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E-LEARNING, HUMAN ANATOMY, NEURAL NETWORK, EXPERIMENT

Abstract

Objective: This paper presents an empirical study of a formative neural network-based assessment approach by using mobile technology to provide pharmacy students with intelligent diagnostic feedback.

Method: An unsupervised learning algorithm was integrated with an audience response system called SIDRA in order to generate states that collect some commonality in responses to questions and add diagnostic feedback for guided learning. A total of 89 pharmacy students enrolled on a Human Anatomy course were taught using two different teaching methods. Forty-four students employed intelligent SIDRA (i-SIDRA), whereas 45 students received the same training but without using i-SIDRA.

Results: A statistically significant difference was found between the experimental group (i-SIDRA) and the control group (traditional learning methodology), with $T(87) = 6.598$, $p < 0.001$. In four MCQs tests, the difference between the number of correct answers in the first attempt and in the last attempt was also studied. A global effect size of 0.644 was achieved in the meta-analysis carried out. The students expressed satisfaction with the content provided by i-SIDRA and the methodology used during the process of learning anatomy (M=4.59).

Conclusions: The new empirical contribution presented in this paper allows instructors to perform post hoc analyses of each particular student's progress to ensure appropriate training.

1. Introduction

Major changes are currently occurring in pharmacy curricula so as to take advantage of scientific advances in order to assist students to become competent pharmacy practitioners [1,2]. A clear example of this tendency is found in the design and discovery of drugs. The way in which the dynamics of drug-target interactions occurs has an impact on pharmacotherapy decisions, resulting in a substantial shift in the paradigm of teaching [3]. For example, simulators showing the 3-dimensional (3D) structures of proteins may be used to describe the properties of a drug.

A recent study reported that about 87% of all colleges and schools of pharmacy in the United States (US) use active learning techniques [4]. One of the most beneficial means of active learning is collaborative learning, which can be achieved by putting students in small groups to work on a topic [5]. Several studies have empirically demonstrated that the use of clickers promotes active collaborative learning [6]. Clickers or audience response systems (ARSs) are just one of the educational technologies in health science education in general, and pharmacy in particular, and it is noteworthy that 45% of US colleges and schools of pharmacy have adopted audience response systems or clickers as an active learning strategy [4]. An ARS is a handheld piece of equipment which allows students to respond electronically to questions, typically in the multiple-choice format, that instructors pose in class. A response receiver that plugs into a USB port or a server connected to the Internet receives the students' choices during a specified amount of time or at the instructor's discretion. A software polling program installed in a PC allows instructors to prepare and launch tests, and to display the frequency of responses to each question. Both the instructor and the students can see the responses displayed as aggregated results without individual responses being identified. These results can lead to a discussion on why each of the incorrect answers is unsuitable, stimulate dialogue [7], and permit the use of techniques such as think-pair-share [8]. ARSs promote active learning, and improve student engagement.

ARSs have been introduced, and particularly in the last 5 to 10 years, into various medical education disciplines such as clinical cardiology [9], family medicine [10], gynecology [11], physiology [12], physical basis of medicine [13], radiology [14] and the prescribing of safe medication [15]. This technology has been employed in several experiences and empirical studies with different goals: to check understanding [15], to evaluate classmates [13], to evaluate current or previous knowledge [16], to facilitate participation, for post hoc analysis [9], and to maintain attention [11].

Smartphones are becoming a valuable tool as regards not only improving the delivery of healthcare [17-20], but also supporting education in medical disciplines [21,22]. Note that smartphones have already been successfully used to emulate an ARS [23]. In this paper, a formative mobile-based assessment approach with which to provide pharmacy students with intelligent diagnostic feedback is proposed. To the best of the authors' knowledge, no other studies have to date combined ARSs and the intelligent analysis of the students' responses on a pharmacy course. This work is in line with the necessary evaluation and comparison of the specific ARS question types and format [24]. The results of the statistical study may be used to improve pharmacy degree students' human anatomy education.

2. Intelligent SIDRA, a neural network-based mobile e-learning system

The intelligent SIDRA (SistemaInstantáneo De Respuesta de la Audiencia, in Spanish; Immediate Audience Response System, in English), or i-SIDRA, is a client-server application developed at the University of Murcia (Spain). There are two roles in i-SIDRA: the student and the instructor. This application provides instructors with the capacity to create, collect and analyze responses to multiple choice questions (MCQs). Students are allowed to respond to MCQs proposed by an instructor as many times as they wish in a previously determined time interval. Users can access i-SIDRA by employing a PC, through the use of a web browser or a mobile device (the app can be obtained from the Apple App Store and Google Play). The user interface has been designed to be user-friendly. Technologies such as HTML5/Javascript, CSS3, NodeJS and PhoneGap/Cordova have been used to develop the mobile applications for students and instructors, while PHP, AJAX and HTML have been used to develop the web application. A web service has been developed using NodeJS and the library "socket.io" for communication with the client (students).

An instructor can register with i-SIDRA free by filling in an online form. The instructor then receives the account credentials at the corresponding e-mail address. In a typical scenario, an instructor can create an MCQ test by using a server side account. During a lecture, this instructor can give the test created previously. A student can respond to this set of MCQs by using the client side. Finally, the instructor can export the results of the test and obtain the information related to the students' answers.

The i-SIDRA is endowed with an unsupervised learning algorithm [25] (the Snap-Drift Neural Network) which is used to categorize student responses to MCQs [26,27]. The SDNN algorithm is based on a simple modal learning method. This means that the learning method changes periodically from one learning mode to another (snap and drift) [27,25,28,29]. A complete description of the algorithm can be found in [25,30].

The steps followed in order to work with i-SIDRA are: (1) collect data from the responses to a test in order to train the SDNN; (2) generate the groups (states of knowledge with regard to the questions formulated in the test) by training the SDNN; (3) introduce the MCQ test into i-SIDRA; (4) write and include the feedback associated with each group or knowledge state created in Step 2; (5) give the MCQ test; (6) the students complete the test as many times as they wish in a time interval imposed by the instructor and i-SIDRA receives the answers; (7) show the results.

Note that when a student submits a set of answers, i-SIDRA compares these answers with those expected and the i-SIDRA system then classifies the responses into a pattern grouping and returns its associated feedback. If all of the questions have been answered correctly, the online session finishes.

3. Method

This study has concerned a sample of first-year pharmacy students enrolled on a Human Anatomy (HA) course at the University of Murcia during the academic year 2013/2014.

HA is a first term course which provides an overview of the whole anatomy, focusing on structural and functional aspects. HA allows students to learn the basic and clinical concepts of anatomy, in addition to the use of an anatomical language that will enable them to carry out their professional activities. HA is divided into 4 thematic blocks: Block 1: Introduction to gross anatomy and musculoskeletal anatomy of the trunk (thorax, abdomen and pelvis) and upper limb; Block 2: Musculoskeletal anatomy of the lower limb and chest and abdominal viscera; Block 3: Musculoskeletal anatomy and viscera of the head and neck; Block 4: Introduction to the Nervous System. The students attend 3h of lectures/week, 1h of skills practice/week and 1h of seminars/week, thus completing a total of 6 ECTS credits during a period of 15 weeks.

The potential participants in this study were given a detailed verbal presentation to the study during the first day of class for recruitment purposes. The participants in the experimental group received a detailed verbal presentation, along with a tutorial that highlighted the goal of the study, a description of the tasks to be carried out, and an explanation of the mechanics of how to use the i-SIDRA system. A total of 108 students (57 students in the experimental group and 51 students in the control group) gave their individual oral consent. The students were permitted to abandon the study at any time without prejudicing their final academic assessment.

Four i-SIDRA tests (or experiments) corresponding to the thematic blocks depicted above were performed with the experimental group during the seminars. Each of the four sessions was led by the same instructor and lasted 60 minutes. Each session was divided into two parts. In the first part (30 minutes), a number of multiple-choice questions (11, 10, 13 and 10 for experiments Exp1, Exp2, Exp3 and Exp4, respectively) concerning the representative content of each block covered in class were presented, and the participants responded via i-SIDRA. Each individual student was assigned an identifier that had previously been introduced into the system by the instructor. The students were asked to complete each test as many times as required in a time interval of 30 minutes or until all the correct answers had been presented. In the second part, neural network-based feedback (i-SIDRA) was not provided and the anonymous mode in SIDRA (a conventional audience response system session, which is a preliminary version of the tool [23]) was used to ensure that the students were not identified. A 30-minute test containing the same questions was then given and the instructor gave a short lecture with slides, during which s/he identified which response to each question was correct. A discussion with students regarding the selection of wrong responses then took place in order to clarify any misunderstandings and to resolve doubts or misconceptions about the anatomical topics of theoretical study in the corresponding block. The sessions using the SIDRA anonymous mode were designed according to recommendations for using ARS [31]. Preparing the MCQs was an extremely time consuming task[32], since we attempted to ensure that each question had an explicit pedagogical purpose [33]. The primary objective of the first part was to measure the increase/decrease in the participants' knowledge when using neural network-based audience response technology. The objective of the second part was to clarify concepts or doubts about the thematic block involved in the i-SIDRA test, because most of the students did not know the correct answers during the first part of the process. This second part therefore addressed the confusion and frustration that students may feel when the state of perfect knowledge (all of the questions have been responded to correctly) is not achieved [34].

The questions and feedback (texts, images or videos) related to human anatomy that were used in i-SIDRA are part of the learning material and resources given on the human anatomy (HA) course. The students in the control group received the same information but using a methodology based on traditional lecturing, seminars and face-to-face instruction. In this case, the students did not receive feedback that was customized to their knowledge and behaved as passive subjects during their learning process.

The students that used i-SIDRA received feedback adapted to their knowledge, according to the pattern group in which their MCQ answers were classified. The feedback provided by i-SIDRA aimed to address misunderstood concepts with hints, explanations or concepts with texts, images or videos related to human anatomy to allow the students to effortlessly deduce and comprehend the lesson being taught [34]. In no case did the feedback reveal the correct answer, or even which question the feedback referred to. The students did not know to which questions they had responded correctly. If a student progresses towards a flawless test, given the number of possible combinations of answers, we believe that the increase in his/her score is the result of having reflected on the feedback between one attempt and another, and that this cannot be achieved by means of a trial-and-error strategy. **Fig.1** shows an example of feedback received by a student.

FEEDBACK OF THE KNOWLEDGE STATE 7

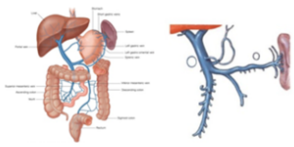
- The laryngopharynx or hypopharynx corresponds to the lower pharynx. It is immediately posterior to the larynx and connects with the esophagus.
- The respiratory and digestive tracts share a common area in the oropharynx, at which point the communication of the oral cavity intersects with the esophagus and the nasal cavities with the larynx.
- 
- The coronary arteries arise from the aortic sinuses of the aortic sigmoid valves in the initial area of the ascending aorta
- 
- The femoral nerve lies in the anterior surface of the thigh. Identify the front and the back of the lower limb.
- It is very important that you can identify the anatomical structures through their relationships. With the knee flexed and fibula as references, you can identify the internal or external positions.

Fig.1–Feedback associated with knowledge state 7.

The final exam was specifically performed for the subject of Human Anatomy in the 1st year of the Pharmacy degree, and consisted of 60 questions directly related to the subjects taught during the term: Gross anatomy and musculoskeletal anatomy of the head, trunk and limbs, the viscera of the head and neck, chest and abdominal cavity, and an introduction to the Nervous System. There were 40 theoretical and 20 practical questions, with four possible choices, only one of which was correct. The same number of questions (15) was posed for each of the four blocks and all the blocks were scored equally. The variable performance was measured by using the score in the final exam. The final exam was scored on a scale of 0 to 10 points. The theoretical part was worth 65% of the final score, and the practical part was worth 35%.

An anonymous survey was carried out to collect feedback about the students' perceptions of their participation in the experiment and their experience with i-SIDRA. A total of 11 questions were formulated using a five-point Likert-type scale (5 = very high; 4 = high; 3 = medium; 2 = low; 1 = very low). The questionnaires were administered by means of paper and pencils in the classroom. The responses to the completed questionnaires were entered on an Excel sheet by the medical instructors for further analysis.

The following hypotheses were investigated in this study:

H1: The final exam grades of the pharmacy degree students who use i-SIDRA will be higher than those of the students who do not use i-SIDRA. Two variables were defined for this statistical hypothesis: Teaching method (independent variable) and Performance, measured by the final exam grades (dependent variable).

H2. The feedback provided by i-SIDRA will help pharmacy degree students to clarify misconceptions about human anatomy. Two variables were defined to test the statistical hypothesis: Time (independent variable), and Correct Responses (dependent variable), which represents the number of correct answers at the beginning or at the end of the experiment.

H3: The final exam grades of the pharmacy degree students, whose performance will improve when using i-SIDRA, will be higher than those of the other i-SIDRA students. Two variables were defined for the statistical hypothesis: Improvement achieved when using i-SIDRA, which was measured by the average of the difference between the scores at the beginning and at the end of the four experiments, and Performance, which was measured by the final exam grades.

H4. Students are satisfied when using i-SIDRA.

The stages of the experiment are outlined in Fig.2.

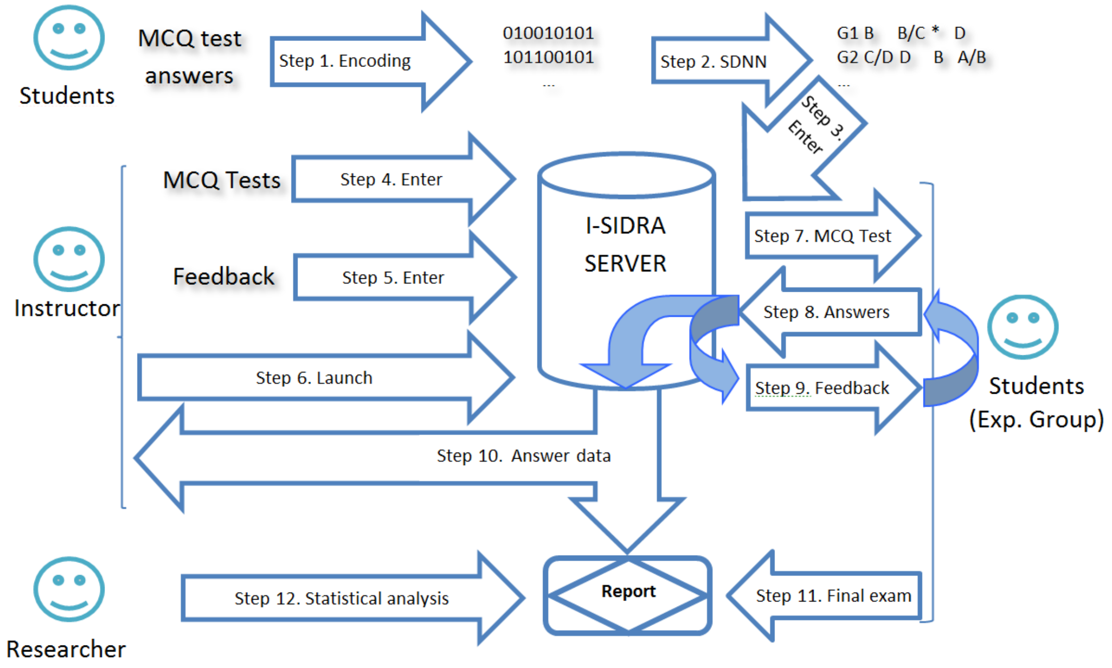


Fig.2–Outline of the experiment carried out.

4. Results

4.1. Performance

Table 1 shows the median, mean, and standard deviation of Performance in the experimental group and the control group. On average, the students using i-SIDRA achieved better results in the final exam than the students in the control group. The students had to have taken at least three or four i-SIDRA tests to be included in the statistical analysis. Note that the results of 11 students in the experimental group were discarded because they did not achieve the threshold of three i-SIDRA tests. The final participation was 44 in the experimental group and 45 in the control group, given that two out of the 46 students who did three or four i-SIDRA tests in the experimental group and six out of the 51 students from the control group did not take the final exam. The students were overworked owing to the difficulty of the first-year pharmacy subjects.

Table 1.Descriptive statistics for Performance."N": Number of students; "M": Mean; "Md": Median; "SD": Standard deviation.

Group	N	M	Md	SD	p
Experimental(i-SIDRA)	44	6.47	6.25	1.48	0.00
Control	45	4.46	4.58	1.38	

A t-test for unpaired samples for the Performance variable was applied which revealed a statistically significant difference ($T(87) = 6.59$; $p < 0.01$) between the experimental group (the students using i-SIDRA) and the control group (those using a traditional learning methodology). These data allow us to accept hypothesis H1. Descriptive statistics regarding the students, attempts and the effectiveness of the feedback in i-SIDRA are provided in Table 2.

Table 2.Detail of the classification of the students and the attempts by experiment.

Description	Exp1	Exp2	Exp3	Exp4
Students				
Total number of students	43	51	46	47
Number of students attaining the “state of perfect knowledge”	23	11	0	9
Number of students not attaining the “state of perfect knowledge”	20	40	46	38
Number of students with only one attempt or submission (students did not receive feedback)	3	1	1	1
Number of students with more than one attempt or submission (students received feedback)	40	50	45	46
Number of students attaining the “state of perfect knowledge” with only one attempt (no feedback)	3	1	0	0
Number of students attaining the “state of perfect knowledge” with more than one attempt (feedback)	20	10	0	9
Attempts				
Total number of attempts	449	294	237	392
Overall time taken to make the attempts (minutes)	685	920	721	879
Average time taken per attempt (minutes)	1.53	3.13	3.04	2.24
Number of attempts per student	10.44	5.76	5.15	8.34
Average time taken per student (minutes)	15.93	18.04	15.67	18.70
Maximum number of attempts made by a student	36	16	15	22
Feedback’s effectiveness				
Number of students with more than one attempt (improvement after feedback)	37	38	23	35
Number of students with more than one attempt (worsening after feedback)	1	5	7	3
Number of students with more than one attempt (neutral after feedback)	2	7	15	8

Pearson’s correlation coefficients were then calculated. The correlation between the number of attempts and the final score is 0.04, 0.16, 0.01 and 0.05 for experiments Exp1, Exp2, Exp3 and Exp4, respectively. The correlation between the time taken per student and the final score is -0.02, -0.19, 0.10 and 0.01 for experiments Exp1, Exp2, Exp3 and Exp4, respectively. This means that no significant relationship with the final score has been found as regards the time taken per student or the number of attempts. Note that many attempts in quick succession, which minimizes the time needed for cognition, may be a sign of guesswork.

4.2 Meta-analysis of knowledge improvement when using i-SIDRA

The increase in the number of correct answers in the four MCQ tests performed during the course was studied with the objective of checking the effectiveness of i-SIDRA. There were average increases of 30.46% (Exp1), 27.72% (Exp2), 12.54% (Exp3) and 30.47% (Exp4) in the number of correct answers. **Table 3** shows the results of the t-test for paired samples regarding the Correct Response variable. This test revealed a statistically significant difference between the correct responses in the first submission (at the beginning of the i-SIDRA session) and the correct responses in the last submission (at the end of the i-SIDRA session) in the four MCQ tests. These data permit us to affirm that the feedback written by academics and received by learners through i-SIDRA allowed the students to clarify misunderstandings and learn new concepts. The students' level of knowledge was therefore increased, thus permitting to accept hypothesis H2.

Table 3.Descriptive statistics and paired Student's t-test results for NumberCorrectAnswers in four experiments. "N": Sample size; "M": Mean; "SD": Standard deviation; "T": T-Student; "p": p value.

Time point	N	M	SD	T	P
FirstTestExp1	43	7.56	1.93	8.29	0.00
LastTestExp1	43	9.86	1.55		
FirstTestExp2	51	5.24	2.33	6.84	0.00
LastTestExp2	51	6.69	2.42		
FirstTestExp3	46	6.07	1.90	3.60	0.00
LastTestExp3	46	6.83	1.76		
FirstTestExp4	47	5.21	2.02	6.47	0.00
LastTestExp4	47	6.96	2.21		

A meta-analysis was then carried out to discover the global effect size of i-SIDRA as regards the students' performance in the class assignment (MCQ tests) in the four experiments. Meta-analytic effect size statistics were calculated by using the fixed effects model [35]. The global effect size was estimated as proposed by Hedges [36]. **Fig.3** shows the forest plot for Correct Responses. The size of the squares in the forest plot represents each experiment's individual weight (Exp1, Exp2, Exp3 and Exp4) and error bars delimit the 95% CI. The weights are proportional to the size of the experiment. The diamond, which is at the bottom of the forest plot, represents the global effect size. For each experiment, values higher than zero of the Hedges' g metric signify that the students achieved higher scores (correct responses) in the last test than they did in the first test when using i-SIDRA. Note that the students obtained better scores in the last test in all the experiments. The global effect size was found to be 0.644 (p=0.000) which, according to Kampenes et al. [37], can be referred to as *medium*. The global effect of i-SIDRA's feedback on human anatomy learning is therefore statistically significant, thus supporting hypothesis H2.

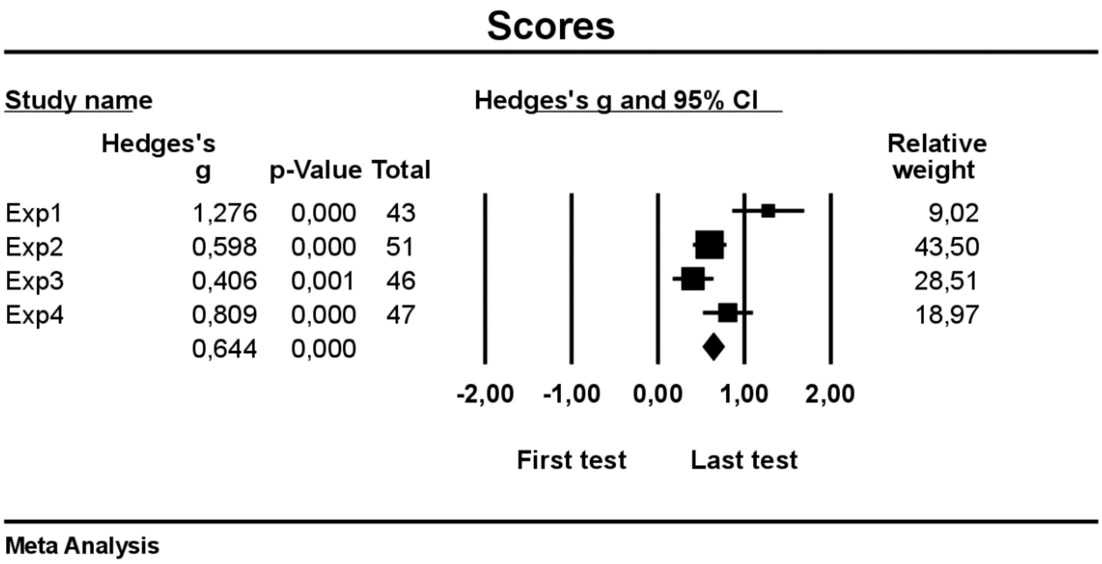


Fig.3 - Forest plots showing a meta-analysis of Correct Responses when using i-SIDRA.

Finally, a low positive correlation (*r*=0.01) between the variable SIDRA Improvement and the Performance was observed when using Pearson's correlation coefficient for the experimental group data. This data led us to reject hypothesis H3.

4.3 Survey

A total of 46 students completed the survey (about 77.90%). The means and standard deviations for the students are shown in **Table 4**.The use of i-SIDRA was positively evaluated by students (median: 4 in Q1-Q2 and Q9, median: 4.5 in Q5, median: 5 in Q3-Q4, Q6, Q8 and Q10-Q11), indicating that hypothesis H4 is supported. Note that these perceptions confirm our findings on the student's performance when using i-SIDRA.

Table 4. Means and standard deviations of students' perceptions. "M": Mean; "SD": Standard deviations.

Id	Question	M	SD
Q1	You are satisfied with the use of i-SIDRA	4.39	0.65
Q2	The time allowed for each activity was sufficient	4.24	0.77
Q3	You found the use of i-SIDRA useful during the course	4.43	0.72
Q4	The i-SIDRA system promotes the clarification and understanding of concepts	4.40	0.86
Q5	The i-SIDRA system favors and improves the learning process	4.43	0.62
Q6	The i-SIDRA system is useful as a self-assessment tool	4.50	0.69
Q7	The feedback received has been useful to improve my learning	3.35	1.22
Q8	I would like to use this system again in other subjects	4.41	0.91
Q9	I believe that the use of this system will positively influence my grades	4.29	0.73
Q10	I found that the content provided and the methodology used in the subject are suitable for learning anatomy	4.59	0.69
Q11	The instructors used and incorporated i-SIDRA appropriately in the classroom	4.78	0.42

5. Discussion

As shown by our findings, learning environments supported by combining the strengths of ARS-mediated instruction and intelligent feedback-based learning can lead to improvements in students' learning and facilitate the acquisition of competencies in pharmacy. The use of i-SIDRA in the classroom setting was a well-received and effective application as regards promoting active learning and critical thinking in pharmacy students. The students reflected on their own learning in each block, through prompt formative feedback. The application also allowed them to identify areas of weakness early in the semester. This leads us to believe that stress and anxiety later in the course may be reduced, which could impact upon their performance in the final exam. This is particularly important for first-year pharmacy students who have significantly higher stressors than older students, as reported in an on-line national survey of 1332 pharmacy students in the US [38].

Our findings support other pharmacy education studies that describe positive student outcomes associated with student engagement [39-45] and performance [3,40,46,42,43] in ARS based learning. In fact, ARS is one of the most commonly used active learning strategies in US Colleges and Schools of Pharmacy [4]. Our experiment has shown that ARSs can be used to practice critical-thinking skills [45] since the MCQs included the determination of pros and cons of different concepts of human anatomy.

The lecturers also took advantage of i-SIDRA to identify blocks or concepts which were problematic. For example, Block 3, which covers the anatomy and viscera of the head and neck, obtained the lowest average increase (12.54%) when compared to Block 1 (30.46%) and Block 2 (27.72%). Since Block 3 built upon previous segments, the improvement in performance was not as evident as in the first two blocks. This indicated to the lecturers that the students had not fully grasped these concepts, thus allowing the instructors to fine tune their style of delivery. After discerning which aspects of the lecture were more or less successful, the instructors revisited the material using the anonymous mode in i-SIDRA and placing special emphasis on incorrectly answered questions. Block 4 obtained a high average increase (30.47%) in the number of correct answers. We suspect that the students may have been more motivated to pay more attention in class and to study at home, since the MCQ tests regarding Block 4 took place close to the final exam.

In the study performed to determine whether the results of individual students in i-SIDRA could predict performance in the final exam, no strong correlation was found between i-SIDRA scores and final exam grades. Only 0.01% of the variability of final exam grades can be explained by the performance of those students that used i-SIDRA in seminars ($r^2 = 0.0001$). This may be owing to the fact that final exam performance can be influenced by many factors: class attendance [47], length and number of examinations [48], students' workload [49], difficulty with assessments earlier in the course [50] and understanding the scoring criteria and the composition of the exam [51], among others.

5.1. Feedback

The average increase in correct answers in our study was significantly higher than in previous experiments carried out on a computer science course (between 0.30% and 5.00%)[26]. This may be justified by the novelty effect of using a mobile technology-based ARS. The increase in the number of correct answers from the first submission to the last submission in the four MCQ tests, with a total of 11, 10, 13 and 10 questions for Exp1, Exp2, Exp 3 and Exp 4, respectively, and four possible answers, could not have occurred by chance. Note that better results were obtained in tests on the gross anatomy and musculoskeletal anatomy of the trunk (thorax, abdomen and pelvis) and upper limb (Block 1), and the nervous system (Block 4). These differences could be owing to the lower complexity of the introductory material in Block 1, and the students' high motivation at a time close to their final exam in Block 4.

Fig.4 presents a knowledge state diagram representing the students' behavior in Exp1. There are fourteen states of knowledge which unite some commonality in the responses to the questions. These states have been organized in five layers: Start, Layer 1 (beginning level), Layer 2 (middle layer), Layer 3 (advanced level), and Final. For example, a student in state 9 may go to state 11, via state 13, before reaching the Final state or 'state of perfect knowledge' which denotes correct answers to all the questions. A knowledge state transition captures the reclassification of the student's knowledge state. Each time a student responds and submits a test, this student is reclassified in a new (or the same) state and receives new (or the same) feedback, if the Final state has not been achieved.

Note that there is a decrease in the average score in Layer 2 (63.30%), the root of which may be that the feedback needed to surpass the states of Layer 2 was insufficient. In fact, knowledge state 12 does not have exit transitions, which means that no student could leave this state. Another evident sign of deficient feedback is a transition in which the target state is the same as the source state (self-transition). Knowledge states 2 and 8 generated between 60 and 80 triggering events in a self-transition. Observe that these states are in Layer 3 (advanced layer). The students' anxiety in these states, with few incorrect answers, may therefore also have resulted in multiple submissions.

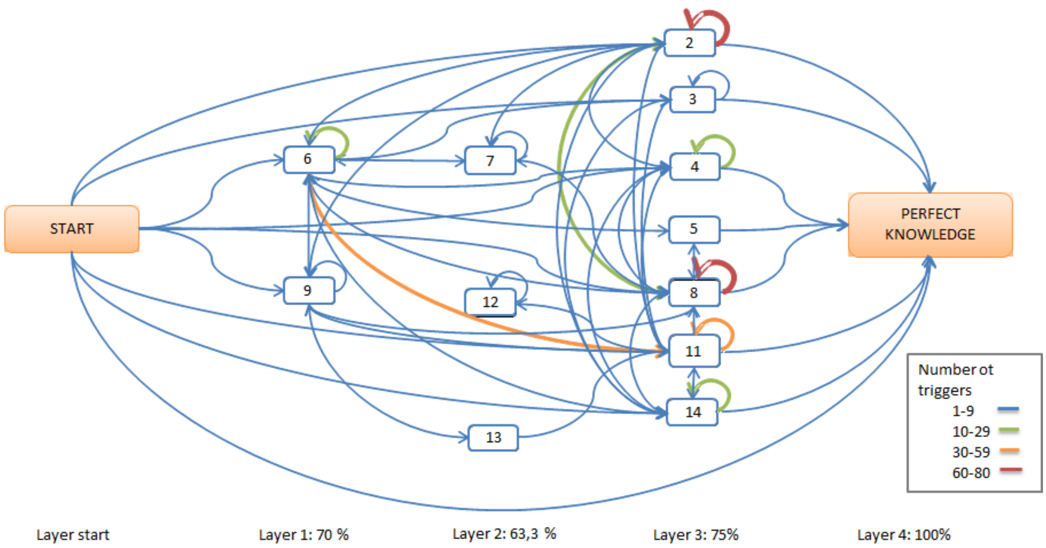


Fig.4 - Knowledge state transitions in Exp1.

The definition of strategies with which to elicit feedback has been identified as one of the hotspots in teaching and learning needs when using ARS [7]. This paper represents a new empirical contribution to the still unexplored field of intelligent ARS in health sciences in general, and pharmacy in particular.

5.2. Survey

Overall, the students' attitudinal responses to i-SIDRA were positive. They expressed satisfaction with the content provided and the methodology used in the process of learning anatomy. This can be attributed to the fact that most of the students surveyed can be classified as belonging to Generation Y [52]. The neural network-based feedback of the i-SIDRA system and its integration with mobile technology address some of the educational preferences of this kind of students.

The survey results showed that i-SIDRA encouraged active learning and helped the students maintain attention, thus improving lecture involvement as reported in previous studies [7,39,46,42,43]. This engagement is particularly critical for first-year pharmacy students, who do not have a background in human anatomy, and thus lack confidence as regards their knowledge of the subject matter. The majority of the students in our survey also reported that the i-SIDRA system promoted the clarification and understanding of concepts (median: 5). These findings are in agreement with those of other studies which report the ability of ARSs to enhance understanding of the material [46,42].

Although the feedback was positively evaluated by the students, this may in their opinion be the weakest point in the system (median: 3). The students' comments during the i-SIDRA sessions allowed us to discover that they wanted to know what questions were incorrectly answered in order to achieve the state of perfect knowledge by using a trial-and-error strategy [34]. However, the aim of the feedback is to help students to clarify misunderstandings and learn new human anatomy concepts. This seems to meet the demanding expectations in the light of the results provided by the meta-analysis which showed that the students' performance in the MCQ tests increased when using the human anatomy feedback generated by i-SIDRA.

While the results shown here relate specifically to the development of human anatomy understanding, there is significant potential for the use of i-SIDRA in other areas of the pharmacy curriculum. The students may also have perceived this benefit, since most of them wanted to repeat the experience in another subject (median: 5), thereby confirming previous findings [42,43].

While the i-SIDRA anonymous mode allowed instructors to determine what percentage of students did not master basic concepts, the anonymity of i-SIDRA let students know the correct answers and determine how to address their own learning needs in the second part of each session. Note that the anonymity conferred by ARS-mode SIDRA is relevant in pharmacy education, as was revealed in a national study of over 10,000 students in 71 schools of pharmacy in the US, in which at least 1 in 5 students scored high for communication apprehension [53].

I-SIDRA also has tremendous potential as a formative assessment tool. E-learning systems [54-57], in general, and intelligent e-learning systems [26], in particular, will likely have an important role in the classrooms of the future. Intelligent tutoring systems and adaptive e-learning environments are an emerging revolution in higher education [58]. These systems adapt content to learners according to learning styles, present this content with the support of expert systems, and assess the extent to which students grasp concepts. The amount of money that students must spend to purchase clickers has been cited as one of the drawbacks of adopting an ARS in the classroom [33]. This is not a problem in the case of i-SIDRA, since 96% of students own at least one mobile IT device (a laptop, tablet, or smartphone), which is in keeping with the findings of a survey performed with Dutch university students [59].

Note that the use of instructional media has no effect if they are not accompanied by an appropriate instructional method [60]. Different learning and assessment strategies (peer-based learning, classroom discussion, the requirement of student preparation before class, interaction, attention, contingent teaching, summative assessment) can be used with an ARS [24]. How an ARS is used will determine its effectiveness. In our proposal, the design of the feedback and the formulation of the questions, taking into consideration well-established recommendations, will dictate the success or failure of the teaching and learning process. Moreover, all teaching methods have limitations. A mixture of methods is often needed to ensure that students are appropriately trained. These must be adapted to the learning context and matched to a particular learning audience by a skilled instructor.

5.3. Limitations

Preparing the MCQs and appropriate feedback text for each of the group of students' possible responses was an extremely time consuming task [32], since we attempted to ensure that each question had an explicit pedagogical purpose [33]. When writing feedback, academics confront a difficult task since the feedback should not be over-detailed so as to avoid confusing the students and to ensure that they can easily interpret it and get the point [61]. The purposes of the MCQs were to elicit, probe, and challenge students' ideas as regards Human Anatomy. The questions included in the MCQ tests were prepared to test remembering, understanding, applying and analyzing, according to the Bloom's

Taxonomy. Moreover, all the questions had to be clear, with different learning aims in order to avoid redundancy in the feedback. Note that the instructors provided i-SIDRA with a piece of text, image or video for each incorrect choice in each MCQ. i-SIDRA then automatically generated the feedback for each pattern grouping. If the atomic feedback associated with each incorrect response is similar, the feedback formed for a pattern grouping could contain redundant information. Nevertheless, instructors could adapt the resulting feedback in order to better guide students towards the concepts of anatomy being taught. However, the responses used to train i-SIDRA system that generate the groups (states of knowledge with regard to the questions formulated in the test) are obtained from previous cohorts of students, thus making it difficult to obtain this information.

As with any new technology, appropriate training may become a barrier. As reported in [7], all faculty members who use an ARS should receive appropriate training in its use. Initial training and a follow-up session addressing any identified issues allow other faculty members to learn from their peers' experiences. Another concern was the malfunctioning of i-SIDRA: mis- or non-recorded answers, a registered answer different to that clicked, among others. Previous studies have also reported complaints about classroom time being used to set up the ARS [23,62]. No problem was found in our experiments, since the i-SIDRA technology worked well and fitted into the course for both the pharmacy students and instructors. Another major limitation to the success of i-SIDRA was the instructors' time constraintsduring the educational session. Lecture times must be planned to allow tests to be given, the presentation of the results, and discussions on responses to questions. This may lead faculty members to feel that the use of i-SIDRA reduces the amount of material covered. Nevertheless, our experience confirms that the faculty members involved in the experiment plan to continue using i-SIDRA.

6. Conclusions

A new educational tool for the diagnostic evolution of students' knowledge levels through feedback has been presented. The most innovative aspect of the proposal is the use of a neural network to discover groups of similar answers that represent students' different knowledge states [26]. The results of our experiment show that the use of i-SIDRA system improves the pharmacy student learning process. Statistically significant differences were found in the following respects: (1) the final exam grades of students who used i-SIDRA, which were higher than those who did not use i-SIDRA; (2) the feedback provided by i-SIDRA helped students to clarify misconceptions; (3) students were satisfied when using i-SIDRA.

In order to address future directions, we intend to prepare an experiment to study the long-term retention of the lecture material when using i-SIDRA versus a traditional learning methodology. The student responses obtained in the study presented here will be used to retrain the neural network, which may result in new groups. The feedback will be enriched if new groups are generated. We also plan to extend i-SIDRA to provide instructors with a full set of tools with which to investigate the progress of the class's knowledge level over time in general, and each student's knowledge state in particular. This feature will make it easier to identify the common mistakes made by the students and to study how individual students' learning is influenced by the feedback.

Authors' contributions

José Luis Fernández Alemán contributed to the following: the conception and design of the study, acquisition of data, analysis and interpretation of data, drafting the paper and approval of the version submitted. Laura López González, Ofelia González Sequeros, made the following contributions to the study: design of the four i-SIDRA tests and their feedback, acquisition of data, analysis and interpretation of data, drafting the paper and approval of the version submitted. Chrisina Jayne and Juan José López Jiménez provided support to integrate the Snap-Drift Neural Network into i-SIDRA, drafted and reviewed the paper, and approved the version submitted. Juan Manuel Carrillo de Gea and Ambrosio Toval reviewed the paper and approved the version submitted.

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References

1. Hohlfelder B, Stashek C, Anger K, Szumita P (2015) Utilization of a Pharmacy Clinical Surveillance System for Pharmacist Alerting and Communication at a Tertiary Academic Medical Center. J Med Syst 40 (1):1-7
2. Martín D, Alcarria R, Sánchez-Picot Á, Robles T (2015) An Ambient Intelligence Framework for End-User Service Provisioning in a Hospital Pharmacy: a Case Study. J Med Syst 39 (10):1-10
3. Satyanarayanajois SD (2010) Active-Learning Exercises to Teach Drug-Receptor Interactions in a Medicinal Chemistry Course. Am J Pharm Educ 74 (8):147

4. Stewart PDW, Brown SD, Clavier CW, Wyatt J (2011) Active-Learning Processes Used in US Pharmacy Education. Am J Pharm Educ 75 (4):68
5. Prince M (2004) Does Active Learning Work? A Review of the Research. J Eng Educ 93 (3):223-231. doi:10.1002/j.2168-9830.2004.tb00809.x
6. Blasco-Arcas L, Buil I, Hernández-Ortega B, Sese FJ (2013) Using clickers in class. The role of interactivity, active collaborative learning and engagement in learning performance. Comput Educ 62:102-110. doi:http://dx.doi.org/10.1016/j.compedu.2012.10.019
7. Cain J, Robinson E (2008) A Primer on Audience Response Systems: Current Applications and Future Considerations. Am J Pharm Educ 72 (4):77
8. Bruff D (2009) Teaching with Classroom Response Systems: Creating Active Learning Environments. Jossey-Bass. doi:citeulike-article-id:9759093
9. Schick P, Abramson S, Burke J (2011) Audience response technology: under-appreciated value of post hoc analysis. Med Educ 45 (11):1157-1158. doi:10.1111/j.1365-2923.2011.04084.x
10. Latessa R, Mouw D (2005) Use of an audience response system to augment interactive learning. Fam Med 37 (1):12-14
11. Pradhan A, Sparano D, Ananth CV (2005) The influence of an audience response system on knowledge retention: An application to resident education. Am J Obstet Gynecol 193 (5):1827-1830. doi:http://dx.doi.org/10.1016/j.ajog.2005.07.075
12. Gauci SA, Dantas AM, Williams DA, Kemm RE (2009) Promoting student-centered active learning in lectures with a personal response system. Adv Physiol Educ 33 (1):60-71
13. Nájera A, Villalba JM, Arribas E (2010) Student peer evaluation using a remote response system. Med Educ 44 (11):1146-1146. doi:10.1111/j.1365-2923.2010.03837.x
14. Bhargava P, Lackey AE, Dhand S, Moshiri M, Jambhekar K, Pandey T (2013) Radiology Education 2.0—On the Cusp of Change: Part 1. Tablet Computers, Online Curriculums, Remote Meeting Tools and Audience Response Systems. Acad Radiol 20 (3):364-372. doi:http://dx.doi.org/10.1016/j.acra.2012.11.002
15. Garbutt JM, DeFer TM, Highstein G, McNaughton C, Milligan P, Fraser VF (2006) Safe Prescribing: An Educational Intervention For Medical Students. Teach Learn Med 18 (3):244-250. doi:10.1207/s15328015tlm1803_10
16. Turban JW (2009) The audience response system: a modality for course evaluation. Med Educ 43 (5):488-489. doi:10.1111/j.1365-2923.2009.03348.x
17. Carrion I, Fernandez Aleman J, Toval A (2012) Personal Health Records: New Means to Safely Handle our Health Data? IEEE Comput 45 (11):27-33. doi:10.1109/mc.2012.74
18. Zapata B, Fernández-Alemán J, Idri A, Toval A (2015) Empirical Studies on Usability of mHealth Apps: A Systematic Literature Review. J Med Syst 39 (2):1-19
19. Ouhbi S, Fernández-Alemán J, Toval A, Idri A, Pozo J (2015) Free Blood Donation Mobile Applications. J Med Syst 39 (5):1-20. doi:10.1007/s10916-015-0228-0
20. Fernández-Alemán J, Seva-Llor C, Toval A, Ouhbi S, Fernández-Luque L (2013) Free Web-based Personal Health Records: An Analysis of Functionality. J Med Syst 37 (6):1-16. doi:10.1007/s10916-013-9990-z
21. Ozdalga E, Ozdalga A, Ahuja N (2012) The Smartphone in Medicine: A Review of Current and Potential Use Among Physicians and Students. J Med Internet Res 14 (5):e128. doi:10.2196/jmir.1994
22. Juanes J, Ruisoto P (2015) Computer Applications in Health Science Education. J Med Syst 39 (9):1-5
23. Fernández-Alemán JL, Sánchez-García AB, López-Montesinos MJ, Jiménez-Lopez JJ (2014) Examining the Benefits of Learning Based on an Audience Response System When Confronting Emergency Situations. CIN-Comput Inform Nu 32 (5):207-213

24. Kay RH, LeSage A (2009) A strategic assessment of audience response systems used in higher education. Australian Journal of Educational Technology 25 (2):235-249
25. Lee SW, Palmer-Brown D, Tepper JA, Roadknight CM Snap-drift: real-time, performance-guided learning. In: Neural Networks, 2003. Proceedings of the International Joint Conference on, 20-24 July 2003 2003. pp 1412-1416. doi:10.1109/ijcnn.2003.1223903
26. Fernandez-Aleman JL, Palmer-Brown D, Jayne C (2011) Effects of Response-Driven Feedback in Computer Science Learning. IEEE T Educ 54 (3):501-508. doi:10.1109/te.2010.2087761
27. Brown DP, Draganova C, Sin Wee L Snap-drift neural network for selecting student feedback. In: Neural Networks, 2009. IJCNN 2009. International Joint Conference on, 14-19 June 2009 2009. pp 391-398. doi:10.1109/ijcnn.2009.5178859
28. Lee SW, Palmer-Brown D, Roadknight CM (2004) Performance-guided neural network for rapidly self-organising active network management. Neurocomputing 61 (0):5-20. doi:http://dx.doi.org/10.1016/j.neucom.2004.03.001
29. Lee SW, Palmer-Brown D, Roadknight C Reinforced snap-drift learning for proxylet selection in active computer networks. In: Proceedings of IEEE International Joint Conference on Neural Networks, 25-29 July 2004 2004. pp 1545-1550. doi:10.1109/ijcnn.2004.1380185
30. Palmer-Brown D, Jayne C (2013) Self Organisation and Modal Learning: Algorithms and Applications. In: Bianchini M, Maggini M, Jain LC (eds) Handbook on Neural Information Processing, vol 49. Intelligent Systems Reference Library. Springer Berlin Heidelberg, pp 379-400
31. Robertson L (2000) Twelve tips for using a computerized interactive audience response system. Med Teach 22 (3):237-239
32. Allen D, Tanner K (2005) Infusing Active Learning into the Large-enrollment Biology Class: Seven Strategies, from the Simple to Complex. Cell Biol Educ 4 (4):262-268. doi:10.1187/cbe.05-08-0113
33. Caldwell JE (2007) Clickers in the large classroom: current research and best-practice tips. CBE Life Sci Educ 6 (1):9-20
34. Guo R, Palmer-Brown D, Lee SW, Cai FF (2014) Intelligent diagnostic feedback for online multiple-choice questions. Artif Intell Rev 42 (3):369-383. doi:10.1007/s10462-013-9419-6
35. Hunter JE, Schmidt FL (2000) Fixed effects vs. random effects meta-analysis models: implications for cumulative research knowledge. Int J Sel Assess 327 (8):272-292
36. Hedges L, Olkin I (1985) Statistical Methods for Meta-Analysis. Academia Press,
37. Kampenes VB, Dyba T, Hannay JE, Sjøberg DI (2007) A systematic review of effect size in software engineering experiments. Inform Software Tech 49 (11-12):1073-1086
38. Votta RJ, Benau EM (2014) Sources of stress for pharmacy students in a nationwide sample. Currents in Pharmacy Teaching and Learning 6 (5):675-681. doi:http://dx.doi.org/10.1016/j.cptl.2014.05.002
39. Clauson KA, Alkhateeb FM, Singh-Franco D (2012) Concurrent Use of an Audience Response System at a Multi-Campus College of Pharmacy. Am J Pharm Educ 76 (1):6. doi:10.5688/ajpe7616
40. McLaughlin JE, Gharkholonarehe N, Khanova J, Deyo ZM, Rodgers JE (2015) The Impact of Blended Learning on Student Performance in a Cardiovascular Pharmacotherapy Course. Am J Pharm Educ 79 (2):24. doi:10.5688/ajpe79224
41. Medina MS, Medina PJ, Wanzer DS, Wilson JE, Er N, Britton ML (2008) Use of an Audience Response System (ARS) in a Dual-Campus Classroom Environment. Am J Pharm Educ 72 (2):38
42. Slain D, Abate M, Hodges BM, Stamatakis MK, Wolak S (2004) An Interactive Response System to Promote Active Learning in the Doctor of Pharmacy Curriculum. Am J Pharm Educ 68 (5):1-9

43. Lymn JS, Mostyn A (2010) Audience response technology: Engaging and empowering non-medical prescribing students in pharmacology learning. BMC Medical Education 10:73-73. doi:10.1186/1472-6920-10-73
44. Cain J, Black E, Rohr J (2009) An Audience Response System Strategy to Improve Student Motivation, Attention, and Feedback. Am J Pharm Educ 73 (2):21
45. Poirier TI (2008) A Seminar Course on Contemporary Pharmacy Issues. Am J Pharm Educ 72 (2):30
46. Trapskin P, Smith K, Armitstead J, Davis G (2005) Use of an Audience Response System to Introduce an Anticoagulation Guide to Physicians, Pharmacists, and Pharmacy Students. . Am J Pharm Educ 69 (2):190-197
47. Landin M, Pérez J (2015) Class attendance and academic achievement of pharmacy students in a European University. Currents in Pharmacy Teaching and Learning 7 (1):78-83. doi:http://dx.doi.org/10.1016/j.cptl.2014.09.013
48. Cor MK, Peeters MJ (2015) Using generalizability theory for reliable learning assessments in pharmacy education. Currents in Pharmacy Teaching and Learning 7 (3):332-341. doi:http://dx.doi.org/10.1016/j.cptl.2014.12.003
49. Cleland J, Arnold R, Chesser A (2005) Failing finals is often a surprise for the student but not the teacher: identifying difficulties and supporting students with academic difficulties. Med Teach 27 (6):504-508. doi:10.1080/01421590500156269
50. Yates J (2011) Development of a 'toolkit' to identify medical students at risk of failure to thrive on the course: an exploratory retrospective case study. BMC Medical Education 11:95-95. doi:10.1186/1472-6920-11-95
51. Froncek B, Hirschfeld G, Thielsch MT (2014) Characteristics of effective exams—Development and validation of an instrument for evaluating written exams. Stud Educ Eval 43:79-87. doi:http://dx.doi.org/10.1016/j.stueduc.2014.01.003
52. Eckleberry-Hunt J, Tucciarone J (2011) The Challenges and Opportunities of Teaching “Generation Y”. Journal of Graduate Medical Education 3 (4):458-461. doi:10.4300/jgme-03-04-15
53. Berger B, Baldwin H, McCroskey J, Richmond V (1983) Communication apprehension in pharmacy students: a national study. Am J Pharm Educ 47 (2):95-102
54. Gazibara T, Marusic V, Maric G, Zaric M, Vujcic I, Kisic-Tepavcevic D, Maksimovic J, Maksimovic N, Denic L, Grujicic S, Pekmezovic T, Grgurevic A (2015) Introducing E-learning in Epidemiology Course for Undergraduate Medical Students at the Faculty of Medicine, University of Belgrade: A Pilot Study. J Med Syst 39 (10):1-7
55. Menendez E, Balisa-Rocha B, Jabbur-Lopes M, Costa W, Nascimento JR, Dósea M, Silva L, Lyra Junior D (2015) Using a virtual patient system for the teaching of pharmaceutical care. International Journal of Medical Informatics 84 (9):640-646
56. Reis LO, Ikari O, Taha-Neto KA, Gugliotta A, Denardi F (2015) Delivery of a urology online course using moodle versus didactic lectures methods. International Journal of Medical Informatics 84 (2):149-154
57. Sowan AK, Idhail JA (2014) Evaluation of an interactive web-based nursing course with streaming videos for medication administration skills. International Journal of Medical Informatics 83 (8):592-600
58. Özyurt Ö, Özyurt H, Baki A (2013) Design and development of an innovative individualized adaptive and intelligent e-learning system for teaching–learning of probability unit: Details of UZWEBMAT. Expert Syst Appl 40 (8):2914-2940. doi:http://dx.doi.org/10.1016/j.eswa.2012.12.008
59. Kobus MBW, Rietveld P, van Ommeren JN (2013) Ownership versus on-campus use of mobile IT devices by university students. Comput Educ 68 (0):29-41. doi:http://dx.doi.org/10.1016/j.compedu.2013.04.003

60. Clark R (1994) Media will never influence learning. Educ Tech Res 42 (2):21-29. doi:10.1007/bf02299088
61. Hatziapostolou T, Paraskakis I (2010) Enhancing the impact of formative feedback on student learning through an online feedback system. Electron J E-Learn 8 (2):111-122
62. Stuart SAJ, Brown MI, Draper SW (2004) Using an electronic voting system in logic lectures: one practitioner's application. J Comput Assist Lear 20 (2):95-102. doi:10.1111/j.1365-2729.2004.00075.x