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Use of practice tests with immediate feedback in an undergraduate molecular biology course

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Abstract

Multiple studies have shown that testing contributes to learning at all educational levels. In this observational classroom study, we report the use of a learning tool developed for a Genetics and Molecular Biology course at the college level. An interactive set of practice exams that included 136 multiple choice questions (MCQ) or matching queries was developed in the open-source Moodle platform. All MCQ questions contained four answer choices and configured for immediate feedback upon answering. Feedback consisted of providing the right answer and a short explanation of the learning objective examined. The interactive material was tested and refined for several semesters. Usefulness of this tool was assessed in two distinct settings: (1) during a face-to-face semester (Fall 2019) by comparing the grades in a final departmental exam between students who used the tool and those who did not, and (2) during an online semester (Fall 2020) by analyzing the grades in the first and last attempts on study sessions and students' performance in monthly exams. We found that when solving practice tests, students obtained a significantly higher scores in the last attempt compared with their first attempt, and that students who used the material performed better than those who did not. In all cases, answering the practice exams was optional, but students made full use of them preferentially during the online semester. This classroom research exemplifies the documented effectiveness of practice tests enhanced with feedback in biological sciences education through an open-source learning platform.

KEYWORDS

molecular biology, retrieval practice, test-enhanced learning, undergraduate education

1 | INTRODUCTION

Multiple studies have provided evidence that active learning can improve undergraduate science, technology, engineering, and mathematics education and multiple strategies have shown to be effective for increasing student learning.[1,2] In Biological Sciences, the operational definition of active learning given is: "... an interactive and engaging process that may be implemented through the employment of strategies that involve metacognition,

discussion, group work, formative assessment, practicing core competencies, live-action visuals, conceptual class design, worksheets, or games."[3] Among the active learning strategies, formative assessment, can be implemented as low-stakes or no-stakes exams to assess students' progression, but also as a learning tool.[4]

Students employ a wide range of studying and learning approaches, mostly based on previous experience and familiarity, and lack metacognitive awareness of the most effective strategies. In a survey applied to 177 college students, they were asked to list and rank strategies they used when studying; 11 different strategies were listed but only 10.7% of the students recognized practice recall (self-testing) as a strategy employed. Moreover, such strategy was ranked as #1 by only 1.1% of the surveyed students, while rereading the notes or textbook received the highest rank by most 54.8% of students.[5]

Self-testing exercises and solving practice tests provided by the teacher are part of retrieval practice which can enhance learning and these benefits appear to extend to the classroom.[4,6] Retrieval practice focuses on recalling the information from students, and evidence have shown that this strategy is more effective in promoting learning than elaborative studying, such as multiple reading sessions or assembling concept maps.[7–9] Retrieval practice can be implemented in the classroom, mainly through frequent testing and quizzing, or as a home assignment through solving questionaries or practice tests.[10,11]

Retrieval practice questionnaires or practice exams can be constructed with multiple-choice or short-answer questions, as both formats have shown its usefulness.[12] However, multiple-choice exams are widely used, both as formative and summative assessments and research has shown that they enhance learning, but also might lead to the acquisition of false knowledge.[8] A simple approach to minimize the detrimental effect poised by multiple-choice tests in learning is to provide feedback after testing. Students might correct their errors upon receiving feedback and such implementation results in improved performance on a subsequent test as compared when no feedback is provided.[13,14] Feedback can range from pointing to the correct response to a more detailed format indicating why each distractor is not the correct response or a general review of the topic tested in each question.[10,15,16]

The question addressed in this study was to validate whether solving practice tests online with immediate feedback is an effective tool in a Molecular Biology course. In this project, an interactive set of eight practice exams that included 136 multiple-choice and matching questions was developed in the Moodle platform. The practice exams were configured for immediate feedback upon answering and it consisted of providing the right answer and a short explanation of the learning objective examined.

2 | MATERIALS AND METHODS

2.1 | Course materials

Genetics and Molecular Biology is a mandatory course for Biochemistry and Pharmacy majors in their junior year at the School of Chemistry, UNAM. Class meets two times per week for 2 h, with a total duration of 64 h. The breadth of the syllabus comprises eight module units from Mendelian Genetics to Molecular Biology, gene expression regulation and principles of Genetic Engineering. Table S1 depicts the eight units and the main topics revised in each one of them. Faculty involved in teaching this course developed a comprehensive list of learning objectives according to Bloom's taxonomy, where most of them fall in the knowledge, comprehension, and application categories.[17,18]

2.2 | Practice tests in the Moodle platform

Moodle (https://moodle.org) is an open-source learning management system employed world-wide with a group of features, grouped as activities, that allows students to interact with other students and the teacher. The Quiz or Exam activity provides 11 types of question formats (True/False, Multiple-choice, Matching, Embedded answer, and so forth) and the exam could be configured to provide feedback if it used as a formative assessment tool or without feedback if it is employed for summative assessment.

Throughout the development of this project, various versions of the Moodle platform were employed and managed by the Informatics Department at the School of Chemistry (Facultad de Química, UNAM). The current version employed is 3.6.10. Multiple-choice questions with four options (one correct answer plus three distractors) and matching-columns questions were generated following the learning objectives for each unit in the Genetics and Molecular Biology syllabus. Question validation was performed by: (1) Review by two faculty member who teach other groups of the same course, and (2) Using Facility Index and Discrimination Index, two statistics provided by Moodle analysis of the tests. Such review facilitated the editing of questions and answer options that were employed since.

Table S1 shows the main topics in each unit and the number of items in each practice test. The questionaries for each unit were configured as an exam activity in Moodle with immediate feedback upon answering each question. Figure 1a shows an example of a multiple-

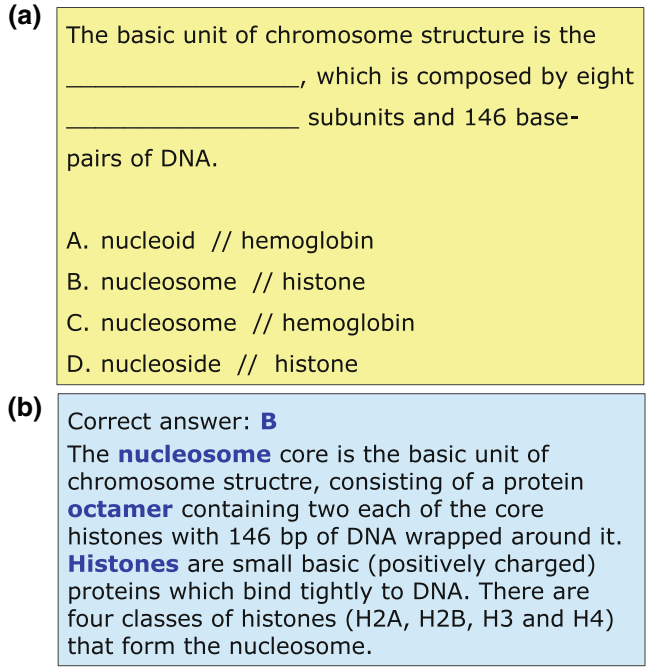

FIGURE 1 Example of a multiple-choice question on chromatin structure in a practice test. (a) the question requires to complete with the two correct answers; upon answering, immediate feedback is provided indicating whether the correct choice was selected or not and (b) a short paragraph with a description of the examined learning objective is provided.

choice question and the immediate feedback given (Figure 1b). Figure 2a shows a screenshot of a matching-columns question and the feedback is presented in Figure 2b,c. The full material is written in Spanish and the examples were translated to English for the purpose of this report.

2.3 | Participants and performance analysis

The learning material was assessed independently in two distinct settings: First, during the 2019 Fall semester (face-to-face), the students of all five course sections ($n = 171$) had access to the interactive material and performance in a final departmental exam was compared between students who fully employed the tool, to those who partially access it or did not employed at all. Second, for the 2020 Fall semester, which was fully online, student ($n = 79$) performance for one of the course sections was analyzed through four monthly exams.

Students were allowed to complete each practice test without limiting the number of attempts, and with the recommendation of spacing the responses at least 24 h so a study session could take place. Because the

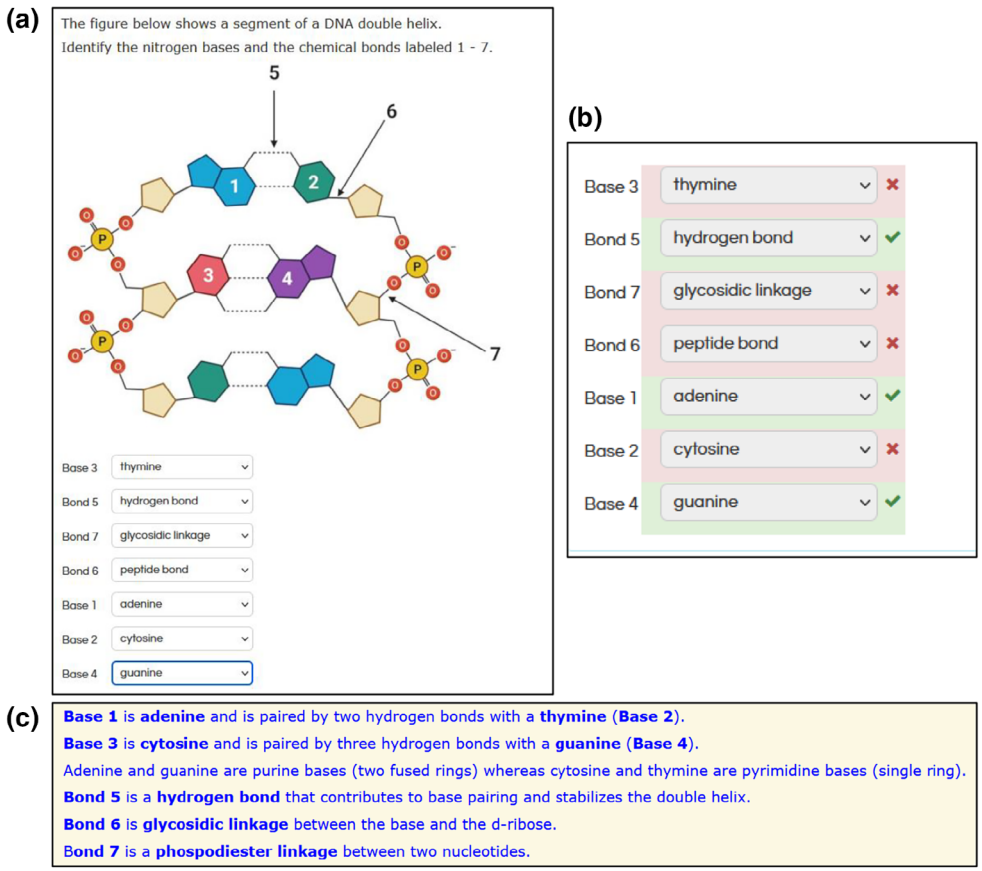

FIGURE 2 Screenshot of a matching-columns question on DNA structure in a practice test. (a,b) The question requires to identify the four bases and chemical bonds in DNA structure. (c) Feedback is provided by pointing out the correct and incorrect answers and a brief paragraph with a description of the examined learning objective. The DNA structure was created with biorender (www.biorender.com).

questionnaires were configured as exams in Moodle, all attempts and grades were registered so the data were analyzed at the end of the semester to assess students' performance. To test if solving two or practice tests was associated with improvement on monthly exams, we carried out a two-sample independent *t*-test. Students were divided in two groups: those who partially completed the assignment (and did not answer the two practice tests at least twice each) and those who solved the two practice tests at least twice. Here we report the data from a Fall Semester 2019 (face-to-face) and a Fall Semester 2020 (fully online). Student feedback was obtained from the Moodle platform and from a Google form configured as anonymous response.

2.4 | Statistical analysis

Data was analyzed using the paired-sample *t* test for comparison between first and last attempts for each unit. The nonparametric Wilcoxon rank sum test was employed to compare median values because of the differences in sample size (number of students in each group). In these cases, *z* scores were calculated to compare groups. The Spearman rank correlation coefficient was calculated to associate the use of practice tests with exam score. Microsoft Excel and Statistix software packages were employed for all calculations.

2.5 | Institutional approval and consent

The interactive material and its evaluation in classroom setting were approved by the Evaluation Committee of the Program on Improvement and Innovation in Teaching (PAPIME, Programa de Apoyo a Proyectos para Innovar y Mejorar la Educación), sponsored by DGAPA-UNAM. Policies in this program encourages the assessment of didactic material in classroom settings; all data is anonymous as no student identity is revealed. Anonymous student feedback has been collected through several semesters by completing Moodle and Google forms questionnaires.

3 | RESULTS

The current version of the practice test was uploaded in spring 2016. Data have been gathered through Moodle activity properties, mainly the number of practice tests answered by each student and their grades. Data from two semesters are presented here to show how this material has been employed in both formats, face-to-face and online. Usefulness of this tool was assessed by (1) comparing grades between first and last attempts during study sessions; (2) comparing performance in monthly exams during an online semester; and (3) contrasting performance in a global departmental exam during a face-to-face semester.

3.1 | Retrieval practice produces higher scores upon answering practice tests for all units

Practice tests were configured in Moodle as exam activity with unlimited attempts. The activity was not mandatory and throughout the semester, each test was solved 1.85 times per student on average, so data for the 2020 Fall semester was gathered to compare scores between the first and last attempts for those students who at least had two grades. Figure 3 shows that solving the practice tests pro-

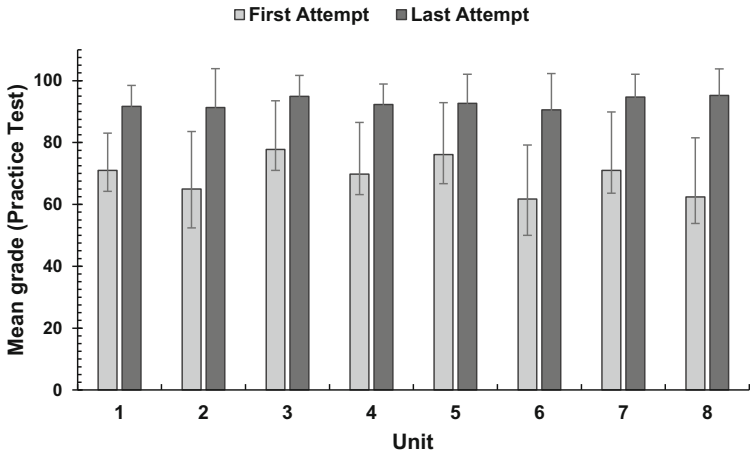

FIGURE 3 Mean scores obtained in practice tests of eight units in first and last attempts during the 2020 fall semester. Data for students who answered at least twice a practice test of each unit; the number of students ranged from 38 to 59 (unit 1, $n = 43$; unit 2, $n = 38$; unit 3, $n = 59$, unit 4, $n = 54$; unit 5, $n = 47$; unit 6, $n = 45$; unit 7, $n = 42$; unit 8, $n = 41$). The bar graph shows average ± SD; for all units, significant mean differences between the first and last attempts were recorded (student *t*-test; $p < 0.01$).

duced higher scores in the second or last attempt for all topic units, despite the complexity of each unit. Average student gain values ($\bar{x}$ last attempt $-$ $\bar{x}$ first attempt) for each topic unit ranged from 1.66 (Unit 5) to 3.28 (Unit 8), with a global average of 2.36. This analysis was limited to those students who solved each unit questionnaire at least twice, and the number ranged from 38 to 59 students in a population of a high-enrollment section of 79 students.

Although a general recommendation was given to space the attempts, most students who employed the learning material, crammed, and answered the two practice tests the day before the monthly exam.

3.2 | Benefits of practice test with feedback on monthly exams performance

Evaluation for this course during the semester is achieved through four monthly exams, where each exam covers two topic units. Monthly exams consisted of multiple-choice questions that were different from those in the practice tests, but that correspond to the main learning objectives. For this analysis, students were divided in two groups: those who partially completed the assignment and did not answer the two practice tests at least twice each (Group A) and those who solved the two practice tests at least twice (Group B). The box plot in Figure 4 shows minimum, 25th percentile, median, 75th percentile, and maximum grades of each group in the four monthly exams. In all cases, the group who used the practice test tool outperformed those who did not use it or used in a limited way. Effect size (θ) values were 0.618, 0.847, 0.974, and 0.789 for monthly exams 1, 2, 3, and 4, respectively. This type of analysis might be biased toward students with better study habits (Group A), but for all exams, there are individuals in Group A who achieved high scores as well but did not employ this tool. Moreover, the data also detected individuals in Group B with poor performance. Because the use of the study tool was not mandatory, differences in group size reflect student's choice as the majority found it helpful.

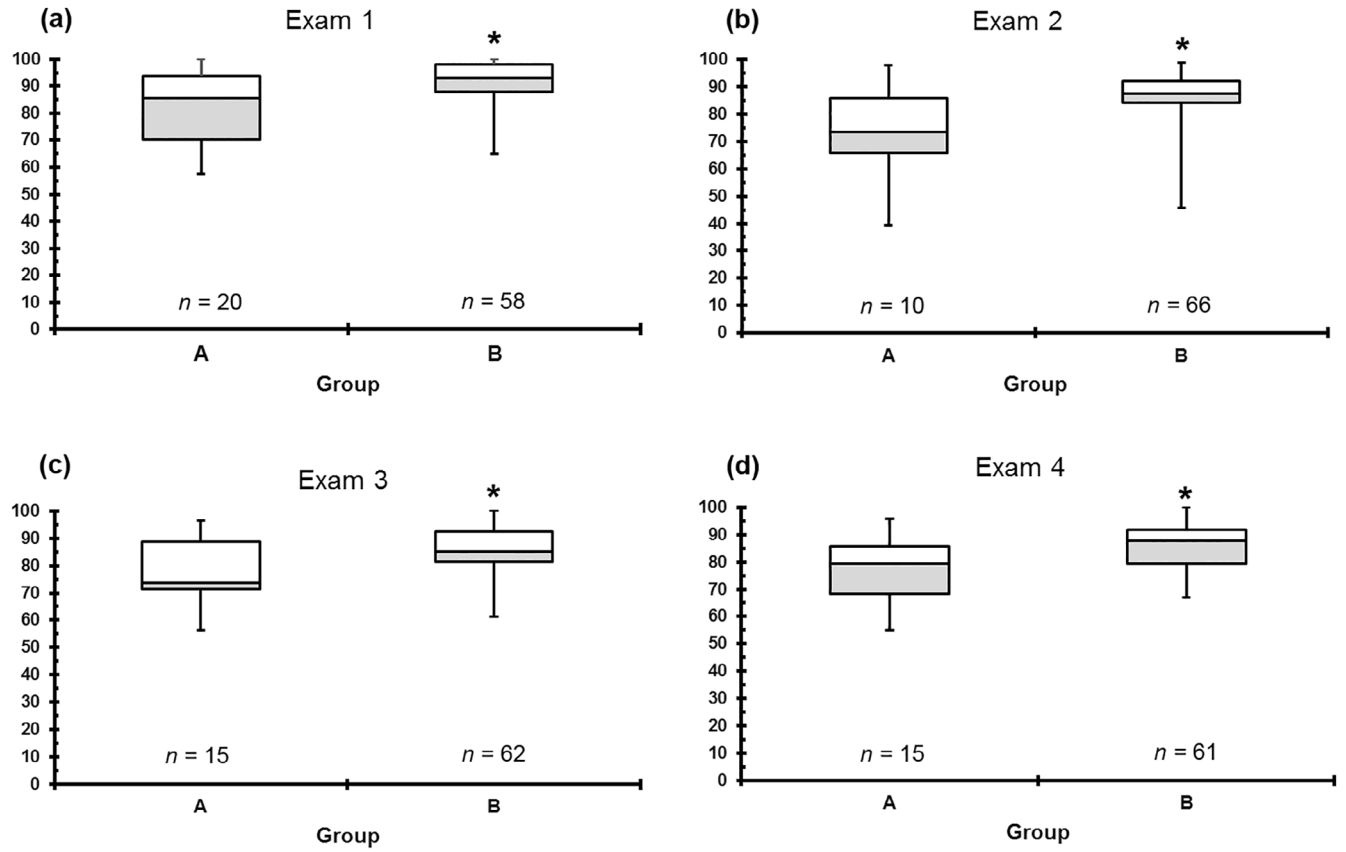

FIGURE 4 Student performance in four monthly exams during the fall semester 2020. For each panel, group a included students who did not answered the practice tests for the monthly period or only answered one of them, and group B those who solved both practice tests at least twice. In each case, median comparison was performed through the nonparametric Wilcoxon rank sum test and found significant differences (*) between group a and group B: For exam 1 (z score = 2.49; $p = 0.00639$), for exam 2 (z score = 2.60; $p = 0.00466$), for exam 3 (z score = 2.49; $p = 0.00639$), and for exam 4 (z score = 2.94; $p = 0.00164$). The number of students (n) in each group is indicated.

3.3 | Benefits of practice test with feedback on a global departmental exam

Each semester, a final global exam is applied to all groups taking this course. For the 2019 Fall Semester, the Moodle material was accessible to all students in the five groups sections, each one taught by a different faculty member. For this analysis, students were clustered in three groups: Group A contained those students ($n = 104$) who did not employ the study material; Group B included those students ($n = 29$) who partially used the study material as they solved one to four practice tests (12.5%–50%); and Group C contained those students ($n = 38$) who fully employed the study material as they solved more than 80% of the practice tests, at least once. Figure 5a shows that Group C significantly outperformed the other two groups (Group C median = 7.40; Group A & B median = 6.46), and the highest score for all the examinees was achieved in Group C. Then, we analyzed whether an association could be established between the performance in the departmental exam and practice tests for students in Group C, so the average score in all practice tests was plotted versus the grade in the departmental exam. Figure 5b shows that a significant correlation ($r = 0.674$; $p < 0.01$) could be established between these two variables.

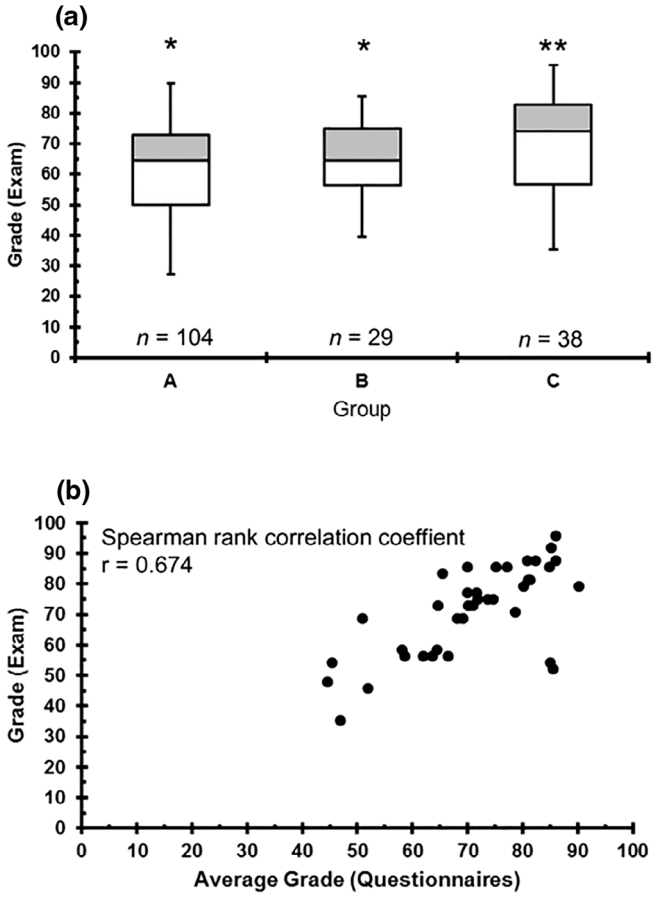

FIGURE 5 Student performance in a departmental final exam during the fall semester 2019. (a) Group a contained those students ($n = 104$) who did not employ the study material; group B included those students ($n = 29$) who partially used the study material (12.5%–50%); and group C contained those students ($n = 38$) who solved more than 80% of the practice tests, at least once. Median comparison was performed through the nonparametric Wilcoxon rank sum test and found significant differences (**z score = 2.17; $p = 0.0150$) between group C and group A, and between group C and group B. Not statistically difference was detected between group a and group B (*z score = 0.42; $p = 0.337$). (b) Correlation analysis between the performance in the departmental exam and practice-test solving for students in group C. the spearman rank correlation coefficient was calculated ($r = 0.674$; df = 36; $p < 0.01$). The number of students (n) in each group is indicated.

4 | DISCUSSION

We found that retrieval practice administered through practice tests with immediate feedback resulted in better student performance assessed in both, a face-to-face and an online semester. The syllabus of our course is quite complex as it includes classical Genetics and Molecular Biology. Although retrieval practice is now widely accepted as a strategy to enhance learning in various subject areas, few experimental studies in an actual educational setting are available at the college-level in advanced Biological Sciences. Most studies on this area have been devoted to Introductory Biology, Psychology, or Medical Sciences courses but few on biochemical or pharmaceutical areas belonging to this type of majors. Application of quizzes each class, even without feedback, enhanced performance compared with the no-activity group in a Statistics course.[19] In addition, Daniel & Broida[20] found that both strategies tested (web-based quiz and in-class quiz) were associated with better results in two examinations than the control and no quiz group in a liberal arts course. Because implementing retrieval practice exercises in class might restrict other class activities, such employment should be carefully planned to achieve the desired learning goals.[21] In this sense, retrieval practice applied as exams could be implemented online as study tools for students to solve them outside class hours. In this project, we found that most students who employed the tool answered each practice tests at least twice during the online semester.

The testing effect refers to the phenomenon that testing improves long-term retention of the material tested and restudying or solving a multiple choice questions (MCQ) test contributes to the recalling of the material, even 1 month after the initial learning session.[22] In

certain educational settings, the testing effect can be greatly enhanced by adequate feedback.[23] In an advanced Psychology course McDaniel et al.[24] found that weekly quizzes in MCQ or short answer questions with feedback were superior in improving performance than additional reading of the material. Within the two testing strategies, the short answer quizzes yielded more robust gains than MCQ. In another setting, medical resident students participated in a teaching session and performed studying and testing at intervals of 2 weeks; feedback was provided after each test, and a final test administered 6 months after the initial lecture. The authors found that repeated testing with feedback results in enhanced long-term retention, and such strategy was superior to repeated, spaced study.[7] Retrieval practice strategies can be performed with flexibility, both in the type of instrument employed and timing. One format, spaced retrieval practice, allows to recall class material beyond the initial learning period.

Because MCQ generally contain one correct answer and three or four incorrect responses, its wide application during a course might have detrimental effects because they expose students to misinformation that can be preserved; even if the correct answer is selected, reading the lures might facilitate the persistence of the false statement.[25] However, this disadvantage can be minimized by providing timely and adequate feedback. The effects of feedback not only neutralize the negative effects of MCQ but increased retention and promotes optimal learning.[13,14] The type of feedback varies and can go from simply stating whether the selected choice is correct or not, to pointing out the correct response, or even further to provide an explanation. Moreover, the timing of feedback seems to also have an effect as delayed feedback results in improved final performance than immediate feedback; however, this delay could also cause that students lose interest and miss it.[26] In our project, we configured the Moodle test activity to provide immediate feedback upon answering each question and the feedback comprised the correct answer as well as a short explanation to fulfill the learning objective. Because the students can answer each practice test at their own pace, without any time limit, this type of feedback seemed adequate. However, further research is necessary to determine the best timing for providing the feedback.

Multiple-choice tests are widely used as summative assessment tools to measure learning. In retrieval practice, MCQ are also employed to promote learning, so a valid question addressed in[27] is whether there is an alignment in the construction and usage of MCQ for these two contrasting goals. Overall, the author concluded that there is a broad agreement about the best practices for generating and applying MCQ test, despite the purpose. Most of the common best practices recommended were followed in the creation of the items used in our learning project. Mainly, we avoided complex item types and answering procedures and never employed "None-of-the Above" and "All-of-the-Above" as response options. All items were generated to fulfill a given learning objective. Matching questions were more complex as more choices were included and most of them comprised a figure.

Most studies showing the benefits of retrieval practice in enhancing learning have employed MCQ, with or without feedback, as practice exams, quizzes or questionnaires. Other type of questions, such as fill-in-the-gap format can be employed as well. Students who solved this type of test after a class presentation performed better than the control group, which was only exposed to the presentation.[28] Moreover, in[29] also employed the Moodle platform to evaluate how answering online questions leads to improved exam scores in a General Biology course. This author employed exclusively multiple-choice questions with delayed feedback consisting of pointing out the correct response or a more specific explanation describing how to reach the correct answer. A real-life class setting showed that students who accessed the online study questions performed significantly better than students without access to the study material.

Although the terms "testing effect" and "retrieval practice" are frequently used as synonyms, Brame and Biel[4] make a notable distinction because of the connotations of the former and increased anxiety in students. In order to reach equivalencies with the cognitive sciences experiments, classroom experiences devoted to promoting test-enhanced learning should involve low-stakes or no-stakes formative assessment. In our project, the practice exams were tagged as homework, but no extra credit was given for answering them, nor any penalty was applied to those who did not solve them. Thus, the material could be considered as no-stake assessment.

As stated above, few studies on this subject course (Molecular Biology, Genetics, Biochemistry) have been carried out at the college level.[30] Most studies comprise mostly introductory Biology courses and our results are comparable to those reported in,[31] who found that solving online quizzes boosts students' competence during course examinations, which is reflected in exam scores as compared with those who did not solve the quizzes. In the cited study, although answering the quizzes was required, compliance declined throughout the semester. In our case, participation remained roughly constant throughout the 2020 Fall semester, above 75%. In this sense metacognitive abilities play a relevant role so students can take the best decision and focus their time and efforts on the best learning tools and strategies. A valid concern raised in[29] is whether the effort of generating this type of interactive material is worthy as students'

choices are highly unpredictable and might depend on specific circumstances and student guidance and motivation; in an introductory biology class, only 50% of the students completed the online quizzes available during the full course.[32] Corral et al.[33] explored this issue in an introductory psychology course in which only 88% of the online reviews provided were not completed, despite a clear benefit shown by higher exam scores for those who completed the task. In both studies, online material was presented in a read format or test format, and students more often chose the latter; moreover, the test format produced better results as a learning tool. In this sense, our observational study shows that during prepandemic face-to-face semester (Fall 2019), only 22% of the registered students fully employed the study material (Figure 5a), but approximately 80% of the registered students completed the practice tests at least twice upon switching to full online semester (Fall 2020; Figure 4). Such experience might influence students' metacognitive abilities as retrieval practice is underutilized as a learning method by most students.[5]

Multiple studies on cognitive psychology have shown the benefits of testing on learning, however, few studies have been performed in actual educational settings assessing the integral material of the course.[34] Observational studies such as this report has some limitations; in particular, the definition of student groups who solve the practice tests was entirely dependent on their choice. We observed a benefit for those who used retrieval practice, reflected as a superior performance on the monthly exams or the final exam. The question remains as to whether those who performed better, were the ones who chose to do the retrieval practice. With the data gathered in this study, the question cannot be unequivocally answered. However, exposure to the educational material could contribute to increase students' metacognition abilities and recognize self-testing and other retrieval practice strategies as useful for their learning.

To seize students' feedback on the usefulness of this learning tool, we performed a qualitative survey at the end of the 2020 Fall semester and found that 90.5% of the users rated the practice exams as extremely helpful for learning (score 5, in a scale 1–5), and 75% of students responded that the feedback provided on the practice tests contributed to reinforce learning. In general, students appreciate the study material as a useful learning tool and most suggestions on its improvement were centered on (1) increasing the number of questions in each practice test, (2) limit the time to answer each test so it might better mimic an actual exam, and (3) provide links to video animations in the feedback answers. Such ideas are considered for improvements.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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