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INSTRUCTIONAL DESIGN AND ASSESSMENT

A Blended Learning Experience for Teaching Microbiology

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Objectives. To create a virtual laboratory system in which experimental science students could learn required skills and competencies while overcoming such challenges as time limitations, high cost of resources, and lack of feedback often encountered in a traditional laboratory setting.
Design. A blended learning experience that combines traditional practices and e-learning was implemented to teach microbiological methods to pharmacy students. Virtual laboratory modules were used to acquire nonmanual skills such as visual and mental skills for data reading, calculations, interpretation of the results, deployment of an analytical protocol, and reporting results.
Assesment. Learning achievement was evaluated by questions about microbiology case-based problems. Students' perceptions were obtained by assessment questionnaire.
Conclusion. By combining different learning scenarios, the acquisition of the necessary but otherwise unreachable competences was achieved. Students achieved similar grades in the modules whose initiation was in the virtual laboratory to the grades they achieved with the modules whose complete or partial initiation took place in the laboratory. The knowledge acquired was satisfactory and the participants valued the experience.

Keywords: microbiology, blended learning experience, Internet-based instruction

INTRODUCTION

People who are able to solve problems successfully not only have an organized and flexible type of knowledge but also have the skills to apply such knowledge to problem solving.[1-4] Accordingly, for more than a decade, the emphasis has been on education based on skills and competences.[5,6] In microbiology, as in many other experimental disciplines, it is not easy to teach the acquisition of skills.[7,8] The following are some of the factors that hinder students' learning skills:

- **Increase in the complexity of the discipline.** The practical teaching of microbiology, mainly based on the culture of microorganisms, is limited by the time required for such culture. Another problem with microbiology is complexity due to the huge variety of microorganisms (bacteria, viruses, yeasts, and molds), all of which require different laboratory skills.
- **Need for efficient use and deployment of costly resources.** The current trend in the identification of microorganisms and microbiological diagnosis is an ever-expanding use of immunological, genetic, and molecular methods, all of which are expensive.
- **Drawbacks in the actual laboratory for immediate feedback.** The high number of students per instructor in laboratory practices makes very difficult the immediate feedback at the optimal time when learners are primed for reinforcement and also reduces control over the skills acquired by the students and prevents an exhaustive assessment of the microbiology skills acquired from being made.
- **Hindrances to the development of intellectual or mental skills.** In an experimental laboratory, difficulties arise in the acquisition of the most complex skills, called competencies, which require not only the acquisition of manual skills but also intellectual acumen for the purpose of analyzing, comparing, and synthesizing the results. In the microbiological analysis of samples and identification of microorganisms, it is not only necessary to be able to correctly handle materials, devices, and techniques, but also to achieve the intellectual expertise necessary for interpreting images (microscope, biochemical, immunological, and molecular tests); consulting tables, manuals, and databases; performing calculations; correctly interpreting and expressing

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the results as a function of the knowledge presumably acquired, etc. Acquisition of these intellectual skills requires sufficient time, together with easy access to different materials or information resources, repetition in certain cases or circumstances, and a calm atmosphere for concentration; none of these are easy to find in an actual laboratory. On the other hand, the development of communication and information technologies allows the learning of laboratory systems in a virtual-learning environment.

The options for Web-based education range from the use of applications in traditional classrooms to comprehensive online courses in which there is no face-to-face contact. A ''hybrid'' course is one that utilizes a combination of the traditional classroom format and distance learning via the Web. A hybrid approach may improve the efficiency of classroom management, especially for large classes,[9] increase the degree of student-led learning,[10] improve student morale and overall satisfaction with the learning experience,[11] enhance information skills acquisition and student achievement,[12,13] and possibly reduce student withdrawals and absenteeism.[14]

Here we describe a blended learning system that was developed to teach microbiological techniques: the identification of microorganisms, general and advanced microbiological methods, and the microbiological analysis of samples. Our aim was to reduce the above-described limitations in the learning of these in the real laboratory.[15] A further aim was to help students acquire the intellectual skills necessary for these competences by means of interactive multimedia virtual laboratory exercises completed via the Internet.

DESIGN

The virtual laboratory exercises were grouped into 6 modules, depending on the educational objective. Each module was implemented within a different learning scenario. Some of the techniques were practiced by students in the ''real'' laboratory while others were taught in a virtual laboratory (either tutored or untutored). With this, our aim was also to determine whether the learning acquired for the interpretation of results was influenced by the amount of practice with the techniques and in the interpretation of the results in the real laboratory.

We describe the results of the implementation of these 6 modules at a school of pharmacy in 2 courses with 107 and 185 students, the learning acquired or academic yield obtained with each module, and an analysis of students' perspectives regarding these blended learning resources.

Two hundred ninety-two students at the University of Salamanca participated in the trial. One hundred seven were second-year students enrolled in *Microbiology* and the other 185 were third-year students enrolled in *Microbiological Analysis and Laboratory Diagnosis*. Both courses lasted 6 months and included formal lectures on theory (5 and 2.5 ECTS [European Credit Transfer System], respectively) plus practical classes (3 and 3 ECTS , respectively) devoted to the teaching of basic microbiological techniques and methods, together with complete analyses of different problem samples.

The online blended-learning activities proposed were essentially laboratory-based multimedia interactive activities, henceforth designated ''virtual laboratory exercises,'' and other online resources for learning reinforcement and communication with the tutors.

Virtual laboratory exercises were divided into 6 modules depending on the educational aim: (1) identification of microorganisms (Identification Module), (2) basic microbiological methods (Methods I Module), (3) microbiological analysis of clinical urine samples (Urine Samples Module), (4) molecular technique-based methods (Molecular Methods Module) (5) microbiological analysis of food samples (Food Samples Module) and (6) advanced microbiological methods (Methods II Module).

The exercises of the Identification Module propose the solving of a case-based problem. To achieve this, the students are shown images of the results of the different tests (eg, biochemical, physiological, etc) required for the identification of the microorganism (between 15 and 17 images). The Identification Module requires that students should be able to interpret images of the results of such tests and successfully use the identification tables.

The exercises in modules 2-6 involved a multimedia tutorial that presented different methods and samples that had been analyzed in a real laboratory, and posed a problem-based case, the results of which were presented with images. Each exercise was assessed through multiple-choice questions and both scoring and correction were accomplished by immediate feedback. Accordingly, there were 5 well-defined stages in each exercise: introduction and aims; a description of the method or analysis to be performed, training in the interpretation of results with immediate feedback, application to the real laboratory case, evaluation by questions, and automatic correction with feedback. Furthermore, the exercises corresponding to module 4 had another section in which students were initiated in the use of different devices and instruments used in molecular biology, eg, the thermocycler, electrophoresis systems, by the corresponding simulator.

Available at the subject's web site were also the following resources: revision of classes and examinations. Materials of the instructors themselves (scripts, summaries, formal lectures, questions and exercises for selfassessment, etc), links to other web sites, other texts or documents, as well as general information about the subject (assessment, teaching agenda, schedule of practical and theory classes).

The blended learning scenario used different learning environments: practical sessions carried out in the real laboratory, and practical sessions carried out on computers, ie, in the virtual laboratory. Of the latter, we differentiate those supervised by an instructor (tutored) and others in which the students carried out the session alone (untutored). The initiation in the microbiological techniques was carried out in different learning environments. For the 6 modules used, Table 1 shows the percentage of techniques carried out for the first time in each of these 3 environments.

This blended approach to learning also required a dual/customized/blended system for evaluating academic performance. As shown in Table 2, students' performance in each of the 6 modules had bearing on the overall final grade, with each module representing a different proportion of the grade depending on the obligatory nature of the material and the scoring system. Assessment of performance in the Identification Module was different from that used for the rest of the modules.

Although its online use was optional, Identification Module was evaluated by means of an independent and obligatory examination at the end of the year. Each student was given 4 cases to identify, with the corresponding images of the tests carried out on each case. The student had to interpret the images, make use of the identification tables, and provide the name of the species identified. To pass the subject, the students had to pass the identification test correctly answering at least 3 of the 4 cases to each.

Teaching of these exercises was accomplished with an initial session in the computer facility of 1-2 hours duration at the beginning of the year. In that session, the instructor explained how to use the identification tables, interpret some of the tests, and access the blended learning resources on the education server. For this type of resource, the students had the following facilities available on the server: help in the interpretation of the different tests with images of the possible results of such tests and their meaning (help); the identification tables (tables); and 31 exercises based on practical cases of identification for training purposes (cases).

In the rest of the modules, assessment was performed with questions at the end of each exercise. A database of blended learning performance was created, based on the total number of activities carried out, the answers given to each of the questions, and the score on each exercise. The amount of time the student spent completing each question/the questions was also recorded.

The students' online activity was logged and analysed using the *Funnel Web Analyzer*, version 4.5 (Quest Software, Inc, Aliso Viejo, Calif). The logged data allowed us to determine how often participants visited each web site, which activities they carried out, and how long they needed to perform the different activities, as well as identifying a variety of other aspects of Web-user interactions.

At the end of the study, participants classified the navigation environment, its design, and the training efficiency of the virtual laboratory exercises based on their own personal perceptions of blended learning. Students were invited to respond to the statements using a 5-point Likert scale ranging from 5 = strongly agree to 1 = strongly disagree. We retained the format of the original instruments for reliability purposes. However, in this article, for reasons of clarity, the 5-point rating scale was merged into a 3-point scale, joining "strongly agree" and "agree," and "strongly disagree" and "disagree."

ASSESMENT

Table 3 shows the number of exercises per module available to the students, the mean number of exercises done by the students, and the learning environments in

Table 1. Learning Environments Used in a Microbiology Course for Pharmacy Students

Module No.	Type of Exercise (n)	First-Time Practice, % Real Laboratory	Virtual Laboratory. Tutored	Virtual Laboratory, Self-directed
Subject, second year				
1	Identification (31)		10	90
2	Methods I (16)	30		70
Subject, third year				
3	Urine samples (14)	100		
4	Molecular methods (8)		100	
5	Food samples (9)	50		50
6	Methods II (16)			100

Table 2. Weight of Performance of Each Virtual Laboratory Exercise Module Used in a Microbiology Course for Pharmacy Students

Module	Type	Max. Score*	Assessment Mode
Second-Year			
Identification	Elective	15	Required examination
Methods I	Elective	5	Questions in exercises
Third-Year			
Urine samples	Obligatory	4	Questions in exercises
Molecular methods	Obligatory	8	Questions in exercises
Food samples	Obligatory	6	Questions in exercises
Methods II	Elective	7	Questions in exercises

*Maximum percentage of the final score obtainable by completing the exercises in that module. Theory examinations, laboratory practices, and oral presentations accounted for the rest of the final grade

which they were performed. Within each module, all exercises were performed by at least one of the students, although some exercises were used more than others. Of all the exercises performed, 88% were completed independently (untutored).

During the course, the 292 students logged on a total of 24,127 times; however, some students used the resources only once or twice during the entire course. The virtual laboratory exercises were used 7 days a week and 24 hours a day during the semester. For the Identification Module, which required an obligatory examination, the students did more exercises on the days immediately prior to the examination.

As mentioned above, the exercises of Identification Module were presented to students in a 2-hour computer session. Then, during the academic year and up to the date of the specific examination, the students were allowed to train using 30 sample cases. To pass the subject, the students had to correctly answer at least 3 of the 4 cases offered on the identification test. Nearly all of the students (91%) passed the examination, and of those, 65% correctly identified all 4 test cases.

The exact amount of time devoted by each student to this learning mode and use of online resources could not be determined. Although the times at which students accessed online materials and the lengths of their online sessions were recorded on the server, students were able to download and or print out materials to review/study elsewhere. The students performed 2012 sessions of practical cases. To do so, they invested 3396 hours, corresponding to a mean of 19 identifications (63.3% of the exercises available on the server) and invested 32 hours in solving the problems (a mean of 1.7 hours per case). Since all 3 resources had to be used simultaneously to solve the cases, we estimated that the time devoted to learning identification procedures was the same as the time devoted to carrying out the case-based activities; hence, a mean of 32 hours per student.

The results of the questionnaire implemented at the end of the year concerning the opinions of the students about this approach to learning and the aims pursued with it are shown in Table 4. Students stated they were to a large extent in agreement with the idea that they had achieved the aims pursued with this approach to learning (the first 4 questions). The fifth aim, being familiar with and understanding the bases of the tests performed, was not a main goal on our agenda since this is a mental skill related to theoretical knowledge, and hence complementary (although appropriate) to the mental skills required for identification.

Multiple-choice questions were used at the end of each exercise to assess the learning achieved in the Methods I, Urine Samples, Molecular Methods, Food Samples, and Methods II Modules. Table 5 shows the mean scores obtained on the exercises of these modules. As may be seen, the mean score was fairly similar for all the modules and hence independent of the degree of technical

Table 3. Exercises Used in a Blended Learning Environment for Teaching Microbiology

			Exercises Performed			
				Environment		
No.	Module	Exercises Available, No.	Exercises Performed/ Student	Real Laboratory	Computer-Tutored	Computer-Untutored
Subject second year						
1	Identification	31	21		2	19
2	Methods I	16	14			14
Subject third year						
3	Urine samples	14	6	1	2	3
4	Molecular methods	8	5		2	3
5	Food samples	9	8	1		7
6	Methods II	16	13			13

Table 4. Questionnaire Addressing Students' Perceptions About the Microorganism Identification Module

Item	Mean	Agree, %*	Neutral, %	Disagree, %*
Achievement of aims				
The ability to use the identification tables.	4.4	94	6	0
The ability to interpret Gram y Ziehl images.	4.7	98	2	0
The ability to interpret images of biochemical tests.	4.3	96	4	0
I am familiar with the steps to be followed in the identification process.	4.3	94	6	0
I know and understand the bases of some tests.	3.9	73	19	8
Assessment of learning and examination				
I have found it interesting and useful.	4.6	98	2	0
I have had difficulties in preparing for the exam.	2.0	6	21	73
I think the identification exam is simple.	4.3	92	4	4
In general, I am glad to have followed this type of learning.	4.6	94	6	0

*The Likert scale used on the survey instrument was from 1 = strongly disagree to 5 = strongly agree. Percentages reported here were obtained by combining responses of 1 and 2 (strongly disagree and disagree are reported in the column "Disagree") and responses 4 and 5 (agree and strongly agree are reported in the column "Agree")

initiation or method used in the real laboratory, which ranged between 0 and 100%, depending on the module.

Table 6 shows the mean number of exercises carried out by each student, the sessions and the amount of time taken to perform the exercises in each module, estimation of the mean time used by each student in solving the problems, and the mean time taken by each student to perform an exercise. On the table, it may be seen that initiation in techniques in the real laboratory influenced the time required by the students to perform the exercises in the virtual laboratory.

Module 3 (Urine Samples) had a mean performance time per exercise of 12 minutes, which is considerably lower than in the rest of the modules. This module was the only one in which 100% of the techniques involved (as well as the analytical protocols and interpretation of the results) were practiced in the real laboratory for at least 4 hours.

The next module with the lowest time taken to perform each exercise (21 minutes) was number 4 (Molecular Methods), the few first exercises being performed in the "tutored" virtual laboratory environment, ie, at the computer facility with explanations by the instructor in a 2-hour session.

The questionnaire aimed at exploring module 4 (Molecular Methods), with a technical initiation of 0% in the real laboratory, in order to determine whether only the virtual laboratory allowed acquisition of the skills for the interpretation of results. Of the 185 students involved in the survey, 152 (82.1%) participated in the evaluation of blended learning module.

The direct aims of the real laboratory exercises were for students to train in the interpretation of the results of the methods and techniques and to acquire laboratory skills. Accordingly, the first goal of the questionnaire was to determine students' perceptions about the effectiveness of Virtual Laboratory Exercises in the acquisition of certain technical skills. Three indicators in the survey related to the effectiveness of Virtual Laboratory Exercises are shown in Table 7. Most respondents to the first 3 items/indicators (67%, 72%, and 81%) reported they were able to carry out those technical aims and hence concluded they had acquired such skills. A low proportion

Table 5. Scores on Required Evaluations Taken by Pharmacy Students After Completing Exercises for Modules 2-6 in a Blended-Learning Microbiology Course

No.	Module	No. of Exercises Available	Initiation in the Real Laboratory	Total Exercises Performed	Score on Exercise Mean (SD)*
	Methods I	16	30	1102	8.9 (1.1)
3	Urine samples	14	100	927	8.8 (2.0)
4	Molecular methods	8	0	982	9.2 (1.9)
5	Food samples	9	50	1014	9.1 (2.2)
6	Methods II	16	0	2086	9.4 (2.2)

*Mean score out of a possible score of 10

Table 6. Exercises Performed by Pharmacy Students in a Blended Learning Microbiology Course

No.	Module	Students, No.	Exercises performed/ student	Sessions Total	Sessions Per Student	Time (h) Total	Time (h) Per student	Time (min) Per Student and Exercise
2	Methods I	107	14	7134	67	1074	9.9	42
3	Urine samples	185	6	1099	6	198	1.2	12
4	Molecular methods	185	5	2471	13	321	1.8	21
5	Food samples	185	8	4733	26	720	3.9	30
6	Methods II	185	13	5915	32	1131	6	27

of the students (3%, 6% and 4%) stated that they did not agree that they had acquired such skills.

An indirect aim of these exercises was to encourage students to understand the basis of the techniques. Thus, the second goal of the questionnaire was to know the perceptions of the students about how this indirect aim had been achieved. Table 7 shows 3 indicators used for such ends. Also in this section, most respondents (89%, 84%, and 71%) agreed with the statements and only 3% of the students disagreed with one of those indicators and none of them with the other 2.

The third aim of the questionnaire was to know students' perceptions about learning with the virtual laboratory in comparison with traditional methodologies. Most students (90%) thought that performing the exercises had allowed them to gain both the theoretical knowledge and practical expertise they would not have learned through conventional teaching methods such as formal classes and textbooks, and 83% considered that teaching based on virtual systems was an essential complement to conventional education. However, when asked if they believed that the virtual laboratory would be of no use if not supported by practical classes (with the physical presence of the students) they were divided, with some who disagreed (36%), some who agreed (34%), and some with mixed feelings (29%). Finally, most of the students (68%) considered that in some cases the virtual laboratory could substitute for theoretical classes in certain topics.

The fourth aim of the questionnaire was to see what the overall perception of the students about this kind of exercise was. As may be seen in Table 7, the means obtained on these items were high, as were the percentages of agreement.

As mentioned before, the participants of this experience had other resources available on the server. The results show that they also used these even though they were optional and bore no rewards in terms of academic credit. The time they devoted to using these resources in hours per student (47.9 hours for second-year students and 12.9 hours for third-year students) was considerably lower than the time recorded for the exercises. However, the number of sessions was higher.

The resources of communication between the students and the instructor (messages, notice board, consultation of grades, etc) were those least used both in terms of the number of sessions and hours devoted to them by each student (5.6 hours and 2.8 hours, respectively, for each group of participants). However, the information resources (electronic library, virtual library, video library, image gallery, etc) were used frequently, both in terms of the number of sessions and the hours spent per student in both subjects.

DISCUSSION

The acquisition of the necessary but otherwise unreachable competencies was achieved by combining different learning scenarios. This study showed that the students achieved similar grades in the modules whose initiation was in the virtual laboratory with no previous instruction in the real laboratory to the grades they achieved with the modules whose complete or partial initiation took place in the real laboratory. These findings show that the learning tasks proposed in the exercises and their assessment can be acquired in the virtual laboratory and that a real laboratory is not essential.

The purpose of the exercise modules in the virtual laboratory was not to teach the students manual skills (aseptic techniques, seeding techniques, etc), which must be learned in the real laboratory, but to acquire other, nonmanual skills such as interpreting microscope images, biochemical tests, or data reading; making mental calculations, interpreting results, deploying an analytical protocol, comparing standard values, and reporting results. Accordingly, assessment of the exercises and of the learning achieved with them was accomplished by measuring the degree to which these skills were acquired. Thus, in the Identification Module, the goal was for the students to achieve competence in the identification of bacteria, a vital component to being a professional microbiologist. Learning to identify bacteria is fairly complex since it involves several independent but interrelated partial

Table 7. Pharmacy Students' Perceptions About Achievement of Goals in a Mircobiology Course Using Blended Learning

		Percentage of Students Choosing This Rating*		
Item	**Mean**	**Agree**	**Neutral**	**Disagree**
Achievement of goals in interpretation of results.				
The ability to determine the sizes of DNA fragments by their electrophoretic mobilities.	3.9	67	30	3
The ability to interpret the results of electrophoretic or polymorphic patterns and determine which are different or identical.	4.0	72	22	6
The ability to read a sequence in a sequencing gel.	4.2	81	15	4
Achievement of goals in the understanding of technical bases.				
Understanding the use of restriction enzymes to cut DNA molecules into fragments of different sizes.	4.2	89	11	0
Understanding how DNA fragments are separated during agarose gel electrophoresis according to their size.	4.2	84	16	0
Understanding how PCR is used to amplify DNA, generating DNA fragments of defined size.	3.9	71	26	3
Virtual laboratory versus traditional methodologies.				
These exercises have allowed me to know both theoretical and practical aspects to which I would not have had access in conventional teaching classes or through text books.	4.4	90	9	1
I consider the instruction based on virtual systems to be an essential complement to traditional teaching methods.	4.2	83	12	5
I consider the virtual laboratory to be of little use unless supported by practical classes with the physical presence of the student.	2.9	34	29	36
I believe that in some cases the virtual laboratory could replace theory classes in certain topics of this subject.	3.8	68	17	15
Overall assessment of the exercises				
I think the time spent on these exercises has been worthwhile in consideration of the learning achieved.	4.3	90	9	1
These exercises have allowed me to understand the practical usefulness of molecular methods.	4.2	88	9	2
I find learning based on practical cases involving analytical and diagnostic techniques interesting.	4.4	92	8	0

*The Likert scale used on the survey instrument was from 1 = strongly disagree to 5 = strongly agree. Percentages reported here were obtained by combining responses of 1 and 2 (strongly disagree and disagree are reported in the column "Disagree") and responses 4 and 5 (agree and strongly agree are reported in the column "Agree")

learning tasks. Students must learn to visually interpret the results of more than 50 different tests; they must become skillful at handling several (more than 30) dichotomic tables, taxonomic tables, and taxonomic guides that cover more than 300 taxa in bacterial classification. In other words, identification is a competence that requires prior knowledge and experience, rather than just learning new information.

As reported under Results, the acquisition of this competence or skill was measured in an independent examination with 4 identification problems in which 91% of the students correctly identified 3 or 4 cases and 65% correctly identified all 4 cases. This indicates a high level of learning especially for second-year pharmacy students.

Many authors have reported good results with blended learning.[16] Most studies addressing efficiency in learning with the virtual laboratory have been done with simulators. Ravert reviewed 513 studies related to computer-based simulation and healthcare education and determined the effect of simulation on education.[17] Ravert reported that 75% of the studies showed positive effects of simulation on skills and/or knowledge acquisition.

The Molecular Module involved exercises that use different types of bench-work simulators (action of restriction enzymes, agarose gel electrophoresis, sequencing gel electrophoresis, thermocycler, action of polymerase, automatic sequencer) and the results had to be interpreted by the students. As with all simulators, the students can and should change the parameters for different results. The students must learn to choose the most suitable parameters and interpret the results, making the necessary calculations and consulting the tables and databases.

Both in module 4, which uses simulators, and in the other modules (2, 3, 5 and 6), which do not use them, the efficiency of the results was similar, from which it may be deduced that the learning achieved was also similar. This is in agreement with what has been reported by other authors concerning the virtual laboratory. The assessment questions were about the acquisition of mental or intellectual skills, such as how to interpret images, how to calculate, or how to consult data or databases, and not about the acquisition of manual skills. As may also be seen, the mean score of the exercises in all the modules was fairly high: above 8.5 out of 10.

According to the questionnaire responses, most students agreed that they achieved the learning objectives for the modules and acquired the desired skills. Furthermore, they indicated overall satisfaction with the way the materials were presented and the time it took to complete the exercises.

These results are partly in agreement with those reported by Masiello et al concerning a microbiology course in which students "exhibited positive attitudes towards blended learning and exposed a possible benefit from its use in the long run."[18] However, the students also seemed aware that using any computer tool simply because it was available and full of features is not the best way to integrate information technology into education, and that to make a good computer tool, there is a need for usability testing with ''real'' users. The students also agreed that Web tools were a good complement to traditional lectures.

Similar perceptions of satisfaction have also been reported in other works addressing the activities of the virtual laboratory and of blended learning in different subjects. Using a virtual laboratory of microscope slides, Dee[19] found that 91% of students strongly agreed that their knowledge of the histopathology of cancer had increased, and in a course with blended learning, Gupta described that most students (79%) wanted virtual activities to be used as a supplement to the undergraduate program and 7% wanted them to replace formal lectures.[20] Also, in some reviews concerning the attitudes and perception of students, similar results were observed.[21,22] However, Song reported that most learners agreed that course design, learner motivation, time management, and comfortableness with online technologies impacted the success of an online learning experience.[23]

In this work we also found that performing techniques in the real laboratory (mainly in module 3: Urine Samples) decreased the time required by the students to perform the exercises, indicating that prior familiarity with the different techniques favorably affects the time required for problem solving or the solution of new cases, and that knowledge of a method or technique requires additional time if learning has not been initiated in practical classes. If the 4 hours of initial instruction in performing the techniques that is required in the real laboratory setting is added to the time required to perform the exercises, the total time for completing the module would be similar or greater than that required if training took place only in the virtual laboratory.

What is clear is that students saved time when they did their learning in the virtual laboratory to acquire experience in different cases or problems; it suffices to compare the times required in the virtual laboratory with those needed in the real laboratory to solve a case. In module 3 (Urine Samples) this was respectively 12 minutes as compared with 4 hours spent over 3 successive days to allow culture growth. In the techniques of other modules, the differences were generally even higher. As mentioned in the Introduction, one of the challenges of teaching microbiology is the limited time available for practical classes. This is further complicated by the time required for culture of the microorganisms and the need to study different cases with different results to ensure learning and the development of skills and competences. Blended learning using the virtual laboratory can help to solve these problems, as the results of our study suggest. Online activities for the acquisition of skills other than manual ones can be used without decreasing the quality of learning, and can result in a considerable savings in the time students must devote to it.

As reported above, with blended learning, we have managed to improve the learning of microbial identification and microbiological analyses by resolving time limitations. Students performed, online, many cases that cannot be addressed with conventional theoretical and practical classes, mainly owing to the time required for microbiological methodology.

Also, with these blended learning activities we have been able to resolve other limitations, described in the Introduction, in the learning of the subject.

- The increase in the complexity of the discipline (modules 2-6).
- The need for a more efficient use of costly resources by simulation of the expensive and highly sophisticated apparatus (module 4) and a general saving of reagents and media through the virtual laboratory.
- Drawbacks in the real laboratory for the immediate feedback necessary for reinforcing students' learning processes and for controlling the skills acquired. This is done through interactivity between

the training part and immediate response from the server in the questions section, signaling the failures, the correct solution, and the score obtained.

- Hindrance to the development of intellectual or mental skills, all of which require an atmosphere of tranquility and concentration, which is facilitated by online learning.

Other advantages of blended learning that we observed in the use of these modules are those inherent to online learning. This type of learning allows students to use resources that are difficult to implement through conventional teaching methods, such as simulations, virtual laboratories, multimedia lessons, tutorials, assignments, research projects, quizzes, and other digital content. Blended learning has enormous versatility and potential but at the same time creates daunting challenges on the front end of the design process. A blended learning design represents a significant departure from either of these approaches. It represents a fundamental reconceptualization and reorganization of the teaching and learning dynamic, starting with various specific contextual needs and contingencies. In this respect, no 2 blended learning designs are identical and this reflects not only the great complexity but also the huge possibilities of blended learning.

CONCLUSION

The acquisition of the necessary but otherwise unreachable competences in microbiology has been achieved by combining different learning scenarios. In the learning of microbiological methods, the students achieved similar grades on modules taught using the virtual laboratory to modules taught completely or partially in the laboratory. The knowledge acquired proved highly satisfactory to them and they placed great value on the experience.

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