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Title: Promoting active learning out-of-class via online “study questions” leads to higher than expected exam scores in General Biology

Abstract:

A rising need for workers in science, technology, engineering and mathematics (STEM) fields has fueled interest in improving teaching within STEM disciplines. Numerous studies have demonstrated the benefits of active learning approaches on student learning outcomes. However, many of these studies have been conducted in experimental, rather than real-life, class, settings. In addition, most of these studies have focused on in-class active learning exercises. This study tested the effects of a form of out-of-class active learning on exam performance for General Biology students at the University of Minnesota. An online database of 1,020 multiple-choice questions covering material from the first half of the course was generated, with feedback provided for 73% of the questions. Students in seven course sections (with an average of approximately 265 students per section) were given unlimited access to the online study questions. These students made extensive use of the online questions, with students answering an average of approximately 1,323 questions (94.5 questions per lecture) covering material from the half of the semester for which the questions were available. The extent to which access to the online study questions improved student learning outcomes was assessed by comparing the performance on exam questions of students in the seven course sections with access to the online study questions with the performance of students in course sections without access to the online study questions. Student performance was analyzed for a total of 89 different exams questions that were not included in the study questions, but that covered the same material covered by the study questions. Each of these 89 questions was used on one to five (average of 2.3) exams administered to students in course sections that had access to the online study questions and on three to 77 (average of 24.8) exams administered to students in sections that lacked access to the online study questions. Data from over 1,800 students in sections with access to the online study questions show that those students scored a statistically significant average of 6.6 percentage points higher on the exam questions analyzed than students in sections without access to the study questions. This difference was greater than the average amount necessary to raise students’ exam grades by one grade (e.g. from a “B-“ to a “B”). In addition, there was a higher correlation between number of questions answered and success on exam questions on material related to the study questions than between number of questions answered and success on exam questions on material unrelated to the study questions. The online study question system analyzed in this work required substantial effort to set up in the first year, but required minimal effort to maintain in subsequent years and was effective in significantly raising average exam scores for even very large course sections.

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Introduction

Due to a rising need for highly trained workers in science, technology, engineering and mathematics (STEM) fields (PCAST STEM Undergraduate Working Group, 2012), and for an electorate better able to make informed decisions regarding complex scientific and technical issues, there is an increasing need to educate students more effectively in STEM disciplines. In recent years, numerous studies have examined the benefits of non-traditional educational strategies on student learning outcomes. “Flipped classrooms” have been shown to promote positive outcomes on student learning (reviewed in O’Flaherty & Phillips, 2015), although recent evidence suggests that most of the benefit of a flipped classroom may be due to active learning, rather than to “flipping” the classroom per se (Jensen, Kummer & Godoy, 2015). Diverse active learning approaches have also been shown to promote student learning. A recent meta-analysis of 225 studies found that inclusion of in-class active learning exercises increased exam scores by an average of 6%, which was sufficient to raise student grades one level (e.g. from a “B-“ to a “B”) (Freeman et al., 2014). Other metaanalyses of the effects of alternatives to traditional lecture formats on student learning outcomes have found similar results (Springer, Stanne & Donovan, 1999; Ruiz-Primo et al., 2011).

Answering questions has been shown to be a particularly effective form of active learning that promotes long-term learning in laboratory studies (reviewed in Brame & Biel, 2015). Studies have also shown that answering questions improves not only rote learning, but also increases students’ ability to draw conclusions by synthesizing multiple facts (Karpicke & Blunt, 2011; Smith & Karpicke, 2014). Different question formats have been found to be effective in improving student-learning outcomes. For example, one study found little to no advantage of answering short-answer or mixed-format questions over answering multiple-choice questions in three out of four experiments (Smith & Karpicke, 2014). However, most of these studies were done in a laboratory environment (Brame & Biel, 2015), with only a limited number of studies (for example, Leeming, 2002; Larsen et al., 2009) demonstrating the efficacy of repeated testing on student performance in real-life educational settings. A small number of studies have also examined the utility of out-of-class testing as a learning strategy. In one such study, students took one online quiz per week (multiple attempts were encouraged for each quiz) for three weeks and then took an exam. Students were found to perform better on exam questions related to material covered by the quiz questions than on exam questions on material not covered by the quiz questions (McDaniel, Wildman & Anderson, 2012). In another study, students took ten online quizzes, each with ten questions, over the course of the semester. Students who took all of the quizzes were found to perform significantly better on an exam than average students from the same class (Orr & Foster, 2013).

Although intriguing, these studies leave open the question of the extent to which providing students with access to study questions can improve overall student performance in a real classroom. To address this question, students in seven sections of BIOL 1009 General Biology at the University of Minnesota Twin Cities were provided with unlimited access to an online study question database. This online database contained 1,020 multiple-choice questions on material taught during the first half (14 lectures) of the course, with feedback provided for 73% of the questions. The effects of access to the online study questions were assessed primarily by comparing the performance of students with access to the online study questions to the
performance of students without access to the online study questions on in-class exam questions.

A total of 89 exam questions were analyzed. Each of these questions was used on one to five (average of 2.3) exams administered to course sections where the students had access to the online study questions, and on three to 77 (average of 24.8) exams for course sections where the students did not have access to the study questions. BIOL 1009 course sections typically contain 200 to 340 students.

**Materials & Methods**

**BIOL 1009 General Biology course**

BIOL 1009 General Biology is a one-semester (14 to 15 week) course that is taught in multiple sections each term on the University of Minnesota Twin Cities campus. This course is intended for students who are not within the College of Biological Sciences, but who do have a specific need to learn biology (e.g. students intending careers in the health sciences). Course sections meet twice per week for 75 min each time. Course sections meet an additional time each week for a 2-h laboratory session. The course as a whole (lecture plus lab) is a four-credit course. Most course instructors, including the author, teach the course using primarily a traditional lecture format, but include some in-class active learning exercises as well. These in-class active learning exercises may include answering a few questions, think-pair-share or similar activities. The author taught the first half (lectures one through 14) of BIOL 1009 section 30 in 2012 and sections 1 and 30 in 2013-2015. The sections taught by the author had approximately 220 to 320 students per section.

**Online study questions**

An online question bank was developed by the author for the first half of BIOL 1009 General Biology in 2012. This online question bank was developed in Moodle, an online learning platform ([https://moodle.org/](https://moodle.org/)). The question bank contains a total of 1,020 questions covering material taught by the author during the first 14 lectures (= half) of BIOL 1009 General Biology. There are an average of 73 questions/lecture, with a range of 47 to 98. All of the questions in the question bank are multiple-choice questions with a single “best” answer for which full credit is assigned and three distractors for which no credit is assigned. Most of the questions fit into one of the three lower levels (remembering, understanding and applying) of a revised version ([Anderson, Krathwohl & Airasian, 2001](https://www.amazon.com/Ataxonomy-Bloom-s-A-Structure-Scientific/dp/007340080X)) of Bloom’s anatomy ([Bloom & Krathwohl, 1956](https://www.jstor.org/stable/27829838)). A smaller number of the questions test analyzing or evaluating. Approximately half of the questions were written by the author. Most of the remaining questions were adapted by the author from questions on the MasteringBiology website ([http://www.pearsonmylabandmastering.com/northamerica/masteringbiology/](http://www.pearsonmylabandmastering.com/northamerica/masteringbiology/)) that cover material from Campbell Biology Ninth Edition (Reece et al., 2011). Correct answers were indicated for all of the questions and more detailed feedback was provided by the author for 73% of the questions. This feedback includes descriptions of how to arrive at the correct answer and/or explanations of why particular distractors are incorrect.
Sets of study questions were arranged for each of the first 14 course lectures using the quiz generating function of Moodle. These sets of study questions were set up so that each time a student chose to answer a set of study questions for a particular lecture, ten questions were randomly chosen from amongst the questions in the online question bank that pertained to that lecture. Sets of study questions were also arranged to cover material from lectures 1-3, 1-5, 1-8, 1-14, 9-10, 9-12 and 9-14. The number of questions per set for sets covering more than one lecture ranged from 10 to 27. After a student finished answering a set of study questions, the student was shown a page indicating which questions the student had answered correctly or incorrectly, the correct answer for each question and providing more detailed feedback for an average of 73% of the questions. This form of delayed feedback (i.e. feedback received after a student has completed answering all of the questions) has been shown to be particularly effective in promoting learning (Butler & Roediger 2008). The students had unlimited online access to the sets of study questions throughout the semester. The students received no credit towards their course grade for answering sets of study questions, but were encouraged to make frequent use of them.

To determine the number of questions answered by each student, excel files indicating the number of times each student in a particular course section answered questions from a particular set of study or quiz questions were downloaded from Moodle. Columns were added to each file indicating the number of questions in that set of study or quiz questions. The excel files were then combined into a single excel file and sorted by student name. The numbers of questions answered were then added together and recorded for each student.

### Online quizzes

The online study questions were also used to generate online quizzes on Moodle. There were seven quizzes covering material from the first half of the course in 2012 and 2013 and ten quizzes in 2014 and 2015. To receive credit for a particular quiz, students had to complete the quiz before a deadline that was typically one to two weeks after the last class session covering material included on that quiz. Quizzes typically had 24 questions, randomly chosen from amongst all the questions in the online question bank on material covered by that quiz. Once started, a quiz needed to be completed within 1 h. Immediately after submitting each quiz, students were shown a page indicating the correct answers for each question on their quiz and providing more detailed feedback for an average of 73% of the questions. Students were allowed to use any resources (notes, textbooks, the web) in answering quiz questions. Students were allowed to attempt each quiz a maximum of three times, with only their highest score for each quiz being counted. In addition, the lowest two quiz scores were dropped for each student. These quizzes, as a whole, accounted for 10% of students’ course grades for the first half of the semester, or 5% for the course as a whole.

### Biology Program exam question database

The Biology Program at the University of Minnesota Twin Cities established a database of exam questions for BIOL 1009 General Biology in fall 1978. Each term new questions are added to this database by the different faculty members teaching the course. This database currently contains a total of 2,284 active questions covering material from the entire course. Records are
maintained for each question, indicating each course section for which that question was used on an exam and the percentage of students that answered the question correctly each time it was used on an exam. Using this information, an “expected” exam score can be calculated for each group of questions chosen from the exam question database, by averaging the average facility indexes for the chosen questions. For this work, “expected” scores were calculated using only results from questions that had been used at least three times in exams for course sections for which online study questions were not available, and that were not honor’s sections. On average, the questions from the exam question database analyzed as part of this work were used in 24.8 exams for course sections for which online study questions were not available and that were not honor’s sections (Supplemental Table S1). In total, 34 different course instructors (including the author) used one or more of the questions analyzed on an exam.

Exams

There were three course exams. All exams took place in class and lasted for a maximum of 75 min (exams 1 and 2) or 120 min (final exam). Students were not allowed to use any resources (notes, textbooks, etc.) during exams. All exams consisted of multiple-choice questions with one “best” answer and three distractors. There were 40 questions each for exams 1 and 2 and 50 questions for the final exam. Exams 1 and 2 each accounted for 16.67% of students’ final course grades and the final exam accounted for 20.83% of final course grades. Exam 1 covered material from lectures one through eight. Questions for exam 1 were drawn from two sources. For each exam 1, 20 to 21 questions were chosen by the author from the online study questions. The remaining 19 to 20 questions (Supplemental Table S1) were chosen by the author from an exam question database maintained by the Biology Program at the University of Minnesota. Both groups of questions covered material from lectures one through eight, but none of the questions chosen from the exam question database were written by the author, whereas approximately half of the questions chosen from the study questions were written by the author. Exam 2 covered material from lectures nine through 17 (2012 and 2013), nine through 18 (2014) or nine through 19 (2015). Study and quiz questions were available only for lectures one through 14 until 2015, when study questions became available for the entire course. Questions on exam 2 can be divided into three groups. Each year the first group of 13 to 15 exam 2 questions was chosen by the author from amongst the study questions covering material from lectures nine through 14. The second group of 11 to 13 questions (Supplemental Table S1) was chosen by the author from amongst the questions in the Biology Program exam question database that cover material from lectures nine through 14. The third group of 13 to 16 questions was chosen by the faculty member who taught the second half of the course and covered material from lectures 15 through 17 (2012 and 2013), 15 through 18 (2014) or 15 through 19 (2015).

Ethics statement

All data analyzed in this study was obtained as a result of normal course activities. In other words, no students participated in any activities specifically designed for gathering data for the purposes of this study. In addition, due to the fact that all the course sections from which data were collected had over 200 students, and that all identifying information has been removed, it is not possible to identify information for any individual students from materials presented here.
Statistical analyses

“Actual” versus “expected” scores for questions chosen from the Biology Program exam question database were analyzed using a two-tailed, paired Student’s t-test. Correlations between numbers of questions answered versus performance on different groups of exam 2 questions were calculated as the Pearson product moment correlation coefficient, r.

Results and Discussion

Students made extensive use of online study questions

A database of 1,020 questions covering material from the first half (first 14 lectures) of BIOL 1009 General Biology was developed in 2012 and made available online to students in seven course sections from 2012-2015. In addition to indicating the correct answer for each question, feedback (e.g. explaining how to arrive at the correct answer or why a particular distractor is incorrect) was provided for 73% of the questions, as providing feedback has been shown to increase the benefits of answering questions (Butler & Roediger, 2008). A concern in developing a study question database that students can access outside of class is whether students will make sufficient use of the database to justify the effort of generating it. Therefore, incentives were provided to encourage students to make use of the study questions. First, students were informed that questions from the study question database would comprise 100% of the questions used for a series of seven (in 2012 and 2013) or ten (in 2014 and 2015) online quizzes. Together these quizzes accounted for 5% of final course grades. Secondly, students were told that half of the exam questions covering material from the first half of the course would be chosen from the study questions. Together these exams accounted for 54% of final course grades. Students were also informed at the beginning of the semester that answering questions has been shown to be a particularly effective means of learning new material. To help emphasize that the online questions were intended primarily to help students learn the material, rather than as a means of knowledge assessment, beginning in 2014 the sets of online questions were labeled as “study questions” rather than as “practice quizzes”.

From 2012-2015, students answered an average of approximately 1,323 study questions plus quiz questions, or an average of 94.5 questions per lecture for the 14 lectures for which study and quiz questions were available (Table 1). As a result, during the first part of the semester students spent an average of approximately 2 h per week answering questions outside of class, an amount of time similar to the amount of time students spent in class during the same time period. Thus, the online study questions promoted an amount of time spent on active learning that was roughly equivalent to devoting almost 100% of every class session to active learning exercises.

The majority of the questions answered were optional study questions for which no credit was available, rather than quiz questions for which credit towards final course grades was available. In 2012, for example, 76% of the questions answered by students were study questions (Table 2, Supplemental Table S2). The average number of questions answered per student per lecture did not vary substantially from year to year, ranging from a low of 89.7 to a high of 99.8. Although there was a large degree of variation in the numbers of questions answered by different students,
284 the vast majority of students made extensive use of the online study and quiz questions. For 
285 example, in 2012 and 2013 fewer than 8% of students answered less than an average of 20 
286 questions per lecture (Figure 1, Supplemental Table S3). In contrast, 35% of students answered 
287 an average of 50.1 to 100 questions per lecture and 33.6% of students answered over 100 
288 questions per lecture. The average numbers of questions answered per student per lecture in 
289 preparation for exams 1 and 2 were very similar (Table 1), indicating that students’ motivation 
290 for answering large numbers of questions was maintained over the half of the semester for which 
291 questions were available. Together these results indicate that students can be motivated to make 
292 extensive use of online study questions outside of class.

293 Exam scores were significantly higher than expected in course sections with access to online 
294 study questions

295 The Biology Program at the University of Minnesota maintains a database of questions that have 
296 been used on BIOL 1009 General Biology exams. Records are kept for each question in the 
297 exam question database, indicating the exams on which the question was used and the fraction of 
298 students who answered the question correctly (the facility index) on each exam. Using this 
299 information, it is possible to calculate an expected exam score for questions chosen from this 
300 exam question database. For the seven sections of BIOL 1009 that are the focus of this study, 19 
301 to 20 questions from the Biology Program database were chosen for exam 1 each year and 10 to 
302 13 questions were chosen for exam 2 each year. The author used the same exams for both 
303 sections of the course taught in the same year, and used some questions on exams in more than 
304 one year. In addition, only questions that had been used by a minimum of three course sections 
305 for which online study questions were not available, and that were not honor’s sections of the 
306 course, were analyzed. Consequently, a total of 50 exam 1 and 39 exam 2 questions chosen from 
307 the Biology Program exam question database were analyzed. Each of these questions was used 
308 on an average of 24.8 exams, with a range of 3 to 77 exams, excluding exams from one of the 
309 seven course sections being analyzed as part of this work and exams from honor’s sections 
310 (Supplemental Table S1).

311 The actual scores achieved by students in the seven course sections for which online study 
312 questions were available were consistently higher than expected (Figure 2, Supplemental Table 
313 S1). The combined average actual score on exam 1 for the seven course sections for which 
314 online study questions were available was 73.2%. The average expected score for these same 
315 exams, based on the percentages of students who answered each question correctly on exams 
316 administered to BIOL 1009 course sections for which online study questions were not available, 
317 was 64.5%. So, students from course sections where online study questions were available 
318 scored 8.7 percentage points higher, on average, on exam 1 than students from course sections 
319 for which online study questions were not available. The differences between the actual and 
320 expected scores on exam 2 were typically less than for exam 1, but were still statistically 
321 significant when data for exam 2 from all seven course sections for which online study questions 
322 were available are combined (Figure 2). The average increase in exam scores for students in 
323 sections for which online study questions were available relative to students in sections for which 
324 online study questions were not available was 6.6 percentage points for exams 1 and 2 combined. 
325 As the average gap between course grades in BIOL 1009 was 5 percentage points, this increase
in exam scores was greater than the average increase needed to raise a student’s exam scores one
grade (e.g. from a B- to a B).

Answering study questions positively correlates with exam scores

The above analyses indicate that course sections for which online study questions were available
had higher than expected exam scores, relative to course sections for which online questions
were not available. The results of additional analyses indicate that number of questions (study
questions plus quiz questions) answered positively correlates with exam performance. For 2012-
2014, a comparison of the number of questions answered in preparation for exam 2 versus score
on exam 2 showed a correlation coefficient (r) of 0.36 (Table 3, Supplemental Table S4). Of

course, this high correlation coefficient could simply indicate that studying in general improves
exam scores. Therefore, to examine the effects of answering study and quiz questions on exam
scores more closely, students’ scores on exam 2 were calculated separately for each group of
questions on exam 2. The first group of questions on exam 2 for 2012-2014 consisted of 13 to 15
questions that were chosen by the author from the online study questions. The second group of
exam 2 questions during 2012-2014 consisted of 11 to 13 questions that were chosen by the
author from questions in the exam question database maintained by the Biology Program at the
University of Minnesota and that covered the same material covered by the online study
questions. Thus, this second group of questions covered the same material as the first group of
questions, but were questions that were not written by the author and that students had not seen
previously in the study or quiz questions. The third group of questions on exam 2 from 2012-
2014 consisted of 13 to 16 questions that were chosen by another faculty member and that
covered different material from that covered by the study and quiz questions. Not surprisingly,
the highest correlation between number of online questions answered and success on a group of
exam 2 questions was for the group of exam 2 questions drawn directly from the study questions
(Table 3). Interestingly, there was a somewhat higher correlation between number of questions
answered and success on the group 2 questions (those that covered the same material as the study
questions but that were not study questions) and group 3 questions (those that covered different
material than the study questions). This result suggests that the correlation between number of
questions answered and success on the exams is not fully explained by students who tend to
study more doing better on exams.

Conclusions

Students made extensive use of the online study questions. Students answered an average of
approximately 1,323 questions, or 94.5 questions per lecture, over the half of the semester for
which study questions were available. As a result, students spent an amount of time on active
learning outside of class that was approximately equal to the total amount of time spent in class
during this period. The availability of the online study questions significantly raised students’
test scores, with students in course sections for which online study questions were available
scoring an average of 6.6 percentage points higher on exam questions than students in sections
for which online study questions were not available. This increase in exam scores was greater
than the average amount needed to raise a student’s exam score by one grade (e.g. from a “B-” to
a “B” or a “B” to a “B+”). This study therefore indicates that students should be provided with
active learning opportunities outside of class, in addition to participating in active learning exercises during class. The online study question system analyzed in this work provides an effective means of achieving this goal, as it requires substantial effort to set up in the first year, but requires minimal effort to maintain in subsequent years and is effective in significantly raising average exam scores for even very large course sections.

Acknowledgements

The assistance of Dr. Rogene Schnell (University of Minnesota Twin Cities) in entering study questions into Moodle and in providing helpful advice on how to organize online quizzes and sets of study questions is gratefully acknowledged.

Supplemental Information

Supplemental Table S1. Actual versus expected scores on exam questions from the University of Minnesota Biology Program exam question database. This table provides information on the exam questions from the University of Minnesota Biology Program exam question database for BIOL 1009 that were analyzed as part of this work.

Supplemental Table S2. Numbers of study and quiz questions answered and exam scores in 2012. The numbers of study and quiz questions answered by each student in preparation for exams 1 and 2 during 2012 are shown. The overall exam 1 score and the scores on different groups of exam 2 questions are also shown for each student.

Supplemental Table S3. Total numbers of questions answered in preparation for exams 1 and 2 in 2012-2013. The total numbers of questions answered by each student in preparation for exams 1 and 2 in 2012 and 2013 are indicated.

Supplemental Table S4. Number of questions answered versus scores on different groups of exam 2 questions. In 2012 through 2014, questions for exam 2 were drawn from three sources: the online study questions, questions from the Biology Program exam question database that covered the same course material as the online study questions and questions on material not covered by the study questions. This table shows the number of questions answered, and the scores obtained on each of the three groups of exam 2 questions, for each student from BIOL 1009 section 30 in 2012 and sections 1 and 30 in 2013 and 2014.
References


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Available at: https://www.whitehouse.gov/administration/eop/ostp/pcast/docsreports (accessed July 7, 2015)


Table 1. Numbers of questions answered in preparation for exams 1 and 2. The average numbers of questions (study and quiz questions combined) answered per student per lecture in preparation for exams 1 and 2 are indicated. There were an average of approximately 265 students per course section.

<table>
<thead>
<tr>
<th>Year, section</th>
<th>Exam 1</th>
<th>Exam 2</th>
<th>Mean of exams 1+2</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012, 30</td>
<td>88.7</td>
<td>98.3</td>
<td>92.8</td>
</tr>
<tr>
<td>2013, 1</td>
<td>89.1</td>
<td>94.0</td>
<td>91.2</td>
</tr>
<tr>
<td>2013, 30</td>
<td>88.6</td>
<td>91.1</td>
<td>89.7</td>
</tr>
<tr>
<td>2014, 1 and 30</td>
<td>95.3</td>
<td>105.7</td>
<td>99.8</td>
</tr>
<tr>
<td>2015, 1 and 30</td>
<td>104.9</td>
<td>83.6</td>
<td>95.7</td>
</tr>
<tr>
<td>Mean, all 7 sections</td>
<td>95.0</td>
<td>93.8</td>
<td>94.5</td>
</tr>
</tbody>
</table>
Table 2. Numbers of study questions versus quiz questions answered in preparation for exams 1 and 2 in 2012. The average numbers of study questions and quiz questions answered per student per lecture in 2012 in preparation for exams 1 and 2 are indicated. N = 273.

<table>
<thead>
<tr>
<th></th>
<th>Exam 1, 2012</th>
<th>Exam 2, 2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study questions</td>
<td>64.9</td>
<td>77.9</td>
</tr>
<tr>
<td>Quiz questions</td>
<td>23.8</td>
<td>20.4</td>
</tr>
<tr>
<td>Total questions</td>
<td>88.7</td>
<td>98.3</td>
</tr>
</tbody>
</table>
Table 3. Correlations between numbers of online questions answered and scores on different groups of exam 2 questions. In 2012 through 2014, questions for exam 2 were drawn from three sources. For each exam 2 during those years, 13 to 15 questions were chosen by the author from the online study questions (= “Study questions”). Each year, an additional 11 to 13 questions that covered the same course material covered by the online study questions were chosen by the author from questions in the exam question database maintained by the Biology Program at the University of Minnesota (= “Questions on same material”). The final group of 13 to 16 questions was chosen each year by another faculty member, and covered material taught by that faculty member that was not covered by the online study questions (= “Questions on other material”). “All questions” refers to all of the 40 questions included on each exam 2. The correlations (Pearson product moment correlation coefficients, r) between the numbers of online questions answered by each student in preparation for exam 2 and the student’s scores on each of the three groups of exam 2 questions are indicated. There were an average of approximately 265 students per course section and two sections were taught in both 2013 and 2014 (data from sections taught in the same year were combined).

<table>
<thead>
<tr>
<th>Year</th>
<th>Study questions</th>
<th>Questions on same material</th>
<th>Questions on other material</th>
<th>All questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>0.36</td>
<td>0.22</td>
<td>0.11</td>
<td>0.28</td>
</tr>
<tr>
<td>2013</td>
<td>0.46</td>
<td>0.25</td>
<td>0.24</td>
<td>0.39</td>
</tr>
<tr>
<td>2014</td>
<td>0.41</td>
<td>0.31</td>
<td>0.28</td>
<td>0.39</td>
</tr>
<tr>
<td>2012-2014</td>
<td>0.41</td>
<td>0.27</td>
<td>0.21</td>
<td>0.36</td>
</tr>
</tbody>
</table>
Figure 1. Percentages of students answering different numbers of questions per lecture. The percentages of students that answered different numbers of study and quiz questions per lecture in preparation for exams 1 and 2 in 2012 and 2013 (sections 1 and 30) are indicated. There were an average of approximately 290 students per course section.
Figure 2. Actual versus expected partial exam scores. Some of the questions on each of the above exams were chosen from an exam question database maintained by the Biology Program at the University of Minnesota. Records are kept for each of these exam questions, indicating the percentages of students that answered each question correctly on each exam on which each question was used. Using this information, the average expected scores (based on the performance of students in course sections for which online study questions were not available) for the questions chosen from the Biology Program exam question bank are indicated by the black columns. The average actual scores (of students in course sections for which online study questions were available) for the same groups of questions are indicated by the light grey columns. The average actual and expected scores for all questions used for the first exams for all seven course sections combined are also indicated, as well as the average scores for exam 2 from all seven sections and for exams 1 and 2 combined for all seven sections. The questions analyzed were used a minimum of three times and an average of 24.8 times on exams administered to students in course sections for which online study questions were not available. The numbers of questions analyzed for each exam were 18 to 20 for exam 1 from each year and 10 to 12 for exam 2 from each year. Note that the same questions were used for exam 1 in 2012 and 2013. Also, both course sections taught in a particular year used the same exams. As a result, a total of 50 exam 1 and 39 exam 2 questions were analyzed for all seven course sections combined (Supplemental Table 1). There were an average of approximately 265 students per course section. A paired Student’s t-test was used to compare the expected and actual scores for the questions from the Biology Program exam question database for each of the indicated exams or groups of exams. \( P \) values are indicated as follows: * = < 0.05, ** = < 0.01 and *** = < 0.002.