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ORIGINAL RESEARCH

Self-directed learning using computer simulations to study veterinary physiology: Comparing individual and collaborative learning approaches

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Abstract

Background: Advances in technology enable new educational resources geared towards situated learning and leading students to a more active education. Self-directed learning methodologies used along with simulators may represent a good alternative to traditional teaching methods. The aims of this study were to analyse veterinary students' degree of acceptance of self-directed learning using the PhysioEx simulator in physiology, and to evaluate self-directed learning outcomes using different approaches (individual vs. collaborative).

Methods: The study was carried out over three academic years. Students conducted different activities on the PhysioEx simulator, either in an individual or cooperative mode. Once the activities were finished, students voluntarily participated in an opinion survey regarding self-directed learning methodology. Finally, an evaluation of learning outcomes was made through Kahoot!.

Results: Students expressed a high degree of satisfaction with this self-directed learning method, with the combination of self-directed learning and gamification being scored the highest. Although students prefer the collaborative method, no differences in learning outcomes were found between the two learning approaches.

Conclusion: The self-directed learning method in combination with gamification increased the motivation of students, who obtained suitable learning outcomes regardless of whether an individual or collaborative approach was followed.

INTRODUCTION

Traditional teaching strategies, whereby the teacher leads the education of students, may have some limitations on learning because their passivity provides no opportunity for students to take the initiative to think and develop problem-solving skills.[1,2] The role of the lecturer in the 21st century is not merely to transfer information, but rather to facilitate the development of students' ability to apply basic knowledge and gain higher levels of understanding.[3] In this context, educational institutions must implement new strategies in their active teaching-learning methods, based on acquiring knowledge and developing abilities and skills, to prepare students for a professional career and to be competitive in the labour market.[4] Educators are tasked with developing and incorporating innovative educational materials and adopting more modern techniques that enhance traditional lectures.[5] Active learning has been seen to increase examination performance, further supporting the adoption of this teaching practice in the regular classroom.[6]

In some degree courses, such as veterinary education, it is necessary to complement the theoretical lessons with practical sessions, many of which require the use of live animals as a working tool. However, European society increasingly rejects the indiscriminate and/or unjustified use of animals, and legislation restricts the use of laboratory animals for teaching and for research purposes (Directive 2010/63/EU). The need to replace or reduce the use of animals has led to the implementation of pedagogical innovations,

which involves the creation of scenarios conducive to critical and reflective analysis in given situations. Such intentions help explain the gradual increasing trend of using computer simulations.[7–12] Computer simulation is considered as an effective method for imparting different skills,[13] since such learning allows the transfer of the real situation to prepared and predictable scenarios in a safe environment without risk. Simulators are commonly used to motivate students, enhance their understanding of complex topics, and foster critical and problem-solving skills.[14,15] Likewise, they provide the opportunity of training to repeatedly, increasing student autonomy by means of virtual environments.

The success of interactive teaching depends, among others, on communication between the teacher and students, on communication among the students in the form of collaborative learning,[3] and also on self-directed learning.[3,16] Such self-directed learning is a process that requires learners to explore their learning needs, frame learning goals, identify learning resources, use relevant learning strategies, and to evaluate learning outcomes and interactions of learners with each other.[17,18] In this scenario, there are two possible strategies in the self-directed learning process. In the first approach, the learner studies in an individual manner. In this respect, several studies emphasise that students may benefit from the versatility and command that this model gives, since it allows them to choose their learning objectives and make autonomous decisions.[19] However, individual study may lead to reduce motivation or frustration at having to focus attention during learning.[19] Despite this, many students choose individual over collaborative study because of the emergence of 'free riders' or interpersonal confrontations[13,20,21] that hinder learning. The other approach is collaborative learning, which is based on the interaction between individuals to achieve a common objective. In this system, each member's knowledge and skills are transferred to the other members through discussion and negotiation,[2] which, among other advantages, allows students to correct their misconceptions.[3] Exposure to different perspectives and backgrounds results in a greater quantity and quality of group idea generation[22] and promotes critical thinking. This collaborative model mimics the real-life interactions needed in health care.[23] Of course, collaborative learning is not a cure-all, and its effectiveness may depend on the type of learners, the task, the interactions with the learners and the environments.[24]

In this context, the change from traditional lectures to more interactive teaching activity, such as self-directed learning using a computer simulator, has to be addressed to allow the teacher to ascertain the best learning process. For this reason, the main objective of the present study was to analyse and interpret the application of a self-directed learning strategy as best practice in veterinary physiology using a computer simulator (PhysioEx). Two specific aims were: (1) to determine student perceptions of a self-directed learning strategy through a seven-point survey, and (2) to assess individual versus collaborative self-directed learning by analysing the time per activity and learning outcomes through gamification (defined as the 'use of game design elements in non-game contexts including education').[25,27] This gamification activity was performed through Kahoot! application.

METHODS

Academic setting

The study was undertaken at the University of Murcia, a public university in the south east of Spain. Specifically, the study was performed in the subject of 'Veterinary Physiology I', which is taught during the second semester of the first year of the veterinary medicine degree. It is composed of five different sections: body fluids and homeostasis, and the cardiovascular, respiratory, urinary and digestive physiology systems. Associated with lecture-based theoretical sessions, there are 10 hands-on practical sessions. Each of the practical sessions lasted 3 hours, with approximately 20 students per group, who are assigned in alphabetical order and remain in the same group throughout the semester.

Self-directed learning in renal physiology practice using PhysioEx

The self-directed learning activity included in the present study was carried out during the renal system section using the PhysioEx 9.0 software. In general terms, this program contains 12 different exercises about laboratory simulations in physiology: (1) cell transport mechanisms and permeability; (2) skeletal muscle physiology; (3) neurophysiology of nerve impulses; (4) endocrine system physiology; (5) cardiovascular dynamics; (6) cardiovascular physiology; (7) respiratory system mechanics; (8) chemical and physical processes of digestion; (9) renal system physiology; (10) acid–basic balance; (11) blood analysis; and (12) serological testing. Each exercise has different activities (ranging from three to nine) divided into several sections: (1) overview—a summary of the main concepts related to the exercise; (2) objectives of the activity; (3) introduction—theoretical framework; (4) pre-lab quiz—multiple-choice questions about concepts reviewed in the introduction section; (5) experiment (Figure 1a); (6) post-lab quiz—multiple-choice questions about the activities performed during the experiment; (7) review sheet—short answer questions; and (8) lab report—downloadable file including the results of pre-lab quiz, experiment, post-lab quiz and review sheet. Specifically, the present study was performed using exercise 9 of PhysioEx, 'The simulation of Renal System Physiology', which is composed of six activities. This

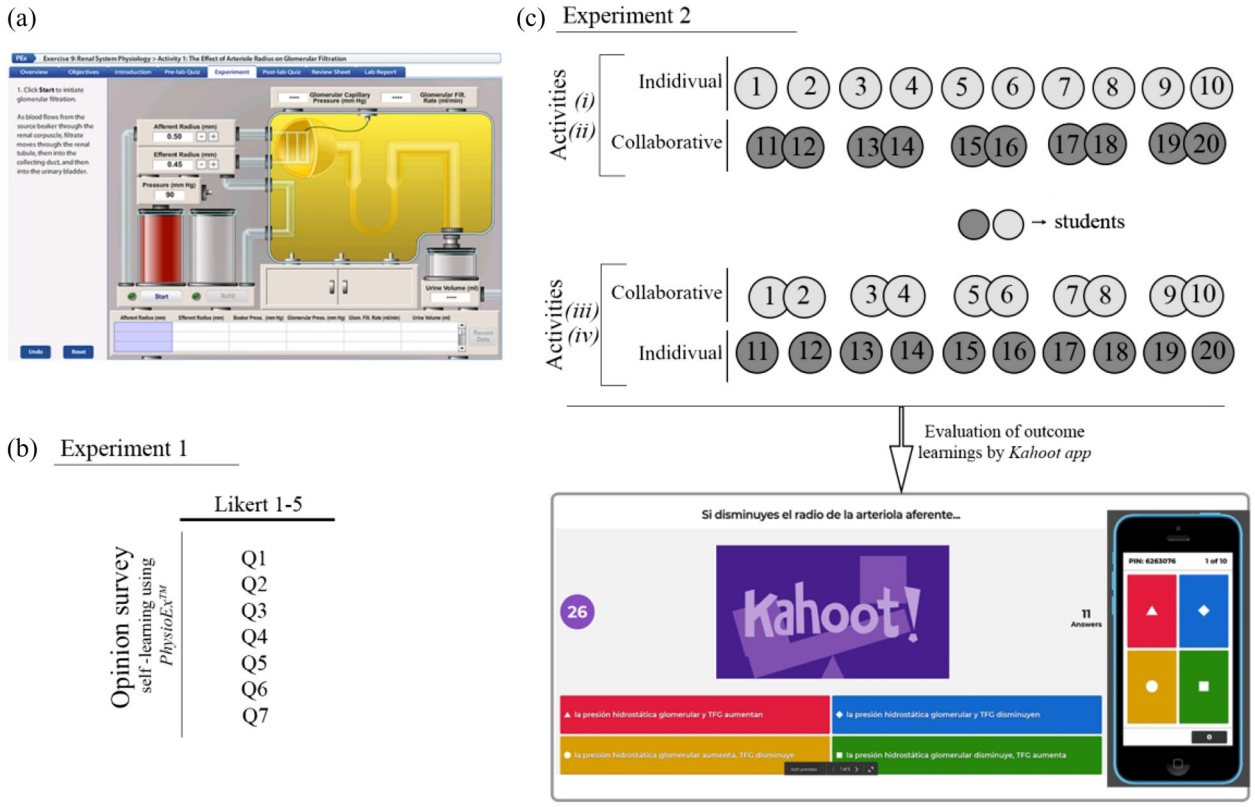

FIGURE 1 (a) An example of renal system activity provided by the PhysioEx program. (b and c) Scheme of the experimental design—(b) experiment 1: a survey of students' opinions about self-directed learning practices during 2016–2017, 2017–2018 and 2018–2019 academic years composed of a questionnaire [seven raised questions (Q1–Q7) answered on Likert scales from 1 (strongly disagree) to 5 (strongly agree)]; (c) experiment 2: students performed PhysioEx activities in an individual versus collaborative manner (top image). After activities, the students' learning outcomes were evaluated by a Kahoot! quiz. The bottom image represents an example of a Kahoot! quiz question and online student response using a mobile device

exercise simulates the function of a single nephron, including the following topics: factors influencing glomerular filtration, the effect of hormones on urine function and glucose transport maximum. During the development of the practice, the students performed just four of the six activities included in this exercise: activity 1 (named (i) in the experimental design) — the effect of arteriole radius on glomerular filtration; activity 2 (ii)—the effect of pressure on glomerular filtration; activity 4 (iii)—solute gradients and their impact on urine concentration; and activity 6 (iv)—the effect of hormones on urine formation. The practical was performed using laptops (computer classroom) belonging to the Veterinary Faculty The students acted autonomously during the activities, making their own decision as regards (experiment repetition, the time required to understand the activities, etc.). At the end of each activity, the results were discussed and shared among all the students under teacher supervision.

Study design

Experiment 1: Opinion survey on self-directed learning practice

A total of 177 students (2016–2017, N = 64 students; 2017–2018, N = 74; 2018–2019, N = 39) completed an anonymous and voluntary opinion survey (seven-point questionnaire) about the self-directed learning methodology at the end of the corresponding practice (PhysioEx-Renal System Physiology) (Figure 1a,b). The questions were answered on a Likert scale ranging from 1 to 5 (1: strongly disagree; 2: disagree; 3: neither agree nor disagree; 4: agree; 5: strongly agree). The survey was performed and completed online through the University of Murcia application (www.encuestas.um.es).

Experiment 2: Self-directed learning: individual versus collaborative

During the practice (academic years 2017–2018 and 2018–2019), the students were divided into two groups: (1) students working individually, and (2) students working in collaboration with another student. In the first part of the practice, activities (i) and (ii) were performed by each group of students (working individually vs. collaboratively); while for activities (iii) and (iv) (the second part of the practice corresponding to activities 4 and 6 in PhysioEx-Renal System Physiology) students changed roles, those who had worked individually in the first part now worked with a partner and vice versa (Figure 1c). The time required to perform each activity (individually and collaboratively) was recorded. At the end of each set of activities (set 1: activities [i] and [ii] and set 2:

activities [iii] and [iv]) performed through PhysioEx program, the students were individually evaluated by means of the mobile application Kahoot!. Kahoot! is one specific software that promotes the active learning theories through gamification and could be utilised in a classroom or remote through the computer or mobile device.[26] To play Kahoot!, the teacher enters into the application and gives the students a pin to access the game. Once all the audience is connected, the teacher projects the screen on the classroom and the game can start. In our case, the evaluation of learning outcomes through Kahoot! consisted of five multiple-choice questions (four possibilities and only one true). The points awarded in each question depended on the correct answer and speed of the response (the limit maximum time for each question was 30 seconds). The top scores for each question were revealed to the whole class, and the winners (top three) were displayed on a scoreboard at the end of the session.

Statistical analysis

The statistics were performed by the R program (vs. 3.6.2, R Core Team 2019). Data from experiment 1 were compared (academic years) by Kruskal–Wallis test. For experiment 2, the data (time per activity and score) were analysed for normality (Shapiro–Wilk test) and homogeneity of variances (Bartlett test). If both tests were fulfilled, two-way ANOVA (with type III square correction) was performed. When homogeneity of variances was not accomplished, robust factorial ANOVA was applied. Differences were considered statistically significant at $p < 0.05$.

RESULTS

Experiment 1: Opinion survey on self-directed learning practice

Student evaluation of this methodology over three academic years was high, as reflected in the total average score of 4.19 ± 0.86 (mean ± SD) on the Likert scale (Figure 2). Analysis of the results showed Q6 to be the most highly evaluated with a Likert scale score of 4.71 ± 0.58, which reflects good acceptance of introducing games to strengthen concepts. On the other hand, the question obtaining the lowest score (3.90 ± 1.04) was Q5, which rises to the dynamics followed during the practical class. When the scores were compared according to the different academic years (Figure 3) no significant differences were observed for any of the questions ($p > 0.05$), which means that scores remained consistent regardless of the academic year. This same trend, with no inter-annual differences was also the case for the overall average of the survey, scores constantly being above 4.00. Most of the negative opinions (red and orange in the graphs) refer to the academic year 2017–2018 in the case of most questions (Q1–Q5). By contrast, positive opinions (dark and light blue in the graphs) fill the greatest volume of the bars in all cases, with a minimum of 64.9% for Q1 and Q5 for the academic year 2017–2018 and maximum values exceeding 96% for Q6 during the 2016–2017 (96.9%) and 2018–2019 (97.5%) academic years (Figure 3).

Experiment 2: Self-directed learning: individual versus collaborative

In three of the four activities (75%), the time spent by the students was greater ($p < 0.001$) when they worked with a collaborator than when they worked individually (Figure 4a). Only in activity (i) was the time to conclude the experiment similar in both groups. However, the evaluation of learning outcomes by Kahoot! pointed to no significant differences ($p > 0.05$) that could be attributed to the way (individual vs. collaborative) the activities were carried out (Figure 4b).

DISCUSSION

Parallel to advances made in technology, new learning methods have been implemented at all educational levels. However, it is in universities where the models of self-directed learning have really imposed themselves in recent years as an adaptation to the fresh profile of students, who no longer wish to be a mere spectators in their education. Using a computer simulator (PhysioEx) for imparting practical lessons the present study looks at students' opinions concering self-learning methodologies, and analyses the results of the learning evaluation after different approaches (individual vs. collaborative). The data reported here indicate that (i) self-directed learning is an appropriate teaching methodology for students, and (ii) this methodology is particularly beneficial for students' understanding of concepts whether they work alone or with a companion.

The results summarise the experience gained over three consecutive academic years (2016–2017, 2017–2018 and 2018–2019). In all three academic years, the students evaluated the self-directed learning practical lessons involving the PhysioEx simulator as being very positive, giving an average score of over 4 on the Likert scale (from 1 to 5). The findings show that students prefer to increase their knowledge autonomously and that self-directed learning is better than lectures for understanding material.[27] Moreover, the fact that the self-directed learning method proposed in this study can be regarded as technological probably increased the acceptance of its use by the students. Indeed, some studies have suggested that familiarity with technology and the experience and perceptions that students have concerning on online learning systems influence their satisfaction with such approaches.[28,30] Modern-day students have been raised in a digital environment, which has shaped the way they think, behave and act,[30] so they have a high degree of self-efficacy of

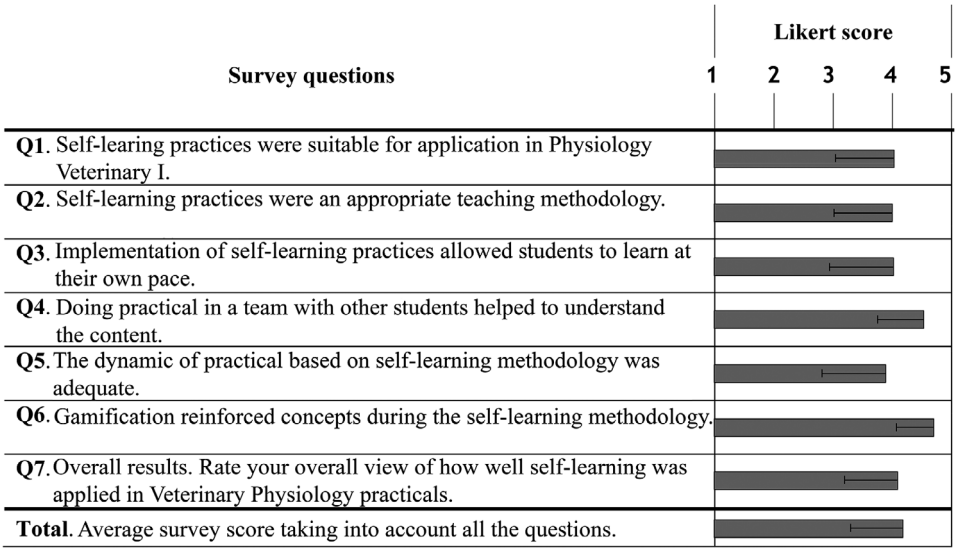

FIGURE 2 Opinion survey of the students about self-directed learning practice. Bar graphs show the average score (±SD) obtained on each question (Q1–Q7) and the total survey score ('Total') using all data collected during the three academic years studied (2016–2017, 2017–2018, 2018–2019). A total of seven questions were raised to be answered on a Likert scale ranging from 1 to 5 (1: strongly disagree; 2: disagree; 3: neither agree nor disagree; 4: agree; 5: strongly agree)

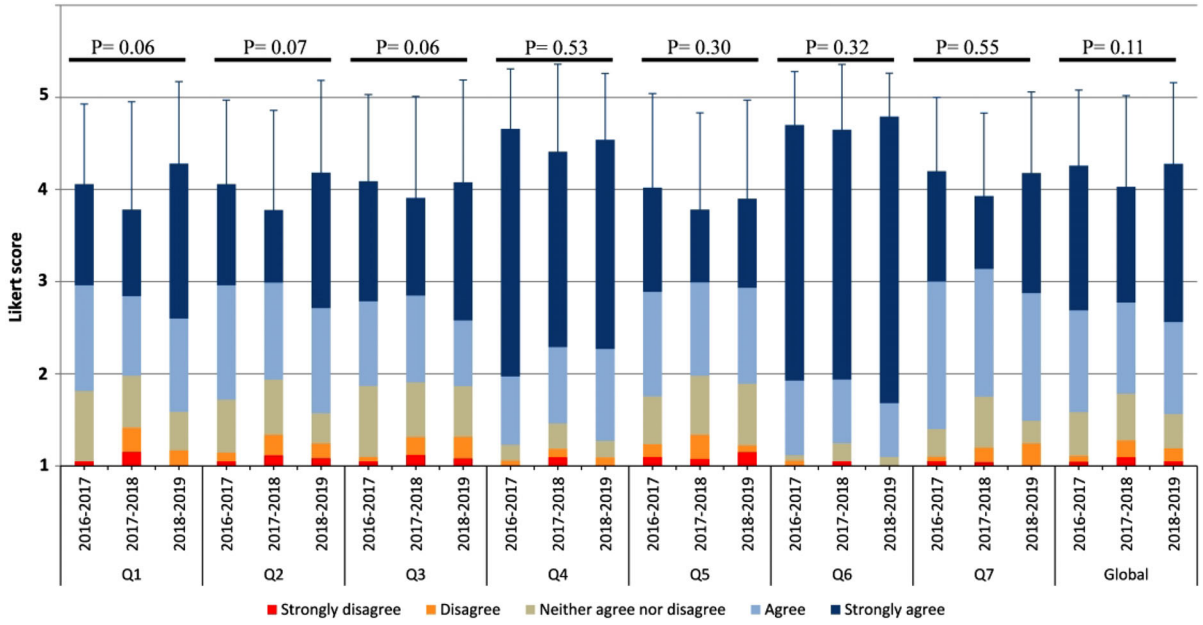

FIGURE 3 Average score (±SD) on the Likert scale obtained for each question (from Q1 to Q7) and the global survey score divided by the different academic years studied. No significant differences were found between the academic courses. Different colours inside the same bar refer to the percentages of the different degrees of satisfaction expressed by the students (red: strongly disagree; orange: disagree; green: neither agree nor disagree; light blue: agree; dark blue: strongly agree)

technology, and a high perception of its usefulness and ease of use,[31] which affects the acceptance of technology by users.[32] The literature in general supports that a higher level of experience with new technologies is linked to a greater preference for these learning environments.[33,35]

After this study, we have been able to verify that implementing a mandatory mini test at the end of each laboratory class (gamification) reinforced autonomous learning by generating a sense of competition and collaboration, but also improved students' motivation, as reflected in the surveys, which gave the highest score (4.71 points) to the question addressing this point (Q6). This shows that the continuous assessment of knowledge encourages students to focus more during study session thus improving the teaching–learning process.[35] At the other extreme, there was the least valued concept (although it, too, scored well) related to the lack of dynamism during the practical session (Q5, 3.90 points). This suggests a need to provide greater variation to increase the rhythm of the activity, which should increase even further the good opinion held by the students about the usefulness of the approach.

A simulation learning environment is useful for the level of knowledge acquired by the user or its

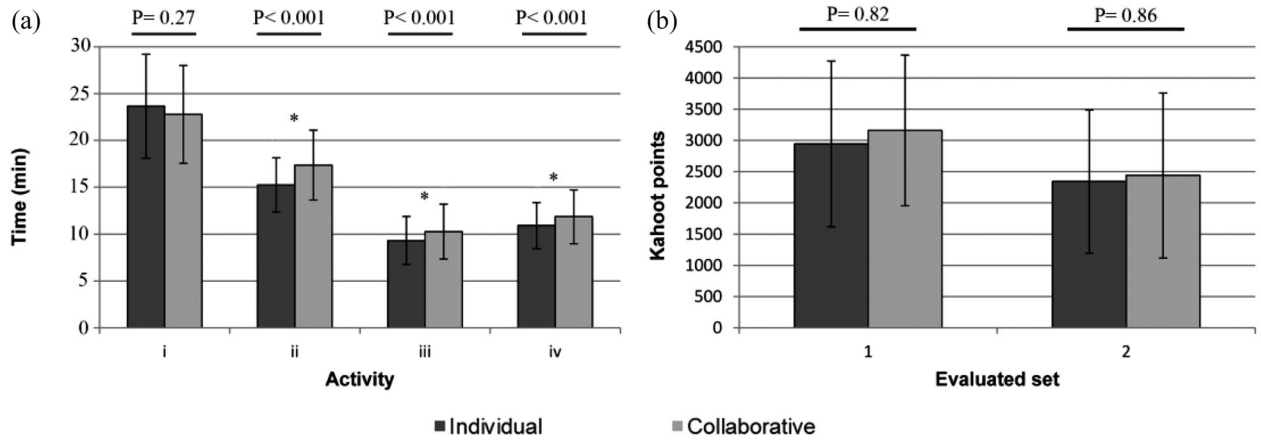

FIGURE 4 (a) Time required by the students to complete the different activities according to the way they were performed (individual or collaborative). (b) Points obtained in the individual test through Kahoot! for each of the evaluated sets (1 and 2) according to the mode used by the students to accomplish the activities (individual or collaborative). Data are shown as mean ± SD and the asterisk between bars denotes significant differences ($p < 0.001$)

reinforcement whether the activity is performed alone or with a partner. Although students spend more time in the collaborative study mode, there is no difference in terms of learning outcome (when knowledge acquisition was evaluated). However, as reflected in other studies, students prefer collaborative to individual learning enviroments[36–38], as reflected in the survey (Q4). Some studies consider voluntariness of collaboration and redundancy as the main causes of why collaborative learning is not better considered than individual learning.[39]

Several studies have recently looked at student learning based on gamification to increase motivation, improve knowledge and skills or to make activities more pleasurable.[40,42] In this scenario, the present study has combined a self-directed learning methodology with gamification using interactive activities through PhysioEx and Kahoot! applications. This combination was marked highest in the survey in the three academic years that the study lasted (scores ranging from 4.65 to 4.79 on a Likert scale). This agrees with previous reports on how students perceived Kahoot! web-based interactive gaming as a valuable active learning strategy,[42] since it made learning enjoyable and motivated students.[43,45] One aspect that should be borne in mind is that our method, which combined self-directed learning and gamification, is structured in such a way as to avoid surface learning. It has been shown that simply applying a game design element has a less beneficial impact than in combination with traditional methods.[45] So, educators need to identify the benefits and difficulties of gamification before including it in curriculum design, taking into consideration both the learning objectives and the type of student.[46] The introduction of new teaching strategies, such as the combination of self-directed learning with digital resources, has the potential for a better and more standardised learning experience. Moreover, gaming encourages the involvement of all learners and enhances engagement with content. In that sense, gaming can aid learner's self-awareness by providing feedback to more easily detect their weaknesses. The students can access the program at any time after the session so that they can reinforce the detected deficiencies. Overall, the results indicate that students enjoy the combination of self-directed learning, digital simulators and gamification, and think that it helps them learn better.

The fact that learning outcomes were similar for both individual and collaborative strategies could be due to two non-mutually exclusive hypotheses. First, the teacher explained the dynamics of the practice at the outset, so that the students knew that after the self-directed learning practice they were going to be evaluated by Kahoot!, which may have increased the attention paid to the lesson because motivation is known to increase when there is a gamification element.[46] Second, learning outcomes obtained were similar regardeless of the approach (individual or collaborative). Nevertheless, we also have to consider the small number of questions used during Kahoot! Then, this issue may not allow us to properly distinguish the results between both categories of self-directed learning, so this aspect could be raised as a limitation of the study. Peer learning is effective[47,49] in a wide range of health disciplines,[49,50] which may facilitate students acquiring missing information, clarifying misconceptions or enhancing cooperative learning.[51,53] Whether this teaching strategy is reflected in outcome learning results is not clear. However, the collaboration with their classmate can lead to increased engagement and motivation for learning, which is a helpful and positive effect. Moreover, in veterinary professional practice, it is often that an individual veterinarian is not solely responsible for the care of a particular patient.[53] Therefore, communication between the team members or veterinary colleagues is important. Then, the inclusion of teamwork in the curricula of the first years of the veterinary degree could be positive for best practices of the professional future of the students.

During pandemics, such as COVID-19, academic staff need to minimize disruptions to curricula by modifying educational activities.[54] The situation

created by COVID-19 has forced many institutions to abandon face-to-face teaching and to implement the use of online platforms that allow for distance learning.[55] Indeed the COVID-19 pandemic has exposed the need to bring education completely online or to a hybrid course design, allowing students to participate remotely from their place of residence. Therefore, remote learning approaches, including simulated labs, can serve as an alternative means for learning science.[56] In this context, the self-directed learning methodology provided here can be implemented as e-learning, since students are able to connect their computers through online platforms and carry out these activities either individually or collaboratively. The use of computer-supported education may be a problem for students not confident in their self-efficacy[57]; however, the current generation of learners has grown up with technology all around them and lived most of their educational lives with almost continuous access to the internet.[58] They have even been called 'digital natives', with high levels of computer literacy and experience, who prefer technology-infused learning.[59]

CONCLUSION

In summary, although traditional lecturing has long dominated undergraduate teaching for the best part of a millennium and still has its advocates,[60] the results provided by the present study support the adoption of new teaching methodologies, such as self-directed learning. In this respect, several assertions may be made and even be regarded as 'best practices': (1) self-directed learning is suitable for implementation in veterinary physiology. The overall results indicate a very high degree of satisfaction among students (score above of 4), which was similar in each of the academic years analysed indicating the strength of the methodology; (2) using gamification together with self-directed learning methodology was considered an enriching combination by the students for underlining concepts. This statement is supported by the highest score in each of the studied academic years (close to the maximum of 5); (3) the incorporation of active and student-centred learning in physiology in the form of a methodology based on self-directed learning methodology (either individual or collaborative) helps the student to learn because they learn more by doing physiology than by listening to and memorising physiology.[61]

Regarding self-directed learning practical classes, a comparison of academic outcomes between individual and collaborative strategies showed that (1) the students preferred learning in a collaborative manner, which lends weight to the view that collaborative learning is preferred in a self-directed learning context, and (2) the collaborative manner statistically increased the time spent per activity (in three of the four activities), which could mean that the students discussed among themselves (although the theme of discussion was not analysed), and worked and learned together. Even though the benefits of collaborative learning were not represented in the learning outcome through Kahoot!, the students indicated that self-directed learning practices in collaboration with others helped to better understand the contents.

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CONFLICT OF INTEREST

The authors report no conflicts of interest.

ETHICS STATEMENT

Participation in this study (which was carried out over the academic years 2016–2017, 2017–2018 and 2018–2019) was voluntary and informed consent was obtained. Participants were provided with information concerning the design of the study, and were assured that their participation and perceptions would not affect their evaluation. The ethical principles of the Helsinki Declaration were also followed.

AUTHOR CONTRIBUTIONS

Francisco A. García-Vázquez designed the study and interpreted the data. Rebeca López-Úbeda and Francisco A. García-Vázquez analysed the data, wrote the draft manuscript, and edited, read and approved the final manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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