encourage them to write about the relevance of the course topics to their lives, recording videos with messages designed to offset perceived costs of pursuing a STEM major, and individualized constructive feedback about exam performance to enhance self-efficacy that were delivered close to within-semester exams (3-4 times during the semester). The relevance writing prompts asked students to engage in open-ended writing of about 300 words regarding the connection of the course content they were learning at that point in the semester to any aspect of their lives (e.g., self-knowledge, career goals, social relationships; Harackiewicz & Priniski, 2018). The perceived costs-offsetting videos were recorded brief interviews with actual course alumni about overcoming various non-monetary costs of being a STEM major (Perez et al., 2014). The individualized exam feedback was created by dividing participants into score bands (low, medium, or high) on each exam, and presenting a semi-customized graph to each participant showing the pattern of his/her achievement over the semester, together with motivational advice relevant to the student's pattern of scores to promote adaptive attributions to effort and strategies (e.g., ‘You may or may not feel disappointed in your first exam score…Research shows that students who evaluate what worked and did not work as they learn can improve their learning in the future’; based on Muis, Ranellucci, Franco, & Crippen, 2013).

Combining Cognitive and Motivational Interventions to Promote Undergraduate Biology Students’ Learning and Achievement in Large Survey Courses

Initial empirical support for the synergistic effect of combined cognitive-motivational interventions on achievement has been found in a small number of studies with younger students (e.g., Cleary et al., 2017; Guthrie et al., 2004; Toste et al., 2017). Building on this research, we selected four cognitive and three motivational processes that were found in previous research to have positive effects on STEM students’ grades and/or intention to remain in STEM and developed intervention modules for each process that were relevant to the content and practical to administer to students in the context of a large survey course with a relatively rigid curriculum. We then engaged in an iterative testing of different cognitive-motivational module combinations conducted across 10 experiments over four academic years at three different universities in first- or second-semester introductory biology courses in designed for STEM majors, with a cumulative sample of 3,092 undergraduate students. In each of the 10 studies, we compared effects on undergraduate biology course grade of a business-as-usual condition to a cognitive support module (e.g., a video demonstrating worked examples) and/or a motivational support module (e.g., engaging students in relevance writing). All modules were reviewed for scientific accuracy by Ph.D. level biologists who have taught introductory courses for biology majors. In each study, students in the course were randomly assigned to the business-as-usual control condition or to an experimental condition that combined one of several cognitive support modules and/or one of several motivation support modules. Participants received extra credit for participation. All intervention modules were delivered to consented participants via a study-specific Blackboard learning management system site (modules are available to interested researchers as a downloadable package). All modules also included a student feedback form. The Blackboard site allowed us to track students' daily access to the intervention modules.

The iterative process involved applying lessons learned from each previous semester to design a more effective intervention in the subsequent semester. This involved trimming ineffective modules (e.g., videos of study lectures in combination with costs videos had no effect on students' grades), and modifying their delivery (e.g., when we found that students were cramming on the intervention, we made extra credit conditional on timely access to the support modules so that students received extra credit for accessing the study strategies videos relevant to exam 1 before taking exam 1, but not thereafter).

Summary of Findings

In this paper, we describe only a summary of the findings of the 10 experiments—a detailed explication of the procedures and findings is presented elsewhere (Cromley et al., 2019). Our focus here is to emphasize conceptual insights, both from the findings and from our practical experiences of engaging in designing and implementing the intervention in different contexts, with regard to the central role of context, the implications for what can be expected from educational interventions—even those involving multiple components—in different contexts, and the consequences to our understanding of "evidence-based practice."

Findings from Meta-Analysis

We conducted a meta-analysis of the intervention's effects on course grades across the 10 experiments. The findings indicated that, as a collective, the interventions were quite effective. The main effect model with no-moderators showed a statistically significant overall effect of g = .30. This implies that, across our studies, students gained .30 *SD*, on course grade, a magnitude that was significantly different from zero. However, effect sizes varied quite broadly across the individual studies. Of the 50 effects on course grade, 41 were significant and positive, 3 were non-significant, and 6 were significant and negative. In addition, the 41 significant and positive effects varied widely (*gs* =0.2 to 0.66).

Therefore, we conducted univariate tests of moderators that might explain this variation. We included as moderators the specific cognitive and motivational modules delivered, as well as an indicator of fidelity of implementation (i.e., students' timely access to the intervention modules). In addition, we included as moderators the different universities, the academic year, the semester (Fall or Spring), students' college biology background (i.e., whether students were in their first or second semester of college biology, with either possibly happening in fall or spring), the focus of the course content (i.e., molecular and cellular biology versus organismal and evolutionary biology), and also the timing of the study in the iterative development process of the intervention (whether it was in an early phase of development or later, when the research team had developed more expertise). *Each of these moderators was statistically significant in affecting the effect size of the intervention*! For example, effects were larger at the more-selective of the universities of the study (g =.33 and g = .35) than at the less-selective university (g = .11). Effects were larger in the spring semester (g =.42) than in the fall (g = .20), regardless of whether that course was the first (g = .32) or second (g = .28) course in the student's biology sequence. Effects were larger for Organismal/Evolutionary biology (g = .37) than for Molecular/Cellular biology courses (g =.14), again regardless of whether these were held in fall vs. spring or were 1st vs. 2nd in the student's course sequence.

Contextual Differences

The findings that ALL contextual moderators were significant in affecting the effect sizes of an intervetion that is very uniform—different administrations involved the same or highly similar brief videos, writing prompts, and feedback messages—shed light on the crucial role of context in the way the "same" intervention may be "received" in different locations and, in the same location at different times. The combination of moderators suggested that "context" in our set of studies included the combination of multiple known and unknown factors that rendered each distinct study of the 10 *a unique case*.

We do not know what in the combination of characteristics in each context may have contributed to the particular effect (or none thereof) of the intervention. The randomized-control experiment design, in and of itself, does not provide for such insights. What we are left with is the post-hoc consideration of the differences between the contexts. Whereas all contexts shared some important features, such as undergraduate STEM students, a survey lecture-based course, introductory biology content, and exams as the main basis for grades, they also differed on several quite substantive characteristics with potential to frame the way the intervention would have been "received" and approached by students. Below, we provide a richer description of the different contexts—based both on what we know from official documents about the universities and the courses, and—while recognizing the unsystematic and potentially biased nature of the data—on what we know informally from other sources, including hearing students talk, reading comments on "Rate-my-Professor," and interacting with instructors and students and addressing events during administering the interventions. Table 1 provides a summary of characteristics across the different contexts that might have implications to the manner by which the interventions have been received and to the differences in effect sizes on students' achievement at the level of course aggregate.

University A, Organismic Biology Course, Fall and Spring Semesters

University A is a large (~35K), urban, minority-serving, public research-intensive institution of moderate admission standards (acceptance rate of 52%, average SAT 1170) that resides in a large city in the shadow of an Ivy-League institution. Undergraduate student composition at the university includes 70% state residents, 54% females, 55.5% White, 12.5% African American, 11.1% Asian American, 6.2% Hispanic, and 6.9% international students. Graduation rate at the university is 48% after four years, and 70% after six years.

Bio A-1 is an undergraduate survey course designed for students pursuing biology-related careers, and is required for STEM majors such as in biology, health-related fields, and bioengineering. The course covers a broad range of topics including: biological evolution, biological diversity *(microbes, plants, and animals)*, animal physiology, and general ecology.

Course structure. The course meets for a 50-minute large lecture three times a week (Monday, Wednesday, Friday). In addition, students enroll in a mandatory weekly laboratory, and in a mandatory weekly recitation session with an upper-classman student. Students' attendance in all course activities – lecture, lab, and recitation sessions – is monitored through the use of Clickers that students are required to purchase. There are no makeups for assignments: "*There are no curves or makeups!... There will also not be any makeups allowed for [Bio A-1] for any reason*" (Syllabus emphasis in original).

Reading. The course requires the use of the Reece et al. *Campbell Biology* textbook, with its associated MasteringBiology website, and a Temple-specific laboratory manual with a collection of experiments. The instructors also strongly recommend the use of Van De Graaff's Photographic Atlas for the Biology Laboratory, which is a full-color photographic atlas that provides visual representations of diversity of biological organisms.

Grading. Students' final course grade is made of 70% lecture grade and 30% laboratory grade. Lecture grades are made of three components: (1) four closed-book within-semester examinations (30%) among which the lowest grade is eliminated and each of the three highest examination scores count 10% towards the final grade, (2) a closed-book final examination that counts for 30% of the final grade, and (3) approximately 12 required electronic quizzes that together count for 10% of the final grade. The laboratory grade includes attendance and quizzes administered during laboratory. The syllabus states that "*Grades will not be awarded on a curve, i.e. if everyone gets a 75%, everyone will get a C+."*

Motivational climate. The course has a long-held reputation as a "weed-out" course due to its relatively low pass rate. The instructors aim to confront this with an explicit statement in the syllabus: "*Please note that [Bio A-1] is not intentionally designed as a "weed-out course", rather, students "weed" themselves out!*" (Syllabus, emphasis in original). The syllabus has additional advice and instructions to students about what they should do to be successful: "*The best, easiest, and really the only successful approach to doing well in this class includes carefully reading and studying all the presented material (text and otherwise), coming to class* *regularly, taking notes, paying close attention, attending all scheduled labs, attending all scheduled recitations, completing all quizzes, and where appropriate, participating in the discussions*" (Syllabus, emphasis in the original). The course instructor receives mixed reviews in Rate my Professor, with overall higher difficulty to quality ratio (96 ratings: Difficulty-4.5/5.0, Quality-2.1/5.0, 25% will take again).

Difference Between Fall and Spring semesters. Bio A-1 is offered in the Fall and in the Spring semesters; however, while the syllabus is identical, the student body of the course is quite different between semesters. Commonly, Spring semesters have more than twice the size of the student body as in the Fall semesters (~350 vs. ~150). In addition, students in the Fall semester are more likely to be taking the course a second time after not succeeding in the Spring semester.

University A, Cellular Biology Course, Fall Semester

Bio A-2 is a slightly more advanced undergraduate introductory biology course than the one in University A that is designed for students pursuing biology-related majors. The course focuses on fundamental levels of living systems, with topics including: chemical bonds, properties of water, carbon chemistry, the structures and functions of macromolecules, cell-to-cell communication, cellular signaling, the regulation of the cell cycle, and cell motility, the processes of gene expression and DNA replication, chromosome behavior during meiosis and the field of genetics, and their application in aging and cancer.

Course structure. The Bio A-2 course structure is very similar to the Bio A-1 course. It meets for a 50-minute large lecture three times a week (Monday, Wednesday, Friday), and in addition, students enroll in a mandatory weekly laboratory. This course does not have a mandatory weekly recitation session. Unlike in Bio A-1, students are able to make-up a missed exam, although they require a justified reason (e.g., a physician's note).

Reading. The course requires the use of the Urry et al. *Biology* textbook.

Grading. Students' final course grade is made of 75% lecture grade and 25% laboratory grade. Similar to Bio A-1, lecture grades are calculated out of four closed-book within semester exams and a final exam, with the first within-semester exam constituting 11% of the grade, and the following three within-semester exams and the final exam constituting each 16% of the final grade.

Motivational climate. Bio A-2 has a reputation as a content heavy course, but less demanding than Bio A-1 is. On Rate-my-Professor, the instructor receives primarily positive reviews and is described as preparing students very well for the exams (55 ratings: Difficulty-3.2/5.0, Quality-3.7/5.0, 86% will take again).

University B, Organismic Biology Course, Fall and Spring Semesters

University B is a large (~49K), public, research-intensive, flagship institution with high admission standards (acceptance rate of 66%, average ACT 30) that resides in a medium-sized college town. It has high local, state, national, and international reputation. Undergraduate student composition at the university includes 59% state residents, 46% females, 42.6% White, 5.3% African American, 15.6% Asian American, 5.3% Hispanic, and 22% international students. Graduation rate at the university is 69% after four years, and 84% after six years. The university largely draws on students from public high schools in suburbs surrounding the very large city in the state. These are well-resourced, college preparatory high schools that mostly educate children of professionals and offer ample AP and college-bound (e.g., pre-calculus, literature) courses. The emphasis in these schools is largely on fostering high performance (e.g., accurately completing assignments, following directions, extensive time spent on test prep), but not on problem-solving, creativity, innovation, or other goals. This shows up as frequent 'begging' around grades—asking for grades or even research extra credit to be increased (so the student can meet some grade goal). The university is very large (~49k students), and despite freshman 1 credit how-to-succeed courses, students can feel 'lost.'

Bio B-1 is an undergraduate survey course designed for students pursuing biology-related careers, and is required for STEM majors such as in biology, health-related fields, and bioengineering. The course covers a broad range of topics including: heredity, biological evolution, animal physiology, cellular respiration and photosynthesis.

Course structure. The course meets for a 50-minute large lecture three times a week (Monday, Wednesday, Friday). In addition, students enroll in a mandatory weekly recitation session with a TA. These are supposed to be small-group discussion-based meetings but often devolve into TAs telling students the answers to questions.

Reading. The course requires the use of the Freeman *Biological Science* textbook, with its associated Mastering Biology website, and a university-specific course manual with a collection of in-class exercises.

Grading. Students' final course grade is made of five components: (1) three closed-book within-semester examinations (10%, 15%, and 15%), (2) a closed-book final examination that counts for 20% of the final grade, (3) approximately 25 required pre-lecture electronic quizzes that together count for 10% of the final grade, (4) 15 weekly homework sets that together count for 15% of the final grade, and (5) discussion section exercises (13) that together count for 15% of the final grade.

Motivational climate. The course has a reputation as a learning-focused environment, even though 15% of students do earn D's, F's, or withdraw from the course. The instructor statements on the syllabus focus on what students need to do (e.g., arrive on time, silence phones, use laptops only for course related things), where there are opportunities for make-up work/make-up attendance, and how to get help (e.g., electronic Q&A board). Students' attendance is monitored through the use of Clickers that students are required to purchase. The instructor implements many activities designed to foster engagement, including in-lecture paired group work in the course manual, asking for and taking frequent questions that require student reasoning. No attempt is made to make material relevant to students, other than saying 'your future biology courses will cover this in great detail'. Ample office hours—faculty and TA—are offered, together with exam review sessions. Practice exam questions and suggested answers are provided on the course website. On Rate-my-Professor, the instructor receives primarily positive reviews and is described as a caring and supportive instructor who prepares students very well for the exams (68 ratings: Difficulty- 2.5/5.0, Quality-4.3/5.0, 88% will take again)

Difference Between Fall and Spring semesters. The Introductory biology course is offered in the Fall and in the Spring semesters and most students are randomly assigned to either a) take Bio B-1 in the fall and Cellular Biology in the spring, or b) take Cellular Biology in the fall and Bio B-1 in the spring. The syllabus is identical, and the student body of the course is almost the same between semesters; however, spring students will have already completed one semester of college-level biology! Students entering the university with extremely low math ACT scores or university math placement exam scores (using the online system, with re-takes allowed) are encouraged to follow the Bio B-1 Cellular sequence. This means that spring lectures are somewhat smaller (~500) than fall (~700).

A discussion-based section was added in about 2016 that is open only to two groups of students: 1) Biology Merit program-accepted students who are high-achieving URM or rural students who are chosen on a competitive basis and 2) AAP students who come from low-college-going (50% or less) high schools.

University C, Introductory Biology Course

University C is a mid-size institution (~25K) of low selectivity (undergraduate acceptance rate of 86%, median SAT of 1100 with test-optional admission) that resides in a small city. It is a minority-serving institution, with moderate local and national reputations. The vast majority of students come from the close region. Undergraduate student composition at the university includes 87% in-state residents, 56.3% females, 46.8% White, 28.1% African American, 4.5% Asian American, 8% Hispanic, and 1.4% international students. Graduation rate at the university is 26% after four years, and 49% after six years.

Bio C-1is an undergraduate survey course designed for students pursuing biology-related careers, and is required for STEM majors such as in biology, health-related fields, and biochemistry. The course covers a broad range of molecular biology topics including: cell biology, human genetics, and human metabolism. The only pre- or co-requisite is the lab, which is run as a separate 1-credit course.

Course structure. The course has three sections, each with about 150-200 students. Depending on the section, the course meets either for a 50-minute large lecture three times a week (Monday, Wednesday, Friday) or for a 75-minute large lecture that meets two times a week (Tuesday and Thursday). In addition, students may enroll in a weekly laboratory (separate from lecture) and have access to a voluntary weekly academic support program run by former students in the course.

Reading. The course requires the use of Raven and Johnson Connect for Biology and does not require a textbook.

Grading. Students' final course grade is 100% based on the lecture grade and the laboratory grade is separate (it is a separate 1-credit course). Lecture grades are made of four components: (1) four closed-book within-semester examinations making up 70% of the final grade, (2) a closed-book final examination that counts for 18% of the final grade, (3) regular online "connect" assignments completed outside of class count for 9% of the final grade and (4) in-class assignments count for approximately 4% of the final grade. The laboratory grade includes attendance and quizzes administered during laboratory.

Motivational climate. The course is difficult as evidenced by a high rate of D, F grades and withdrawals. The instructor of the course works hard to help students succeed in the class. He incorporates any opportunity to helps students succeed including permitting a voluntary student success program designed to reduce the D, F, and withdrawal rate of difficult courses. According to the instructor the attendance rate is very low and he works to combat this by trying to make the material relevant for students. For example, he invites a professional who works with animals to speak to the class so students can see the relevance of biology in professions they would not typically consider (i.e., professions outside of medical school or other health professions). At times, he also provides extra credit for class attendance (unannounced) to try to encourage students to come to class. The instructor lectures most of the time but also incorporates "clicker" questions to engage students in the lecture. However, he does not take attendance in the course. On Rate-my-Professor, the instructor receives primarily positive reviews and is described as a caring and supportive instructor who prepares students very well for the exams (190 ratings: Difficulty- 2.6/5.0, Quality-4.1/5.0, 80% will take again). Overall, the course seems to be less rigorous than the courses in universities A and B.

Unanticipated Events

In addition to the significant moderators that suggested that combinations of contextual features are influential on the way students' engage with and benefit from the intervention modules, our experiences in administering the interventions also included several unanticipated events that impacted the intervention and its effect. For example, in our first semester of the intervention in University A, it became clear that one intervention module had an unintended effect—sending students a link to segmented recording of the lectures resulted with a drop in attendance. The fact that any combination of this module with a motivational module did not show improved outcomes, and some even showed detrimental effects on achievement, may have been a result of opposing processes—perhaps the contribution of cognitive organization was countered by the lack of attendance, or even by an "illusion of learning" that was due to the perceived ease of learning from the segmented lecture. Following this occurrence and the findings, we eliminated this component.

Another unanticipated event occurred in the 2nd semester of our intervention in University B, when the data indicated that students 'crammed' on the intervention. That is, rather than viewing the study strategies, worked examples, and cost alleviating messages videos and completing the relevant writing soon after we released them to students along the course content and exam schedule, the vast majority of students completed the entire set of modules during the last two weeks of the semester. It caught us unprepared. This happened neither during any of the semesters in University A prior to our engagement with University B, nor in the 1st semester of the intervention in university B. In light of this occurrence, we decided to change the extra-credit incentive to be contingent on timely completion, after which, students' engagement at University

B returned to be timely. Other examples of unanticipated events included mid-semester negotiations with an instructor who, suddenly, reconsidered the agreed amount of extra credit that students would receive for participating in the study, and changed schedules (e.g., snow days) that required modifying the timing of release of intervention modules relative to the course schedule.

Lessons Learned

The findings concerning great variability in effect size, the significance of all contextual moderators, the substantial differences in context and student body across experiments, and the occurrence of anticipated events during the administration suggest several lessons concerning outcomes of motivational interventions, perhaps particularly those that aim to incorporate multiple components. Below, we discuss three such lessons: (1) the aggregate intervention effect masks substantial variability; (2) unknowable contextual differences always prevent simple transfer of practice across contexts; and (3) incorporating multiple components in an intervention is not an additive process. We conclude with a critique of the traditional meaning of "evidence-based practice."

The Aggregate Intervention Effect Masks Important Variability

Our study employed "best practices" in testing for accumulating evidence for the benefit of particular combinations of cognitive and motivational interventions on students' grades in undergraduate introductory survey biology courses. The findings from our meta-analysis suggest that, at the aggregate (across studies, contexts, and students within settings), combining particular cognitive interventions with particular motivational interventions is significantly (statistically) and meaningfully (by magnitude of grade change) beneficial relative to "business-as-usual" control conditions, and to conditions in which students accessed only cognitive or only motivational interventions.

However, our findings also suggest that these aggregated findings mask tremendous variability that prevents the validity of generalizing an expectation for such an effect to any other context—as similar its features may seem to be to the original study's contexts (i.e., introductory undergraduate biology survey courses). The moderator analysis that indicated that ALL contextual moderators were significant in influencing the effect size implies that context is crucial in the way the intervention operates. Importantly, the moderator analysis tested each moderator separately. Of course, these different moderators serve as indices to characteristics that, in the actual setting, do not operate in isolation, but are combined, potentially in unique ways, to constitute each setting in our multi-experiment study a distinctive case.

It is noteworthy that the aggregate effect size in our study involved replications of a positive effect of the multi-component intervention across the majority of the different contexts, even if not of the magnitude of the effect. This means that, in the aggregate, there seems to be validity to the claim that the combination of cognitive and motivational interventions may improve students' achievement relative to no intervention or to single component interventions. However, it is also the case that the aggregate does not, in and of itself, provide justification to expect positive effects to manifest in any new context.

Unknowable Contextual Differences Always Prevent Simple Transfer of Practice Across Contexts

Our meta-analysis included numerous contextual moderators of the main effect—all of which were significant. It is noteworthy that we included the moderators that we could think of and had data about. But, these categorical moderators (e.g., university, semester, course, year) do not provide substantial insight into the actual contextual characteristics and the mechanisms by which contextual differences may affect the intervention. While we are unable to make informed speculations about the nature of these contextual influences on the intervention with our current design and data, a rich description of the different contexts highlights several differences with potential to do so, including the type of university, its size, and its reputation; the characteristics of the student body in terms of number, ethnic composition, prior academic preparation, and prior content knowledge; the course content and structure; and perhaps most meaningfully, the course's motivational climate. We conclude that, even in randomized-control trials, approaching each administration as a case study, in which the normative test of an intervention's effect in that particular setting is conducted as part of a "thick description" longitudinal investigation of the intervention's unfolding, would be highly informative about the features that may have effect on the intervention. Our experiences with unanticipated events suggest that there will always be the possibility of an unexpected feature, whether pre-existing or emerging, that might influence the intervention. Educational contexts are complex phenomena that are characterized by non-linear and serendipitous happenings. In new contexts, one can always expect the unexpected, and therefore, cannot simply transfer successful practices from one context to another with the expectation for direct replication.

Incorporating Multiple Components in an Intervention is Not an Additive Process

This study is part of an emerging trend to incorporate multiple components into interventions. Our study is relatively unique in that trend, since it tested not only multiple components—one cognitive and one motivational—but different combinations of multiple components simultaneously. Our findings suggest that, overall, combinations of components were more effective than single components, and also that some combinations were more effective than others in most contexts. But our findings also suggested that different combinations demonstrated positive effects in the same context. This implies that there is not a clear, single, optimal combination of components that would have a positive effect. Rather, students' motivation, learning, and achievement may take different "paths" (Pintrich, 2003), and may be enhanced by different combinations of cognitive-motivational processes. Obviously, combinations could include more than just one cognitive module and one motivational module. Wouldn't we expect students to benefit from all four cognitive (priming prior knowledge, thematic organization of content, worked examples, and study strategies) and all three motivational (expectancies for success, task value, and low perceived cost) interventions? Some research about motivational interventions actually suggests that this may not be the case, as some of these interventions do not have the expected effects across all students, with some interventions that seem beneficial to some students prove detrimental to others (Schwartz et al., 2016). Notably, even in randomized-control trials, where randomization is assumed to equalize characteristics of participants across conditions, effects within conditions constitute aggregates across students with different characteristics. Cognitive and motivational interventions that aim to improve students' engagement, learning, and achievement target processes that are conceptualized at the unit-of-analysis of the individual (and, those that are more informed, the unit-of-analysis of the "individual-in-context"). This mismatch between the conceptual unit-of-analysis and the analytical unit-of-analysis must raise an important flag of caution to interventionists that any positive effect of administering a component, or a combination of components, to a group of students may be masking individual differences in responding to the intervention. Thus, an important understanding is that, adding more intervention components is not necessarily adding more benefit to different students. It is quite possible that the most effective combination of cognitive-motivational interventions is different for different students, in different contexts, and at different times.

Conclusion: A Critique of the Traditional Meaning of "Evidence-Based Practice"

Our insights about the crucial role of context and of participants' individual differences, with their inevitable partially unanticipated characteristics, are similar to those of Borman et al. (2018) who tested in high school contexts the effects of a self-affirmation intervention that was found to be effective in middle school. At the aggregate, their intervention was impressively effective (reduction in 50% in the growth of the racial achievement gap across the high school transition). Yet, the authors also emphasized the substantial differences across contexts, being careful to highlight the "potential" of the intervention "if implemented broadly," and to note that "these effects will depend on both contextual and individual factors" (p. 1773).

Over four decades ago, Lee Cronbach (1975) pointed to the inevitable limitation of experimental designs, which always concern the interaction of a treatment with the personal characteristics (aptitude) of the participant. Cronbach's concluded that when Aptitude by Treatment Interactions (ATIs) are present—as is the case in motivational interventions—"a general statement about a treatment effect is misleading because the effect will come or go depending on the kind of person treated" (p. 119). Speaking from the perspective of quantitative analyses, Cronbach's recognized the futility of drawing any firm conclusions about the effect of any intervention when there are moderators (i.e., interactions) involved: "Once we attend to interactions, we enter a hall of mirrors that extends to infinity. However far we carry our analysis—to third order or fifth order or any other—untested interactions of a still higher order can be envisioned" (p. 119). His conclusion, drawn on the basis of careful analysis of multiple experimental research programs in different domains of psychology (including education) was that "The experimenter or the correlational researcher can and should look within his [*sic*] data for local effects arising from uncontrolled conditions and intermediate responses" (p. 125). Moreover, he emphatically recommended that instead of conducting experiments that aim at cross-contextual generalizations, researchers should evaluate the benefit of practice on the basis of the context in which it is implemented:

> Instead of making generalization the ruling consideration in our research, I suggest that we reverse our priorities. An observer collecting data in one particular situation is in a position to appraise a practice or proposition in that setting, observing effects in context. In trying to describe and account for what happened, he [*sic*] will give attention to whatever variables were controlled, but he [*sic*] will give equally careful attention to uncontrolled conditions, to personal characteristics, and to events that occurred during treatment and measurement. As he [*sic*] goes from situation to situation, his [*sic*] first task is to describe and interpret the effect anew in each locale, perhaps taking into account factors unique to that locale of series of events (pp. 124-125).

The traditional understanding of "evidence-based practice" fails to account for Cronbach's critique of the pursuit of cross-contextual generalizations. The Institute of Educational Sciences' "What Works Clearinghouse" (WWC) rates randomized-controlled trials as meeting WWC standards "without reservations" (WWC, 2019a). In purporting to "focus on high-quality research to answer the question 'what works in education?'" (WWC, 2019b), this approach equates "evidence-based practice" with the aggregated effects of experiments (with the possible qualification of a moderator), thus ignoring the "evidence" that what has "worked" in one context, may have not actually “worked” for everyone in that context, and may very well not “work” in the same way in any other context. Instead, based on Cronbach’s insights, Borman et al.’s (2018) and others’ findings, and our own lessons learned, “evidence-based practice” would account for the evidence that context matters, that some contextual features are inductive and unpredictable, that interventions unfold in complex ways, and that prior findings about “what worked” in multi-component educational interventions – robust as they may be – provide but a starting point for a design-based investigation in any new context that attends to the emergent, complex, and dynamic nature of educational contexts (Kaplan, Katz & Flum, 2012).

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Table 1
Summary of Characteristics Across Contexts

	University	Students	Course content	Course structure	Motivational climate
Bio A-1 Spring	Moderately large (~35K); urban; research-intensive, minority-serving; public; in shadow of local Ivy-League institution; moderate reputation; moderate admission selectivity; moderate graduation rate (~48% in 4 years).	N~350; required background in college chemistry; vast majority state residents from public schools; ~55% White, ethnic diversity primarily African American and Asian American.	Foundational organismic biology	Three weekly 50-mn lecture, lab, and recitation; grades based on 4 closed-book within-semester exams, final, and lab quizzes. Textbook, lab manual, and clickers required. Attendance monitored. No make-ups.	Perceived as "Weed out" course; Attendance required; RmP: (96 ratings) Difficulty/Quality: - 4.5/2.1, 25% will take again.
Bio A-1 Fall	-"-	N~150; similar characteristics to above, except for higher numbers of course re-takers	-"-	-"-	-"-
Bio A-2 Fall	-"-	N~200; otherwise similar to above	Foundational cellular biology	Three weekly 50-mn lecture, lab, but no recitation; grades based on 4 closed-book within-semester exams, final, and lab quizzes. Textbook and lab manual required. Attendance monitored. Make-ups are allowed with justification.	Instructor perceived as preparing students well for exams. RmP: (55 ratings) Difficulty/Quality: - 3.2/3.7, 86% will take again.
Bio B-1 Fall	Very large (~49K); college town; research-intensive; flagship; public; high reputation; high	N~700; required background in college chemistry; majority state residents from high resourced public college	Foundational organismic biology, slightly more advanced than at	Three weekly 50-mn lecture, lab, and recitation; grades based on 3 closed-book within-semester exams, final, quizzes, homework assignments, and	Reputation as learning-oriented course; RmP: (68 ratings) Difficulty/Quality: 2.5/4.3, 88% will take again.

	admission selectivity; high graduation rate (69% in 4 years).	preparatory and private schools; 43% White, with ethnic diversity primarily international students and Asian American.	University A	discussion exercises. Attendance monitored. Make-ups are allowed.	
Bio B-1 Spring	-“-	N~500; similar to above except an additional college biology course.	-“-		-“-
Bio C-1	Moderate size (~25K); semi-urban; minority-serving; public; moderate-low reputation; low grade selectivity; low graduation rate (26% in 4 years)	N~150/200 per section in 3 sections; only lab as pre-or co-requisite; vast majority state residents from local non-preparatory public schools; ~47% White, with ethnic diversity primarily African American.	Foundational organismic biology	Three weekly 50-mn lecture; lab as a separate course; no recitation; grades based on 4 closed-book within-semester exams, final, online assignment, in-class assignments. Readings are from an online website, no textbook; no monitored attendance (and attendance is low); Course not as rigorous academically as the courses in the other universities.	Instructor perceived as nice and caring; invests much effort in creating an engaging student experience. RmP: (190 ratings) Difficulty/Quality: 2.6/5.0, 80% will take again.