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MILAGE LEARN+: A Mobile Learning App to Aid the Students in the Study of Organic Chemistry

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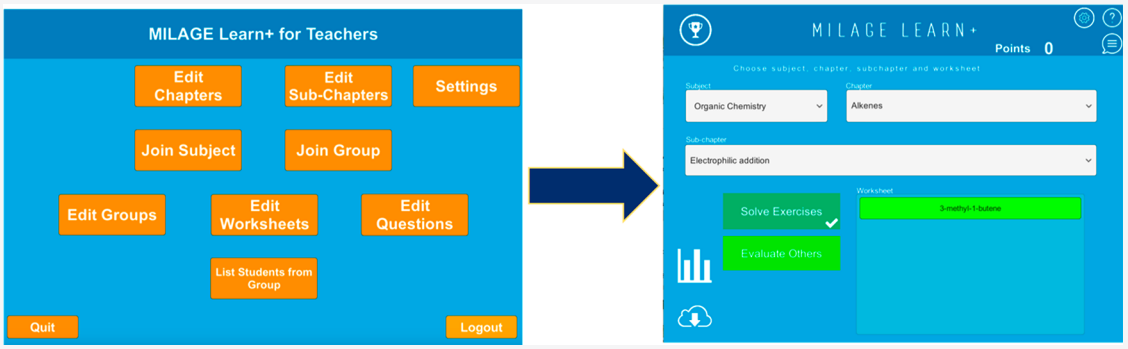

ABSTRACT: Interactive learning is one of the approaches that is very important to explore in higher education. Chemistry students own smartphones, laptops, and tablets and could use appropriate apps to complement traditional forms of learning. Here we introduce a new app, MILAGE LEARN+, which integrates several teaching strategies, such as mobile learning, autonomous learning, peer review, blended learning, and gamification. These strategies were evaluated by the student users through an electronic survey form containing 15 statements with responses graded on a Likert-type scale. Students rate the usage of novel teaching/learning strategies in the MILAGE LEARN+ app as something very positive. There is a positive correlation between the relative grades obtained using MILAGE LEARN+ and the final exam grades. Thus, in this experience, students with better results in MILAGE LEARN+ also had better results in the final exam.

KEYWORDS: *Organic Chemistry, Second-Year Undergraduate, Computer-Based Learning, Multimedia-Based Learning, Testing/Assessment*

INTRODUCTION

Organic chemistry presents difficulties for many students, who believe it is difficult to understand and overloaded with seemingly irrelevant information. Thus, students need to work hard for academic success. Traditional learning involves the use of textbooks and lectures, while interactive learning is one of the novel approaches explored in the classroom,[1,2] with students and teachers using smartphones, laptops, or tablets as working tools. There are a number of applications (apps) available for interactive learning of organic chemistry.[3−6] The majority of these applications are functional, for example, visualizing and processing NMR or MS spectra[7,8] and accessing journals and online databases.[9] Games constitute a different type of applications.[10] These games use the same content as students see in their lectures and thus reinforce the ideas and let students put into practice the concepts to which they have already been exposed. Chairs,[4] Chirality-2,[6] and Nomenclature Bets[5] are good examples of this approach.

Presently, we report our experience in the usage of MILAGE LEARN+,[11−15] a mobile application for teaching organic chemistry. This app was used to supplement classroom teaching in the organic chemistry course for the undergraduate students studying Marine Biology at the University of the Algarve. In the first year of its usage, we explored MILAGE LEARN+ in teaching the reaction mechanisms using curved-arrow notation for the description of the bond-breaking and bond-forming,[16−18] and during the two subsequent years, it was used in all kinds of organic chemistry exercises.

As an application, MILAGE enables mobile devices as a teaching platform[19,20] and has the benefits of a mobile education.[11] It integrates several teaching strategies, within a single platform, such as autonomous learning,[21] self-assessment and peer review,[22] blended learning,[23−25] and gaming.[26−28]

MILAGE LEARN+ is available worldwide free of charge on both the Apple (iOS) and Android (Google Play) operating

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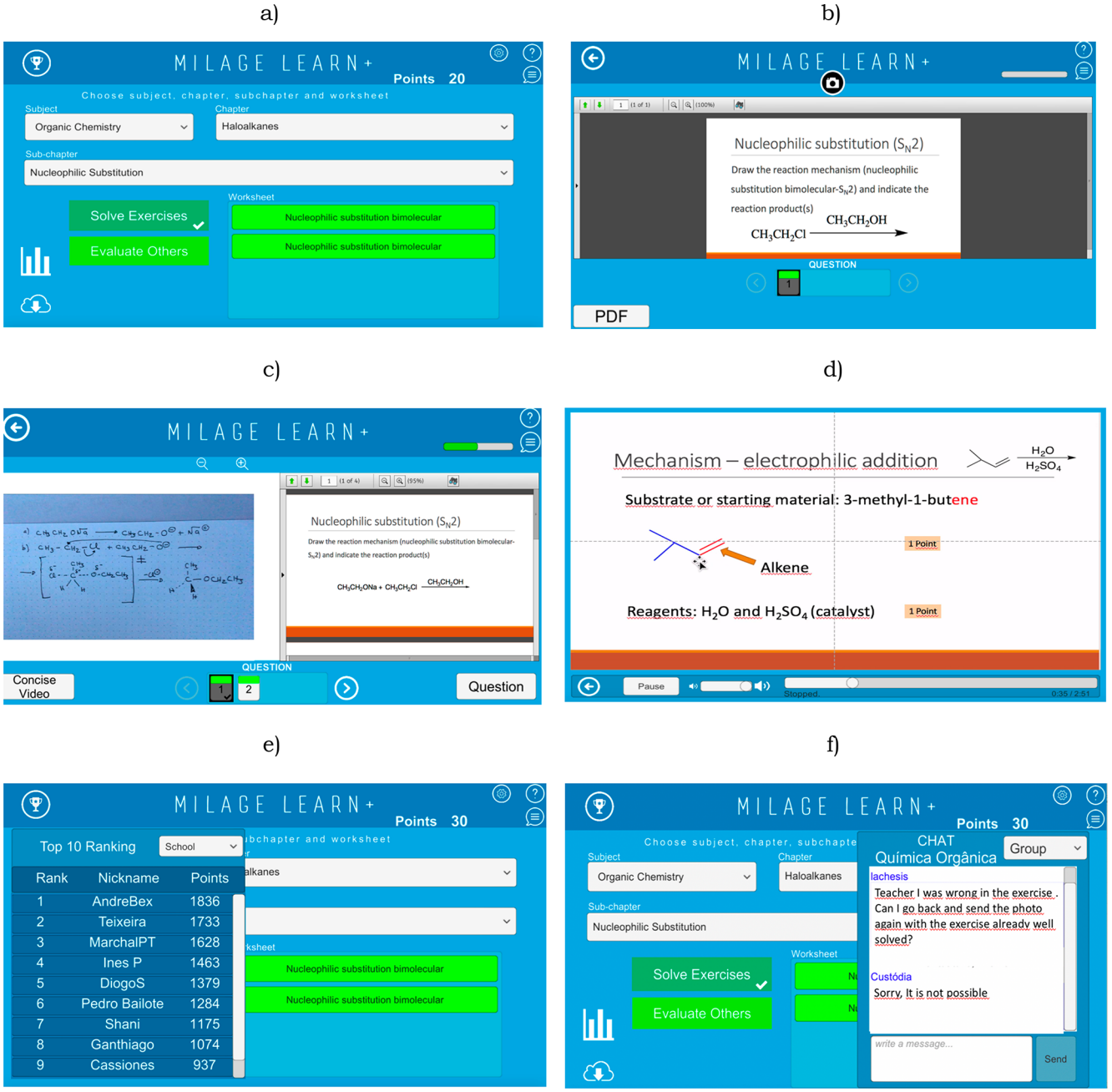

Figure 1. Screens of the app: (a) main screen, (b) example of a question, (c) student submitting their answer, (d) video lecture player overview, (e) student's point ranking, (f) chat between teacher and student.

systems. This application was developed using the Unity Framework,[12] Django 1.7,[13] and Postgres database management system.[14] More details on MILAGE design and programming are provided in the Supporting Information.

The purpose of this work was to answer three main questions about the app: if MILAGE LEARN+ improves students' motivation to learn organic chemistry, whether it facilitates the learning process, and whether it generally improves students' outcomes. In the case of positive results, another goal was to identify the contribution of each strategy to those results.

METHODS

MILAGE LEARN+ employs the format of an exercise notebook structured into chapters, subchapters, and worksheets (Figure 1a). Since it is the teacher who formulates the questions, the topics covered depend on teacher's choice. In this study, the topics covered included functional groups, structure classification, isomers, conformations, chiral carbon atoms, synthesis, and reactivity of compounds with different functional groups. Considering the number of steps necessary to solve the exercise and their own experience in the classroom, the teacher classified the exercises into beginner, intermediate, and advanced, and the students could choose the level they wanted to do. As aforementioned in the Introduction section, the application integrates several teaching strategies that were all implemented in this work and will be discussed in the following sections.

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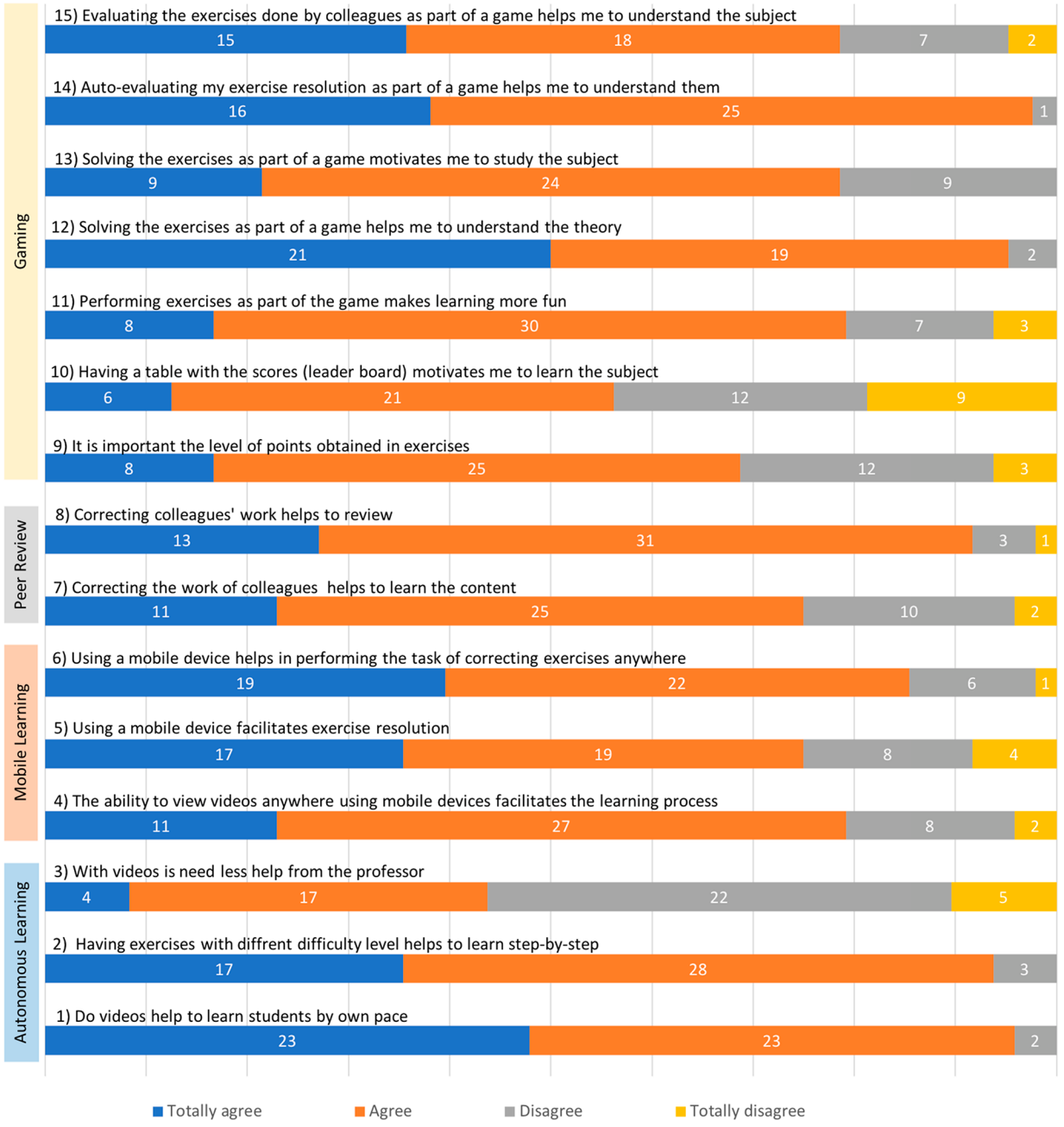

Figure 2. Survey results showing the distribution of Likert scores for the evaluators' responses (N = 48) for each of the survey statements.

Autonomous Learning

As illustrated in Figure 1a, each worksheet has a specified difficulty level represented by color, with green, yellow, and red representing beginner, intermediate, and advanced levels. By choosing the degree of difficulty according to their skills, students can learn at their own pace. Each worksheet includes an exercise, which is elaborated by the teacher (Figure 1b). Students solve the exercises using a pencil and a paper. Having finished, the student uses the camera icon on top of the question, takes a photo, and submits the solved exercise; only afterward, he has the opportunity to see the correct solution. Figure 1c shows what the student sees at this point; the left part of the screen shows the student's answer, while the right part shows the correct solution, with the grading instructions for self-assessment. There is a white button, in the bottom left corner of the screen, showing a video of the resolution produced by the teacher, which aids the student in understanding the correct solution of the exercise (Figure 1d). The students may only see the solution of the exercise and the video after they have already submitted their own answer. This procedure promotes autonomous work.

Using this approach, low-achieving students who struggle to learn the material in the classroom may repeatedly watch the video and the correct solution of the exercise and take as much time as they may need to understand the subject.[15]

Top-performing students can have access to more complex exercises, which receives additional motivation. In this way, the platform accommodates students with different levels of learning skills and achievement.

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Peer Review

The peer review feature of the MILAGE LEARN+ app allows students to learn from each other and consolidate their own knowledge. After submitting their own answers to the respective worksheet(s), students get an opportunity to see the correct solution of the exercise and its grading criteria. Using this information, the students may do self-assessment and have an opportunity to evaluate one of their colleagues, selected automatically by the app. Peer evaluation doubles the score of the evaluator on the respective exercise. Reviewing the content to grade peers' work requires the ability to identify the key steps in solving the exercise and providing for better systematization of knowledge in the long term memory. Peer review has also been acknowledged as a successful strategy of collaborative learning.

Gamification

MILAGE LEARN+ includes some gamification features where students are like players and the goal is to solve the organic chemistry problems proposed by the teacher. The student encompasses the following steps:

(a) Choose the exercise
(b) Solve it
(c) Take a photo of the solution
(d) See the resolution video and read the grading instructions
(e) Self-assess own resolution, attributing grades according to the instructions
(f) Evaluate a colleague's resolution, attributing grades according to the instructions

Students are ranked by the total score obtained through the self-assessment and peer review activities. Figure 1e shows leader charts at the school level. However, it is also possible to see the charts at national or global levels.

Mobile and Blended Learning

The mobile application keeps students connected not only with the study materials but also with the teacher through the chat functionality (Figure 1f) and enables them to practice more organic chemistry exercises outside of the classroom. Mobility enables the implementation of a blended learning approach, which supplements the theoretical lectures and allows review of the contents through the resolution of exercises and the explanatory videos of this resolution.

Target Population, Data Collection, and Analysis

The target population of the study was students enrolled into the organic chemistry course for the Bachelor degree in Marine Biology. The teacher explained the program topics by an oral presentation using a whiteboard and/or projected slides; then, the students were challenged to solve exercises in MILAGE LEARN+. After solving all of the exercises made available in the app, the student users were asked to give feedback through an electronic survey form containing 15 statements with responses graded on a Likert-type scale (Figure 2). The questions were primarily intended to assess whether the use of the MILAGE application had motivated studying organic chemistry and whether the process of learning the contents of this discipline had been facilitated. Second, the survey form aimed to assess students' perception of the different learning strategies used in the application.

Creswell[29] recommends relating the research questions to the survey items in order to better convey the role of each item. Table 1 illustrates the relationship between the research questions defined for the present work (first column) and the statements included in the electronic survey (second column). Since the goal was also to identify the strategy contribution to the results, a third column was included.

Table 1. Relationship between Research Questions, Survey Statements, and Teaching Strategies Implemented in the MILAGE LEARN+ App

Research Question	Survey Statement #	Teaching Strategy
"Does the app improve students' motivation to study?"	9, 10, 11, 13	Gaming features
"Does the app facilitate the learning process?"	12, 14	Gaming features
	7, 8	Peer review
	4, 5, 6	Autonomous learning
	1, 2, 3	Mobile learning

To the third research question, *"Does the application generally improve students' outcomes?"* was answered using descriptive statistics with box plots, graphics, and inferential statistics with *t*-student tests (*t*-tests). *T*-tests were selected due to the numeric nature of data (grades) and the small sample size.

RESULTS AND DISCUSSION

The total number of students who used MILAGE LEARN+ in the study of organic chemistry was 53, of which only 48 responded to their assessment questionnaire. Figure 2 shows the results obtained. The survey statements scored from 21 to 46 positive opinions (48 respondents in total). The positive opinions included "agree totally" and "agree" categories. Therefore, we obtained the following results with good confidence levels:

- **Autonomous learning was evaluated by 48 students:** 46 students think that videos help for learning at their own pace, and 45 think that having exercises with different difficulty levels helps for learning step by step. However, only 21 students believe videos may substitute for live teaching.
- **Mobile learning was evaluated by 48 students:** 38, 36, and 41 students, respectively, think that mobile devices facilitate learning by letting them watch videos, solve exercises, and grade exercises, anywhere and anytime.
- **Peer review was evaluated by 48 students:** 36 students agree that peer grading helps in learning the study matter, and 44 agree that it also helps in reviewing the study matter.
- **Gaming features were evaluated by 42 students:** The students evaluated the level of importance of scores and leaderboards. They also evaluated whether exercises become more attractive in a game, help them understand the material, and motivate them to study and finally the usefulness of self-assessment and peer grading. The opinions were mostly positive with a maximum of 47 positive responses, in a universe of 48, in the autoevaluating question (question 14).

The results obtained suggest that gamification features of MILAGE LEARN+ do improve students' motivation and give a positive answer to the first research question. Regarding the remaining strategies, which were related to the second research question, the facilitation of the student learning process, the results also indicate a positive answer.

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Table 2. Students' Achievements Obtained in MILAGE LEARN+ Exercises vs Final Exam Grades

Students Earning Final Exam Grades in These Categories, %		Final Exam Grades[a]			
		Below 50%	Between 50 and 75%	Above 75%	Total
MILAGE LEARN+ achievement levels[b]	BOTTOM[c]	55	39	6	100
	MIDDLE[c]	18	55	27	100
	TOP[c]	0	50	50	100

[a]The total number of students taking the final exam was 84 (N total). [b]The number of students who used MILAGE LEARN+ exercises was 53 (N_{ML}). The number of students who never used MILAGE LEARN+ was 31. [c]Achievements in MILAGE LEARN+ below 50% were classified as BOTTOM (N_{ML} = 31), between 50 and 75% were classified as MIDDLE (N_{ML} = 14), and exceeding 75% were classified as TOP (N_{ML} = 8).

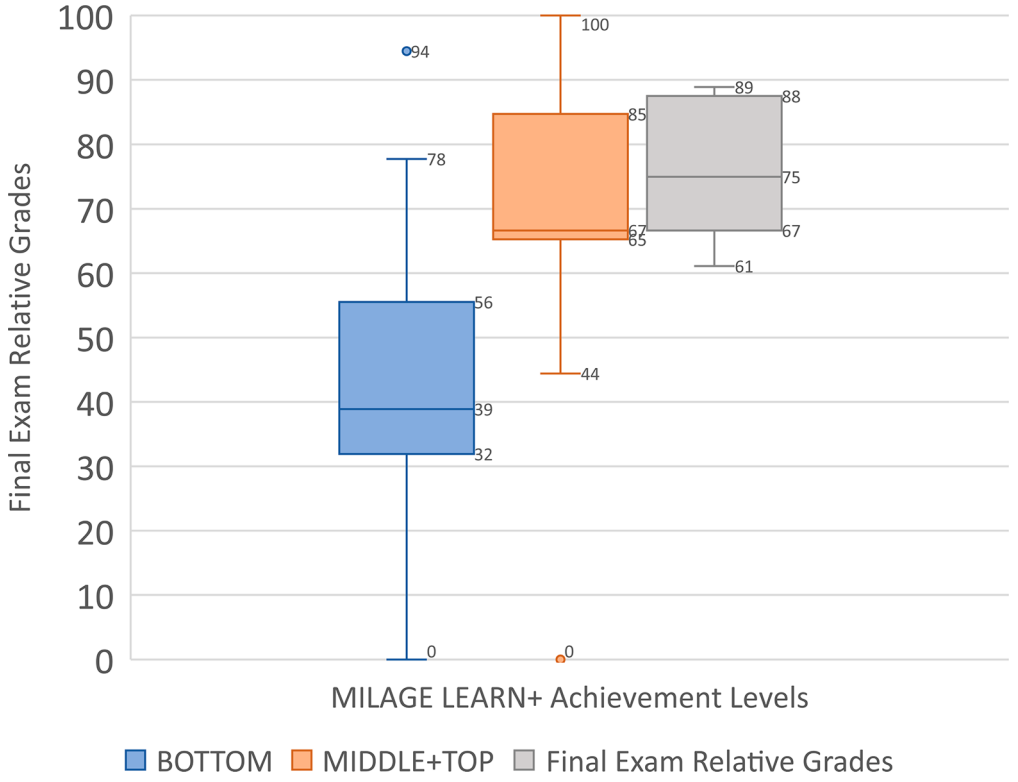

Figure 3. Box plot of the final exam grades grouped according to the MILAGE LEARN+ level of achievement.

In order to answer the third research question, the effectiveness in terms of students' learning outcomes, the students' achievements obtained in MILAGE LEARN+ exercises were compared with the final exam grades. The latter were the most objective learning criteria available in the course. The comparison not only included the 53 students who used MILAGE LEARN+ but all of the 84 students who took the final exam. Thus, 53 students were the experimental group and 31 students constitute the control group for evaluating the MILAGE LEARN+ effectiveness in exams. The results are listed in Table 2. Since the scales used in grading MILAGE LEARN+ exercises and the final exam were different, Table 2 reports relative grades in terms of percentage of the maximum grade. The students who never used MILAGE LEARN+ at all were graded with 0 points for the app. The students were classified into three groups shown in Table 2, according to their overall achievement level in MILAGE LEARN+ exercises: BOTTOM (students with the relative grades below 50%), MIDDLE (students with the relative grades between 50 and 75%), and TOP (students with the relative grades exceeding 75%).

The results of Table 2 show that only 6% of MILAGE LEARN+ BOTTOM achievers had 75% or more of their final exam grade. Notice also the strong correlation between the MILAGE LEARN+ MIDDLE achievement group and final exam grades: the majority of these students (55%) had grades between 50 and 74% in the final exam. These results also show that a significant majority (82%) of the MIDDLE achieving students have passed in the final exam, scoring over 50%. This result is further improved in the TOP achieving group, since 100% of the students in this group also passed in the final exam.

The apparent correlation in Table 2 between MILAGE LEARN+ grades and final exam grades can be better appreciated in the box plot of Figure 3, which shows the final exam grade minimum values, first quartile, median, third quartile, and maximum values, for the three MILAGE LEARN + achievement levels identified in Table 2. The graph illustrates that in general terms all of these statistical parameters improve in parallel to the MILAGE LEARN+ level of achievement. One notable exception observed is in the maximum grade of 100%, which was scored by a MIDDLE rather than a TOP achiever.

It is important to note that the final exam grades of two groups representing MILAGE LEARN+ MIDDLE and TOP achievers (depicted in orange and gray) are closer to each

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other than to the group of BOTTOM achievers (depicted in blue).

In order to determine if the previous results were statistically significant, TOP and MIDDLE achievers were grouped together and their average scores were compared with the scores of BOTTOM achievers through a *t*-test. In this test, the null hypothesis was that there was no difference between the scores of TOP and MIDDLE achievers and BOTTOM achievers. With the alternative hypothesis, the grades between the former group were higher than those of the latter. Before the *t*-test, an *F*-test was performed that determined the difference between the variances of both groups was statistically significant. Hence, an unpaired, one-tailed *t*-test for samples with different variances was performed, resulting in a *p*-value of 8.6×10^{-9}, which allows rejecting the null hypothesis with a confidence value of 0.9(9).

A second *t*-test was performed on individual student scores to compare the scores between individual student scores who used MILAGE and students who did not use MILAGE, where the null hypothesis was that there was no difference between the scores of both groups and the alternative hypothesis stated that the scores of the students who used MILAGE were higher than the scores of those who did not use it. These two groups were also subjected to an unpaired *t*-test (one-tailed) for samples with different variances. Analysis of the data revealed $p = 0.0241$, which allows rejecting the null hypothesis at a confidence level of 97.6%, thus also giving a very significant statistical result.

CONCLUDING REMARKS

Students rate the usage of novel teaching/learning strategies in the MILAGE LEARN+ application as something very positive. The presence of gaming features helps in understanding the study matter and motivates learning of different topics of organic chemistry. The possibility of peer review helps in reviewing the topics studied. All of the above is implemented in a mobile application, allowing its use anywhere and at any time, creating an almost permanent contact of the students with organic chemistry and allowing them to learn by solving exercises. It is nonetheless noteworthy that the student answers to a special question regarding the need for a teacher, even when using the MILAGE LEARN+ app, leading to the conclusion that students regard the app as a complement, rather than a replacement of the teacher.

In terms of improving students' learning, results show there is a positive correlation between the relative grades in MILAGE LEARN+ and the final exam grades. Thus, in this experience, students with better results in MILAGE LEARN+ also had better results in the final exam. However, further studies are required to test if these results can be replicated and, moreover, are statistically significant within a wider organic chemistry student population.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.0c01313.

Details of the content, development, programming, and design of the MILAGE LEARN+ app (PDF)

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Notes

The authors declare no competing financial interest.
MILAGE LEARN+ may be found at https://milage.io.

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