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Application of a low-cost web-based simulation to improve students' practical skills in medical education

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A B S T R A C T

Background: Practical sessions in undergraduate medical education are often costly and have to face constraints in terms of available laboratory time and practice materials (e.g. blood samples from animals). This makes it difficult to increase the time each student spends at the laboratory. We consider that it would be possible to improve the effectiveness of the laboratory time by providing the students with computer-based simulations for prior rehearsal. However, this approach still presents issues in terms of development costs and distribution to the students.

Objective: This study investigates the employment of low-cost simulation to allow medical students to rehearse practical exercises through a web-based e-learning environment. The aim is to maximize the efficiency of laboratory time and resources allocated by letting students become familiarized with the equipment and the procedures before they attend a laboratory session, but without requiring large-scale investment. Moreover, students can access the simulation via the Internet and rehearse at their own pace. We have studied the effects of such a simulation in terms of impact on the laboratory session, learning outcomes and student satisfaction.

Methods: We created a simulation that covers the steps of a practical exercise in a Physiology course (measuring hematocrit in a blood sample). An experimental group (EG, $n = 66$) played the simulation 1 week before the laboratory session. A control group (CG, $n = 77$) attended the laboratory session without playing the simulation. After the session, all students completed a survey about their perception of the difficulty of the exercise on a scale of 1–10 and the HCT final value that they obtained. The students in the EG also completed a survey about their satisfaction with the experience.

Results: After the laboratory session, the perceived difficulty of the procedure was lower on average in the EG compared to the CG (3.52 vs. 4.39, 95% CI: 0.16–1.57, $P = .016$). There was no significant difference in terms of perceived difficulty using the equipment. The HCT measures reported by the EG group also presented a much lower dispersion, meaning a higher reliability, in determining the HCT value (3.10 vs. 26.94, SD; variances significantly different, $P < .001$, F: 75.25, Dfd: 68.19 for EG and CG). In the satisfaction test, the majority of the students in the EG reported that the experience was positive or very positive (80.7%) and reported that it had helped them to identify and use the equipment (78%) and to perform the exercise (66%).

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The simulation was well received by students in the EG, who felt more comfortable during the laboratory session, and it helped them to perform the exercise better, obtaining more accurate results, which indicates more effective training. EG students perceived the procedure as easier to perform, but did not report an improvement in the perceived difficulty in using the equipment. The increased reliability demonstrates that low-cost simulations are a good complement to the laboratory sessions.

1. Introduction

Public undergraduate medical education tries to provide students with the best possible training at a reasonable operational cost. In this sense, the time and resources devoted to practical training are especially critical. In order to properly develop their skills and improve their practical scores, students should be able to repeat laboratory sessions and rehearse clinical procedures as many times as they need to. However, this requires more intensive use of laboratories and/or operating rooms, an extra charge for practice materials, and a higher number of teachers involved (increasing the amount of teacher hours per student).

This extra practice could be structured upon computer-based simulations (also known as immersive learning simulations, game-like simulations or serious games) or virtual 3D environments, which are becoming an increasingly recognized tool in medical education [1–6]. Even though there are multiple forms of simulations in medical training [7], computer-based simulations provide students with interactive, safe test environments, which can be accessed at any time without requiring specialized equipment (other than a computer). Computer simulations can, in turn, range from simple multimedia learning contents to complex simulations providing physical feedback through haptic technologies [8]. In addition, computer simulations can include game elements in order to engage students and enhance their motivation towards learning. Some authors argue that a proper balance between the realism of a simulation model, the engagement of game elements and a proper pedagogical model can be the key to maximizing the effectiveness of learning [9–13].

Nonetheless, simulations still present some inconveniences. Probably the most relevant is that complex simulations can be very expensive. The cost of most of the simulations developed in 2008 fell within the range between $20,000 and $100,000 (70.27%), with a median cost per learner of $102.08 and an average cost per learner of $281.51 [14]. Although in some cases such cost can be justified for ethical reasons (for example when health sciences students have to hone their skills with live patients [15]), some authors argue that whether these investments compensate in terms of learning outcomes is still an open research question [16]. In addition, setting up the space, equipment, and the time required to interact with the simulations can also hinder their application [17]. All these barriers can be troublesome, especially if we take into account that having a simulation does not always imply better training [18,19].

In this work we present a case study in the context of a Physiology course in the School of Medicine at the *Complutense University of Madrid*. The course is given during the second year of medical studies as a combination of theoretical and practical sessions. Laboratory training is distributed through the entire year with a single final practical exam. Students are required to achieve and demonstrate the skills to perform certain processes and must acquire the knowledge to relate biological processes to theoretical concepts, a fundamental aspect of a Physiology course [20,21].

In this pilot we have focused on the practical exercises related to Hematology for several reasons. Firstly, these exercises are performed using blood samples obtained from controlled laboratory rats sacrificed for the session. Secondly, Hematology is the first topic covered in the course, 8 months before the final practical exam. Due to the cost and ethical issues raised by the sacrifice of animals, these are also the only exercises that students cannot reproduce in the open laboratory sessions provided at the end of the course as a reinforcement for the practical exam. In this non-critical context, having a reinforcement simulation would be desirable, but it would be difficult to afford such a huge investment, which motivates the exploration of a low-cost approach.

We have developed a low-cost game-like simulation that covers the steps for the determination of hematocrit (HCT) through centrifugation of blood samples (both pure and in different osmolarity solutions). The simulation was developed using the <e-Adventure> platform [22], which facilitates the creation of game-like simulations by using photos of the real working place without compromising the cost [23]. Using an authoring tool such as <e-Adventure> allowed Medicine instructors to participate directly in the development process, which makes the development process much more dynamic and facilitates the maintenance of the content produced [24]. The web-oriented characteristics of the platform [25] made it possible to distribute the simulation to the students through an e-learning environment following a blended-learning approach. The use of these e-learning platforms (e.g. *Moodle*™, *Sakai*™, or *WebCT-Blackboard*™) as a complement to traditional education has become very popular in the academic field, especially among universities [26,27], where it is an ideal medium to distribute content to students. In this case we used the Virtual Campus of Complutense University (based on WebCT) to distribute the simulation to the students, which allowed them to use it at their own pace by using a web browser, either from the computer laboratories available at the university or from their own homes.

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In order to assess the impact that this approach could have on laboratory sessions, the simulation was presented to a group of students before the actual session. We then gathered information about the actual laboratory session in an attempt to discover whether the simulation improved the effectiveness of the session. After completing our study, we made the simulation freely available to all students through the virtual campus.

2. Methods

2.1. Overview

In order to explore the effect that a game-like simulation could have on the education of students, we developed a low-cost pilot simulation covering one of the practical exercises. From over 400 students enrolled in the Physiology course (separated, at registration, into different laboratory groups), we selected an experimental group (EG) and a control group (CG). Students in the EG were instructed to attend a practice session with the simulation prior to the laboratory session while students in the CG proceeded as usual in the course without practicing with the simulation.

After the laboratory session, students in both the EG and the CG answered an anonymous survey that asked them about their perception of the exercise's difficulty, focusing on both the procedure itself and the complexity of using the equipment. All students also had to report the HCT values they had obtained. Students in the EG completed an additional survey that asked their subjective opinion of the simulation and its educational value.

The objective was to assess (a) whether students in the EG perceived the exercise as easier to perform; (b) whether students in the EG obtained more precise measures; and (c) whether students were satisfied with this approach. The following subsections describe the process in more detail.

2.2. Development of the simulation

In the Hematology practical sessions, students quantify different parameters such as hematocrit, hemoglobin content or hemolysis time from a blood sample taken from an experimental animal. We focused on modeling one specific test: the determination of hematocrit using a classical laboratory test method based on the centrifugation of a blood microsample (a few μl), which separates the plasma and cellular components into two layers. The students have access to a test tube containing the blood. They first shake the blood container gently to homogenize the sample and partially fill a capillary tube with the blood. They then seal the colored end of the tube with Plasticine and place the tube into a centrifuge for 5 min. Finally, they measure the length of the packed cell volume and the total length of the sample in the capillary tube, obtaining the HCT value as a percentage.

The simulation was created using the <e-Adventure> platform as a photorealistic *point-and-click* navigational environment which recreates the laboratory station where the real HCT test is performed (Fig. 1). Therefore the relation between development costs and the realism obtained is well balanced,

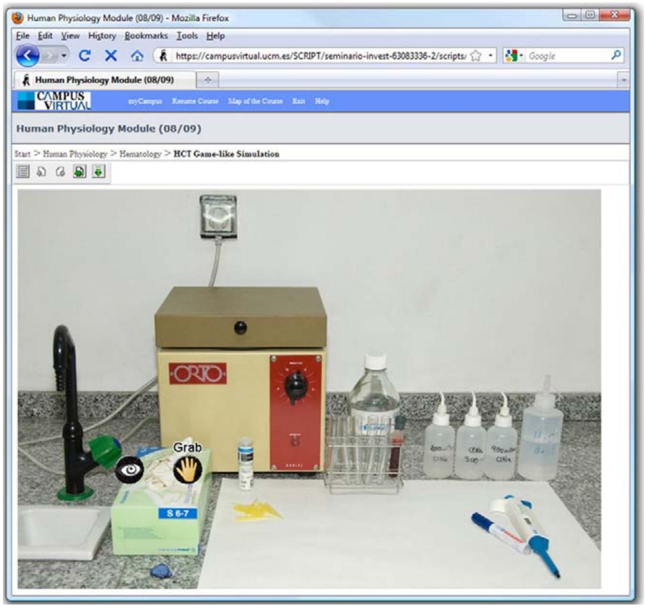

Fig. 1 – The HCT simulation executed directly from the blended-learning web platform of the Complutense University of Madrid.

as with this environment the student visualizes the actual workplace (the simulation is generated from real photos) but without needing costly 3D environments.

In the simulation students can interact with the equipment presented by using the computer mouse and keyboard. The steps of the procedure are simulated by combining the interactive objects in the correct order. For instance, to fill a capillary tube with blood the student needs to combine the capillary tube with the blood sample. Additionally, to complete some steps, students must answer some questions about the exact operations that must be performed. This allows students to explore the effects that even small incorrect variations of the procedure may have on the results. In addition, the learning value of the simulation is improved with embedded videos of some tasks such as how to shake the blood tube correctly or how to seal a capillary tube with Plasticine. The simulation also triggers some random events that can happen during the real session (such as encountering a small clot in the blood sample), using a slightly exaggerated probability to increase the variety of situations experienced by each student.

In order to enhance the attractiveness of the experience and increase student engagement and involvement, the simulation includes game elements. First, the consequences of incorrect steps are humorously exaggerated and bring the student back to the first step (Fig. 2). This both reinforces learning and fosters competition between the students because the total time employed to finish the procedure is measured (fewer mistakes result in a higher score).

In addition, as decided by the instructors, when the student fails to perform some specific steps in the procedure, the feedback is delayed until the end of the simulation. In this manner students can check the real consequences of their acts, even when those are not immediately obvious when working in the laboratory. When the simulation is completed,

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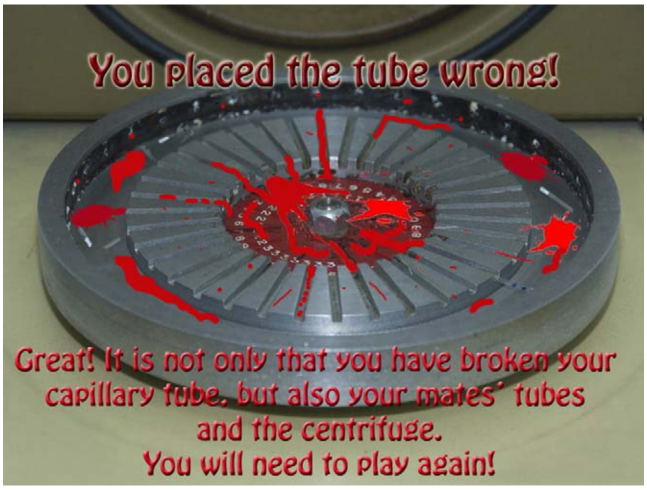


Fig. 2 – Screenshot from the simulation: The student is rebuked when, as a result of the wrong placement of the tube, the centrifuge becomes unbalanced and breaks the capillary tube.

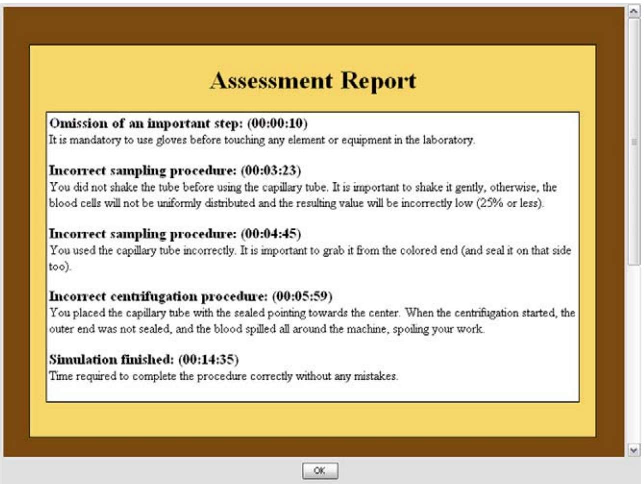


Fig. 3 – An assessment report presented to the student. It can also be automatically submitted via email to the instructor.

the student receives an assessment report showing all the mistakes and correct actions performed during the session (Fig. 3). This is essential for the students to redefine wrong assumptions.

2.3. *Experimental setup*

Once the simulation was ready, we selected an experimental group ($n = 66$) and a control group ($n = 77$). The separation was based on their assigned laboratory groups which are designated alphabetically (and therefore practically random).

During the first stage, the EG was instructed to attend a session in a computer laboratory where they had the chance to practice with the simulation for 30 min. They were given no further guidance from their teachers, other than the previous information provided to all students in the classroom and a short briefing about the HCT simulation. Instructors from both the Medical School and the School of Computer Science were present, but only offered assistance with issues related to interacting with the simulation or technical problems. No assistance with the procedure itself was given. The students practiced with the simulation in a controlled environment and were not given the simulation for further additional practice (until the actual laboratory session was completed).

In the laboratory sessions, both groups performed the classical procedure to determine HCT through centrifugation for both pure blood samples and solutions with different osmolarity, as previously described. After completing the procedure but before leaving the laboratory, all of the students completed a form in which they were asked about their perceptions of the difficulty of the exercise and about the complexity of using the equipment. Students rated the difficulties for each aspect with scores between 1 ("very easy") and 10 ("very difficult") as depicted in Table 1. These questionnaires also collected the HCT value obtained by each student. The students filled out the questionnaires anonymously before leaving the laboratory room.

Questions Q1.1 and Q1.2 were divided into different subquestions for the different parts of the practical session, which includes other exercises related to Hematology, although only the results from the parts related to measuring HCT were considered.

The students in the EG also filled out a second questionnaire asking about their subjective impressions of the simulation and whether they considered that it had helped them to complete the exercise successfully. The questions, described in Table 2, were answered in a 5-point Likert-scale format, where 1 meant "strongly disagree" and 5 "strongly agree". This questionnaire was handed out to the students

Table 1 – Contents of the first questionnaire, completed by students in the CG.

Question #	Wording
Q1.1	Please rate the difficulty you experienced to understand and perform this procedure
Q1.2	Please rate the difficulty you experienced to use the required equipment for this procedure
Q1.3	Please indicate the HCT value you have obtained in the first measurement (pure blood)

Table 2 – Contents of the second questionnaire, completed by students in the EG.

Question #	Wording
Q2.1	The simulation has helped me to identify and use the equipment in the lab
Q2.2	The simulation has helped me to complete the practical session more easily
Q2.3	I think it would be interesting to have more simulations like this one for the other exercises in the course
Q2.4	I think it would be interesting to be able to use the simulation as a reference while performing the practical exercise
Q2.5	I think this has been a positive experience in my training

Table 3 – Perceived difficulty.

	CG (SEM)	EG (SEM)	Difference	95% CI[a]	P[b]	n, CG/EG
Difficulty understanding the procedure (Q1.1)	4.39 (0.16)	3.52 (0.28)	0.86	0.16 to 1.56	.016	77/21
Difficulty using the equipment (Q1.2)	4.02 (0.20)	3.71 (0.40)	0.31	−0.55 to 1.17	.47 (NS)	77/21

[a] CI from unpaired Student's *t*-test.
[b] P-value for a Mann–Whitney *U*-test.

after completing the previous one, and was also completed in the laboratory room.

2.4. *Data analysis*

The differences in perceived difficulty between the EG and the CG (questions Q1.1 and Q1.2 from Table 1) were compared through unpaired Student's *t*-tests and Mann–Whitney *U*-tests. For question Q1.3 we compared the standard deviations (SD) for each group as a measure of the dispersion of the data when determining the HCT value. Since each group worked with blood from several animals, we normalized the values and used an *F*-test to statistically compare the variances. A lower variance of the data indicates a better performance in the process. The answers from the second questionnaire were analyzed in terms of relative frequencies.

3. Results

Due to space limitations, the students were further separated into subgroups to attend the laboratory session. Two-thirds of the students in the EG attended a specific session in which it was discovered that an equipment malfunction had frozen the blood samples overnight. The consequence was a partial hemolysis of the blood, a coloration of plasma and greater variation of the HCT. Given that this event altered the natural course of the session and implied greater difficulty for those students, we decided to focus the comparison on students who had performed the exercise under the same conditions, and thus reduce the EG to 21 students who attended a different laboratory session.

3.1. *Perception of the difficulty of the practical exercise*

The answers to the relevant fields in questions Q1.1 and Q1.2 related to the determination of the HCT value for pure samples, and solutions with different osmolarity were used to determine whether students had perceived a lower difficulty performing the exercise and using the laboratory equipment. Question Q1.1 measured the perceived difficulty in understanding the procedure, while question Q1.2 measured the perceived difficulty in using the equipment.

As observed in Table 3, the results for Q1.1 indicate a mean perceived difficulty of 3.52 for the EG and 4.39 for the CG, a 0.86 difference considered significant after a Mann–Whitney *U*-test ($P = .016$). However, the mean perceived difficulty in using the equipment was lower (0.31) and not significant ($P = .47$).

3.2. *Differences in standard deviations of HCT measures*

The answers to question Q1.3 were analyzed through descriptive statistics as reported in Table 4. The HCT values for blood samples are not comparable in this case because students within the same group used blood from different animals. However, the variability of the measures is relevant as a test of the reliability of the process by the group. Comparing the normalized responses of the students, we see much lower variability in the results of the experimental group (3.10 vs. 26.94 SD for EG and CG groups, respectively). An *F*-test showed that variances between the two groups were significantly different ($P < .001$; *F*: 75.25; Dfd: 68.19).

Additionally, even though the results from the groups which performed the practical exercise with the spoiled blood were excluded from the test to avoid problems with the data, we also measured their dispersion. In spite of the difficulties during the session, the SD for those students was 8.58 ($n = 44$), also significantly lower than the CG ($P < .001$; *F*: 9.86; Dfd: 43).

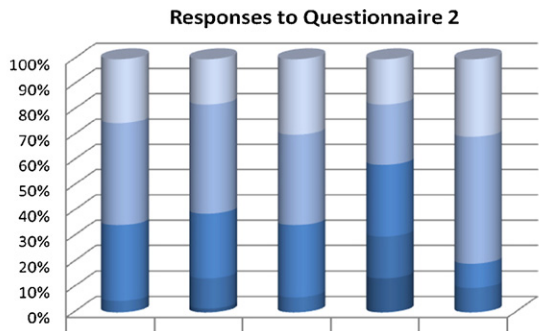
3.3. *Student opinions*

Responses gathered from the students in questionnaire 2 (see Table 2) indicated a good perception by the students. The distribution of the responses is presented in Fig. 4. Overall satisfaction with the experience (Q2.5) indicates that 81% of the students considered the experience to be "positive" or "very positive". A majority of the students "agreed" or "strongly agreed" that the simulation had helped them to identify and use equipment in the lab (65%) and to complete the practical exercise more easily (61%). Some students, however, considered that the game was not helpful in identifying and using the equipment (4%) or performing the exercise (13%).

The students also reported interest in having more similar simulations covering other practical exercises (66%), although

Table 4 – Descriptive statistics for Q1.3. Note that some students in both groups left this question blank.

	Mean (SD)	Normalized mean	SD of normalized mean	*n*
EG	40.78 (1.27)	100	3.10	20
CG	36.62 (9.86)	100	26.94	69



	Q2.1	Q2.2	Q2.3	Q2.4	Q2.5
Strongly Agree	25%	18%	30%	18%	31%
Agree	40%	43%	36%	24%	50%
No opinion	30%	25%	28%	28%	10%
Disagree	4%	12%	6%	16%	10%
Strongly Disagree	0%	1%	0%	13%	0%

Fig. 4 – Distribution of the responses to questionnaire 2.

their opinions about the usefulness of having this type of simulation as a reference during the lab session received varied responses.

4. Discussion

In this work we have evaluated the use of a low-cost, web-based simulation in the field of medical education. The objective was to allow medical students to perform the practical exercise before the actual laboratory session. The limited resources available for this type of exercise (in terms of both laboratory time and materials) do not allow students to get additional practice in the laboratory freely. Our idea was that a low-cost simulation may not be able to substitute the laboratory session, but it could increase the benefits obtained by students during their laboratory schedule without requiring a high investment. The addition of game-like elements provides additional motivation for students in order to engage them and promote the repetition of the exercise after the laboratory session. Finally, having the simulation available online through the Complutense University's Virtual Campus allows students to prepare for their practical exams at their own pace and as many times as they want. This is especially interesting for reviewing for the final exams, which are scheduled months after the first laboratory sessions.

We thus developed a web-based simulation that covers the procedure for measuring hematocrit levels in a blood sample, and studied its impact on the laboratory sessions by measuring the overall satisfaction of the students with this kind of materials, the students' performance reflected in the precision of their results, and their predisposition to use this type of simulation as a complement to the laboratory sessions. The final goal was to improve the students' grades and reinforce their practical learning.

4.1. *Development cost*

The combination of photographs and an easy-to-use authoring tool allowed us to develop the simulation without hiring a third party. However if we estimate the development cost of the simulation if developed by a third party (Table 5) it would have cost around $2630. This year there are 400 students enrolled in the course, which yields a cost of $6.58 per learner (counting only students enrolled this year; note that the simulation will be available for students for the next few years). These figures suggest that the approach is affordable, even in the context of a single course at a specific university.

4.2. *Differences in the laboratory session*

The evaluation of the actual impact of the simulation in the benefit obtained by the students is not an obvious process [29]. We decided to measure it in terms of how difficult each student perceived the exercise to be during the laboratory session, separately measuring the complexity of the procedure itself and the difficulties perceived in terms of handling the equipment. We worked under the assumption that if students perceived the exercise as easier, this would mean a higher focus during the laboratory session.

In these terms, the results seem to indicate that students in the EG perceived the exercise as being easier than those students in the CG did (3.52 vs. 4.39), a difference that was found to be significant under a Mann–Whitney *U*-test ($P = .016$). These results support the idea that students who had previous experience with the simulation were more comfortable during the practical session, which may suggest greater benefits.

Table 5 – Estimation of the development cost of the simulation if produced by a third party.

Concept	Person-hours	Role(s)[a]	Estimated cost/person-hour ($)[b]	Estimated cost ($)	Estimated cost ($)/learner[c]
Conception of the storyboard	16	HT	52	832	2.08
Creation of the art assets	6	P	21	126	0.32
Implementation of the simulation	32	CP, HT	41	1312	3.28
Deployment, testing and improvement	12	CP	30	360	0.90
Total	54			2630	6.58

[a] The roles involved are: CP, computer programmer; HT, health teacher; P, photographer.
[b] Estimated cost per person-hour was gathered from the US Bureau of Labor Statistics and rounded [28]. When more than one role is involved the average is used.
[c] The total number of learners enrolled in the course is 400.

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On the other hand, when queried about the difficulty in using the laboratory equipment, the average difficulty reported by students in the EG was only marginally lower, a difference that was considered not significant. This seems to indicate that the low interactivity provided by the simulation did not facilitate handling the laboratory equipment. This may be influenced by the fact that the equipment required in this exercise is easy to handle. The result, however, also raises some questions about whether a more complex simulation could have had a significant impact on the perception of the difficulty in using the equipment. A low-cost graphical simulation cannot substitute the feeling of actually handling the equipment, and the best experience can only be obtained through hands-on experience in the laboratory or through the use of sophisticated (and expensive) haptics [8,30,31].

The actual performance of the students in the EG during the practical exercise was also higher. In terms of performance, the quality of the result in any process that involves successive mechanical steps (e.g. an analysis performed by a lab worker) greatly depends on the technician. Experienced technicians get more consistent results, where deviations are reduced due to more accurate operation and fewer mistakes. The significant difference in the variances of the data collected from the group which played the simulation and the control group ($P < .001$) indicates that those students performed better in the lab session and yielded more reliable results. Moreover, even the students who had to perform the exercise using spoiled blood (after it froze overnight due to an equipment malfunction) had more reliable results than the CG students, which means that having played the simulation helped to reduce the impact of the incident.

4.3. *Student satisfaction*

The satisfaction questionnaires completed by students in the EG indicate a positive reception among the students. Most students (81%) considered the overall experience as positive, even though it meant added demands on their time in addition to the compulsory laboratory sessions. Even though it is a subjective measure, a majority of the students reported that they felt that the simulation had helped them with the equipment (65%) and with the steps of the exercise (61%). The result regarding the equipment is especially interesting, given that our measurements comparing the perceived difficulty against the CG indicated that, on average, students in the EG did not find it easier to use the equipment. It was also positive to see that 66% of students considered showed interest in having additional, similar simulations covering other practical exercises (in contrast, only 6% considered it uninteresting).

Another important aspect to acknowledge is the smaller but relevant percentage of students who considered that the experience was not positive (10%). These answers suggest that some students considered this exercise a waste of time, and raise questions about whether all students should be required to use the simulation.

Finally, the results regarding their interest in having the exercise available in the laboratory (Q2.4) were very open and varied, with some students considering it interesting as an interactive guide to the exercise, while others considered it a distraction from performing the procedure.

5. Conclusions

The development of this simulation addressed how to use low-cost simulations to reinforce practical laboratory training. Budgetary constraints also meant that a costly simulation of the procedure was not a reasonable option, and we have explored whether a low-cost simulation can have an impact.

The differences reported by students in the perceived difficulty of the exercise suggest that the simulation was beneficial in terms of their comfort levels during the laboratory session. We also observed greater reliability in the results reported by the EG, which means that relatively short exposure to a low-cost computer simulation improves performance in laboratory sessions in medical education. These results suggest that a low-cost computer simulation can improve practical learning and can be used in medical instruction of practical contents. In addition, the improved reliability of the students, when translated to a real setting, can imply a reduction of operational costs. While more complex simulations (e.g. 3D environments with haptic feedback) could have had an even greater impact in the laboratory session, their greater cost and lack of scalability may make them unsuitable for this particular context.

In addition the simulation has been easily deployed on the web via the Virtual Campus provided by Complutense University (although it can also be deployed in other e-learning environments such as *Moodle*™), allowing students to practice as many times as they need and at their own pace, facets which were received positively by the students. These results have encouraged us to develop more similar simulations that can complement the compulsory part of the course.

In the future, it would also be important to explore whether these type of simulations have an objectively significant impact on the final grades obtained by the students. However, this kind of analysis is very complex and requires gathering data for extended periods of time for comparison. Note that each year the exam focuses on only one of the practical exercises performed during the year and it would not be academically acceptable to let this research affect the nature of the exams presented to the students.

Author contributions

P. Moreno-Ger, J. Torrente and B. Fernández-Manjón created the simulation that was presented to the students, according to the guidelines provided by J. Bustamante, C. Fernández-Galaz and M.D. Comas-Rengifo. All authors reviewed the simulation and provided feedback for further improvements, as well as contributing to the design of the experiment and its execution.

P. Moreno-Ger, J. Torrente and J. Bustamante performed the statistical analysis. P. Moreno-Ger created the first draft of the paper and all authors participated actively in its revision and editing.

Conflicts of interest statement

None declared.

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Summary points

What was known before the study

- Computer-based simulations can be complements to medical education, offering engagement, promoting constructivist learning principles and providing safe test environments for students to explore.
- There is a broad range of medical simulations, with only high-end simulations (combining virtual reality and haptic feedback) being appropriate substitutes for hands-on experience.

What the study has added to the knowledge

- Low-cost simulations with a lower degree of fidelity cannot substitute for hands-on experience, but can be a complement which augments the benefits that students get during limited practical sessions.
- The introduction of a low-fidelity simulation before the practical session improved the reliability of the results, helped the students understand the exercise and was received as a positive initiative by the students in spite of the low development cost.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.ijmedinf.2010.01.017.

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