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Taking the pulse of a classroom with a gamified audience response system

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KEYWORDS:

E-LEARNING, HUMAN ANATOMY, GAMIFIED AUDIENCE RESPONSE SYSTEM, HEART RATE VARIATIONS, EXPERIMENT

Abstract

Background and Objective: This paper presents an empirical study of a gamified mobile-based assessment approach that can be used to engage students and improve their educational performance.

Method: A gamified audience response system called G-SIDRA was employed. Three gamification elements were used to motivate students in classroom activities: badges for achievements to increase engagement, points to indicate progression and performance in the subject and ranking for promoting competitiveness. A total of 90 medical students in a General and Descriptive Anatomy of the Locomotor System course were taught using G-SIDRA in the academic year 2019/2020. Smart bracelets were configured to collect heart rate measurements from 30 students with the aim of evaluating the impact of the gamification elements. The control group consisted of a sample of 110 students enrolled on the same course in the academic year 2016/2017 using non-gamified SIDRA.

Results: Statistically significant differences were found between multiple choice questions (MCQ) scores obtained by using SIDRA and G-SIDRA in the four experiments ($U = 1.621,50$, $p < 0,01$ for Exp1; $U = 1.950,00$, $p < 0,01$ for Exp2; $U = 955,00$, $p < 0,01$ for Exp3; $U = 2.335,00$, $p < 0,01$ for Exp4). In the students' final exam grades, statistically significant differences between students that used G-SIDRA as opposed to SIDRA ($T(157) = 3.992$; $p = 0.044$) were obtained. Concerning gamification elements, statistically significantly differences were found in comparing the pulse increases after and before the badge event in the four experiments ($U = 2.484,00$, $p = 0,038$ for Exp1; $U = 2.109,50$, $p = 0,046$ for Exp2; $U = 1.790,50$, $p = 0,025$ for Exp3; $U = 1.557,0$, $p = 0,048$ for Exp4). However, there are not statistically significant differences between the pulse increases after and before the ranking event in the four experiments. In a 5-point Likert-type scale, the students expressed satisfaction with G-SIDRA ($M=4.552$) and thought the system helped to better understand both theoretical and practical concepts ($M=4.092$). Their global assessment of the G-SIDRA platform was 4.471.

Conclusions: Of the three gamification elements used in the study, only badge has an effect on heart rate. Better student responses and academic performance were achieved when using G-SIDRA. Nevertheless, more research is required to evaluate the impact of the gamification elements on the motivation, engagement and performance of students. Physiological measures are promising approaches for gamification elements evaluation.

1. Introduction

Clicker is an in-class interactive tool that allows instructors to survey students to receive instant feedback on their performance in a short amount of time [1]. In the beginning of these systems, clickers were physical handheld pieces which allowed students to respond to questions proposed by lecturers in class. A response receiver plugged into a USB port received the students' choices. Nowadays, clickers have been migrated into a web-based system and students use their mobile phones as handheld devices.

Other synonymous are used for referring to Clicker such as Audience Response System (ARS), Electronic Response Systems (ERS), Student Response Systems (SRS) and Classroom Response System (CRS). CRS has been used in many educational establishments [2] [3] [4]. These systems are also being used successfully in health science degrees [5] [6] [7] [8] [9]. There is evidence that CRS has an important impact on conceptual knowledge [10]. CRS usually employs multiple-choice questions (MCQs) but other kinds of questions are also used such as open-ended and true/false questions. CRS combined with MCQs is an invaluable instrument for medical education since it provides instructors with marking in a reliable and objective manner to measure complex abilities and understanding [11].

Gamification has been widely applied in the different educational disciplines with different outcomes. Gamification has been also used in contexts other than the educational one such as market, health, sustainability work [12]. Game elements such as points, levels, badges, quests, avatar, social reputation and ranking among others are used to motivate and attract user into an activity. All of them are intended to ensure user commitment and motivation to perform their tasks. Generic benefits are reported in previous literature related to gamified systems. Gamification allows students to improve their skills and knowledge [13] stimulate motivation and interest in the learning process [14] [15] and increase the quality of the performed work. Points and rankings have been reported as the most used gamification elements [16]. Research showed that badges, leaderboards, and performance graphs positively have an impact on competence need satisfaction and perceived task meaningfulness [17]. A meta-analysis of 30 independent interventions (3,202 participants) drawn from 24 quantitative studies examining the impact of the gamification on student academic performance showed a medium effect size in favor of gamification over learning without gamification [18].

In recent years, biometric data have been used to measure human emotions [19] and cognitive activity [20]. Among the diverse physiological measurements that can be used, heart rate (HR) is now the peripheral measure most used to assay affect and cognition [21]. The improvement of wireless biometric sensors leads researchers to use them in learning contexts since they enable to monitor students' physiological state in a non-intrusive manner in a classroom. HR monitors have been used to asses students engagement during lecture classes aiming at evaluating different classroom events or activities [22] and, gathering information which allows teachers to intervene in the learning process as soon as he/she detects that a student is not engaged [23]. HR also correlates well with student attention across a lecture [24]. Moreover, active learning sessions with peer-discussion can increase learners' heart rate [22]. Therefore, the use of biometric sensors in education is a promising approach to improve the learning process and students´ outcomes since teachers could adapt they activities and methods according the emotional state of the classroom.

In this paper, an empirical study of a gamified mobile-based assessment approach is proposed. The gamified SIDRA or G-SIDRA (Sistema De Respuesta Inmediata de la Audiencia in Spanish), a mobile gamified audience response system, was used. G-SIDRA is a client-server application endowed with three gamification elements: ranking, badges and points. We intend to engage students in the educational process and improve their academic performance. To the best of the authors' knowledge, no other studies have measured gamified CRS using student's heart rate analysis. The results of this experiment will be used to improve anatomy of locomotor system education which is one of the traditionally more difficult and strongest courses of the first year in the Bachelor of Medicine.

The remainder of this paper is organized as follows. The "Method" section shows the participants in the experiment when giving a course on the anatomy of the locomotor system, the experimental design undertaken, the instruments used and the hypotheses driving our research. The "Instruments" subsection provides a brief description of the Gamified SIDRA, the smart bracelets, the mobile and web applications called Health Supervisor used in the experiment, and describes the security measures adopted in the Health Supervisor System. The "Results" section presents the results obtained after testing the four hypotheses on a sample of 90 students. In the "Discussion" section, the paper analyzes and examines the findings on G-SIDRA and compares them with those of other studies. Finally, the "Conclusions" section outlines some concluding remarks and identifies future research.

2. Method

A detailed overview of the experiment conducted to assess the educational effectiveness of G-SIDRA is provided in this section.

2.1. Participants and Data Collection

The sample of the study consisted of 110 and 90 first-year medical students of the course General Anatomy of Human Musculoskeletal System (GAHMS) of the academic year 2016/2017 and 2019/2020, respectively, at the OMITTEDFORREVIEW. GAHMS is taught in the first term and deals with general anatomy with a focus on the morphology of bone, joint and muscle systems. GAHMS was divided into 3 topics: Block 1: Overview of gross anatomy and musculoskeletal anatomy of the trunk (pelvis, abdomen and thorax); Block 2: Introduction to musculoskeletal anatomy of the lower and upper limbs; Block 3: Musculoskeletal anatomy of the head and neck. Students have to complete a total of 6 ECTS credits which are distributed into 4 h/week of lectures and 2 h/week of skills practice during a period of 15 weeks.

A recruitment session was organized during which the students were encouraged to participate. The students received a written and verbal presentation that underlined the aim of the study, and a description of the procedures and tools used. Prior to the study, ethical approval was sought from the Ethics Committee of OMITTEDFORREVIEW. The study was also approved by the researchers' institution data protection authority. The inclusion criteria for participants were as follows: (1) being enrolled in GAHMS, (2) willing to participate in the study and (3) willing to sign the informed consent. The exclusion criteria for participants were as follows: (1) being a repeater in GAHMS. Students who fulfilled inclusion criteria signed the written consent form before taking part in this study. Students could leave the study at any time without detriment to their educational results.

2.2. Design

Two versions of SIDRA in the context of medical practice were implemented for comparison. An experimental group of 90 students, which used G-SIDRA in the academic year 2019-2020, and a control group comprising 110 participants used SIDRA in the academic year 2016-2017. The same teaching method was applied in both groups. Moreover, the same training concerning GAHMS skills and knowledge was given. The process of giving and collecting the bracelets in class is lengthy as it is individualized. The control and monitoring of the data collected through the Health Supervisor System during the learning activities is also time-consuming. Therefore, for the sake of a manageable experiment, smart bracelets were configured and randomly given to a 30 out of 90 students in the experimental group for the four experiments related with heart rate variations. Heart rate measurements were collected with the aim of evaluating the impact of the gamification elements.

Data were collected at four time points: (1) demographic data were gathered from all the participants prior to the educational intervention; (2) four experiments consisting of MCQ tests concerning gross anatomy and musculoskeletal anatomy of the trunk (Exp1), musculoskeletal anatomy of the lower limbs (Exp2), musculoskeletal anatomy of the upper limbs (Exp3) and musculoskeletal anatomy of the head and neck (Exp4) were taken by the experimental group student using G-SIDRA and the control group students using SIDRA; (3) the pulse increases of two events were collected: the badge event (BE) and the ranking event (RE); (4) a five-point Likert-type questionnaire was administered to evaluate the students' experience during the use of G-SIDRA.

All of the questions were designed by taking into account up-to-date literature regarding current recommended medical practice and recommendations concerning MCQ-writing [25]. Moreover, the questionnaires included between 10 and 14 questions to avoid the fatigue effect.

2.3. Instruments

This section presents the tools used in the study to gamify the class activities as well as monitor and control the students´ heart rate.

2.3.1. Gamified SIDRA (G-SIDRA)

G-SIDRA is an application with a client-server architecture and has two interfaces for two kinds of users: students and instructors. This tool is an extension of SIDRA [26], a tool which allows a teacher to create, collect and analyze answers to MCQ tests. Points are given to students for each response based on correctness and response time, and are used to award badges and establish a ranking. Both web and mobile versions are available.

In G-SIDRA, a test consists of a list of MCQs related to a specific topic. A student can view the MCQs, respond to the questions, and know the rate of correct responses to each question during the online session. A teacher can add students and form teams, build and run an MCQ test, export the results of a test, and show the information related to students' answers along with individual and group ranking. Teachers must first request a G-SIDRA account from the administrator to gain access. There is an individual score and a team score. The team score is obtained from the scores of all team members. Fig. 1 and Fig. 2 depict points, individual ranking and team classification implemented in G-SIDRA, which are shown at the end of each questionnaire.

Clasificación

Global en el cuestionario 4t11r por el grupo ANAGEDES 19

Posición	Nombre	DNI	Seudónimo	Puntuación	Equipo
GOLD	[illegible]	[illegible]	Fran	5920	PALATINO
SILVER	[illegible]	[illegible]	Alejandro C	5360	ESFENOIDES
BRONZE	[illegible]	[illegible]	Tm19	5200	PALATINO
4	[illegible]	[illegible]	Teresa	5190	ESFENOIDES
5	[illegible]	[illegible]	Alejandra	5110	ESFENOIDES
6	[illegible]	[illegible]	Patricio	5080	PALATINO

Fig. 1 – Individual ranking of a test.

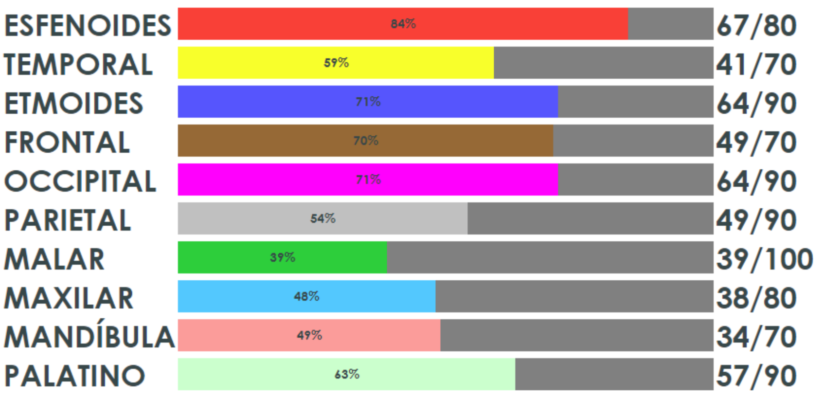


Fig. 2 – Results of the test by team

G-SIDRA was extended to record every action made by the teacher and the exact time when it occurs. Although for the purpose of this experiment only two events (badge event and ranking event) were taken into account, the following actions are monitored in G-SIDRA: launching and closing both test and question, viewing results (percentage of answer in each choice), showing the correct answer, the badge event which consisted of the awarding of badges to the three best students and teams, and publishing the ranking event which consisted of showing a ranking of individuals and teams after each test. In G-SIDRA the students are registered with their name and surname, so that the results of G-SIDRA can be integrated with the Health Supervisor System.

2.3.2. Health Supervisor System

To collect the heart frequency data from the participants, the Health Supervisor System was developed. This system consists of the following elements:

1. Smart bracelets. The smartband was an A6 model and featured an Hs6620D CPU with 128 KB RAM, 1M ROM and an EM7028 heart rate sensor. This smart bracelet also featured a 1.3 inch TFT display screen and a 180 mAh battery. These devices allow us to capture heart rate, blood pressure, real-time measurement of oxygen in the blood, among others. Each smart bracelet is identified with a number that relates it to the user with whom it is registered. The numbering of the smart bracelets is from 1 to 30 corresponding to the 30 students selected who participated in the four experiments (Fig. 3). Smart bracelets were configured to collect heart rate measurements approximately every 5 seconds. Each smart bracelet is given to a student and this (bracelet, student) association was registered on the server by the system administrator.

Fig. 3 – Box with smart bracelets plugged into the electrical power supply.

2. Mobile application Health Supervisor. This application is developed with the hybrid development framework for mobile applications Ionic [27]. The backend part for the services of this application is developed with NodeJS [28] . This application uses Bluetooth communication to connect to the smart bracelet configured to obtain a person's vital signs. The data, once obtained, is sent to a server to be stored. The mobile application "Health Supervisor" (Fig. 4) is published in Google Play [29] and Apple Store [30] for Android and iOS respectively.

The first time the application is opened a username and password is requested. Credentials were given to the students. Once authentication is completed, the application automatically connects to the smart bracelet based on the previously established association. Since that time, the user's heart rate data can be obtained.

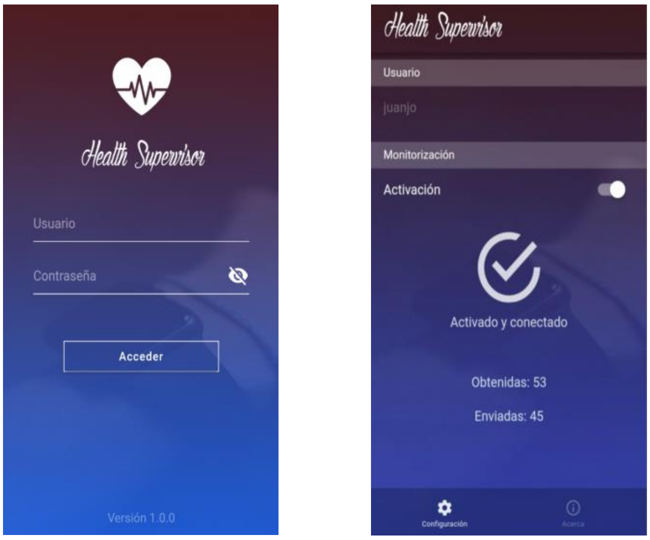


Fig. 4 – Log in of the mobile application Health Supervisor in Google Play and Apple Store.

3. Web application Health Supervisor. The web application "Health Supervisor" is developed in Angular 8 [31] for the frontend and in NodeJS for the backend. To monitor the data extraction process, a dashboard is available for the instructor through website [32]. The following data can be obtained in real time: (1) the last real-time measurement taken about each student, (2) the date of the last recorded measurement and (3) the smart bracelets that are working correctly. Notice that an (red/blue) indicator associated to each smart bracelet (user) shows if data are being sent: blue and red colors indicate that data have been sent in the last 5 minutes or not, respectively as shown in Fig. 5.

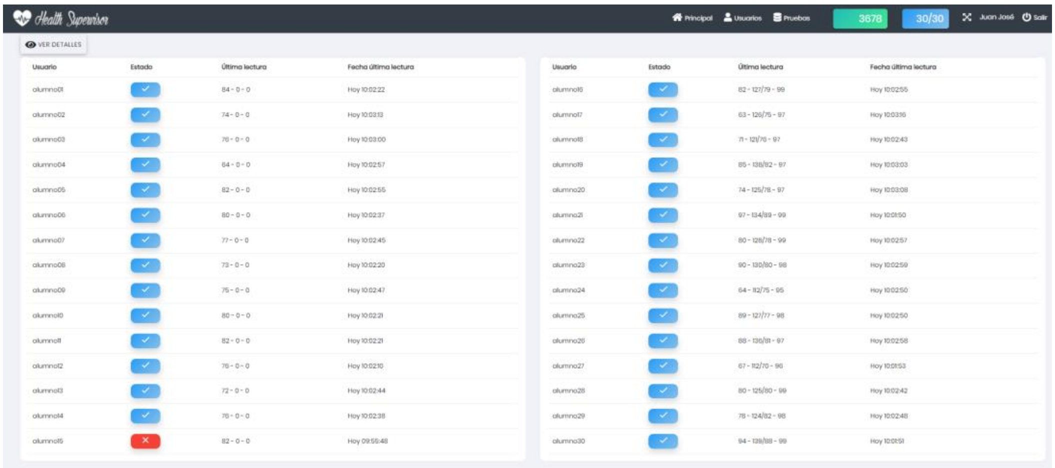


Fig. 5 – Dashboard of web application Health Supervisor.

2.3.3. Security

Two-factor authentication was implemented for the instructor to access the Health Supervision System. This system manages heartbeat data that is considered especially sensitive. The first factor is something the user knows (a password) and the second factor is something the user has (verification code sent by a SMS).

Once the association bracelet-student is created by the teacher, the system can start to capture data. For the sake of security, a process of de-identification is applied. The data collected from smart bracelets, as well as the association between smart bracelet and student's identifier (student1, student2, etc.) are stored in the server. The association between student's identifier and student's surname are not stored in the server. This relation is exported in a file with AES encryption. Therefore, information is protected by an encryption algorithm. In this way, the teacher preserves and keeps in custody identifying information which can be re-linked to analyze and contrast collected data with the student's performance. Other security measures are: (1) a history log is generated so any access or query to the system is recorded; (2) a temporary access lock is performed in case of several incorrect attempts; (3) encryption of the mobile application code and low-level hiding of decryption keys and server API access keys to reduce the attempt of improper access to the server; (4) communications between the client and server are encrypted by SSL; (5) authorization control with JWT. Fig. 6 summarises the process followed to design and run the experiment.

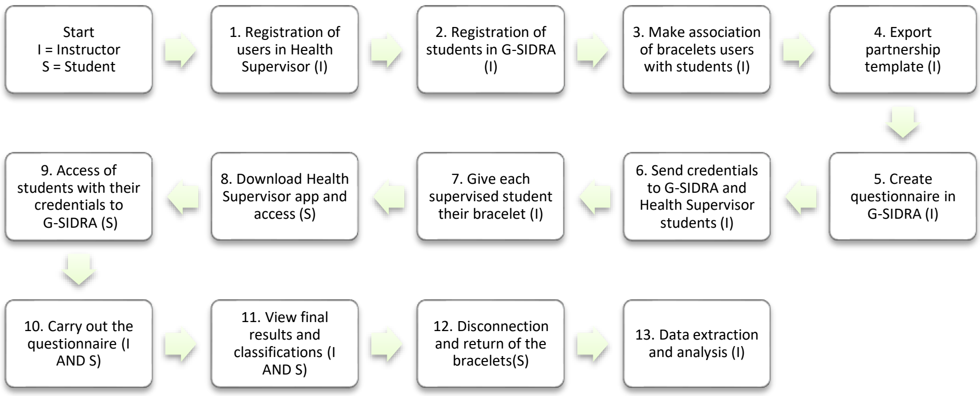


Fig. 6 – Process followed in the intervention

3.3. Hypotheses

The following hypotheses were investigated:

H1: The G-SIDRA and SIDRA MCQ scores and the final exam grades of the students who use G-SIDRA will be higher than those of the other students who used SIDRA. One independent variable named EducationalTool, with two values, G-SIDRA and SIDRA, was defined. Two dependent variables, Score (H1.1) and Performance (H1.2), measured using correct answers normalized on 10 and final exam grades, respectively, were employed to test the statistical hypothesis. The experimental group (G-SIDRA) consisted of students enrolled on the academic course 2019/2020 and the control group was formed by students enrolled on the academic course 2016/2017.

H2. The gamification elements used in G-SIDRA encourage students to attend and participate in class. Two happening events were studied: ranking based on points and badges. Notice that two gamification elements were analysed in the same event. The points and ranking position associated with each student were displayed for the first time at the ranking event. One independent variable (*TimePoint*) and one dependent variable (*PulseIncreases*, measured using the difference between two consecutive keystroke's captures for each student) were defined to test the statistical hypothesis. Time intervals with the same length were used before and after the events. In particular, time lapses of 30 seconds for collecting data were established for ranking and badges events, respectively.

H3. Students are satisfied when using G-SIDRA. A questionnaire using a five-point Likert-type scale was used. The means, standard deviations and medians obtained were calculated for each question.

4. Results

4.1 Knowledge improvement in using G-SIDRA versus SIDRA

Statistically significant differences were found between MCQ scores obtained by using SIDRA and G-SIDRA in each of the four experiments (U = 1.621,50, p < 0,01 for Exp1; U = 1.950,00, p < 0,01 for Exp2; U = 955,00, p < 0,01 for Exp3; U = 2.335,00, p < 0,01 for Exp4). Therefore, this study delivers partially the results predicted by the hypothesis H1 as shown in Table I.

Table I. Descriptive statistics and Mann-Whitney U Test results for MCQ Score in four experiments. "N": Sample size; "M": Mean; "SD": Standard deviation; "U": Mann-Whitney U Test; "P": p value.

Time point	N	M	SD	U	P
MCQScoreSIDRAExp1	70	5,257	2,319	1.621,50	0,00
MCQScoreG_SIDRAExp1	80	6,821	1,752		
MCQScoreSIDRAExp2	80	4,362	2,581	1.950,00	0,00
MCQScoreG_SIDRAExp2	83	6,024	1,773		
MCQScoreSIDRAExp3	57	3,891	1,791	955,00	0,00
MCQScoreG_SIDRAExp3	85	5,988	1,599		
MCQScoreSIDRAExp4	83	5,518	2,008	2.335,00	0,00
MCQScoreG_SIDRAExp4	86	6,709	1,548		

Table II shows the descriptive statistics (median, mean, and standard deviation) for Performance. On average, the students in the experimental group (using G-SIDRA) achieved better results in the final exam than those in the control group.

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

Group	N	M	Md	SD
Experimental (G-SIDRA)	73	7,447	7.760	1,330
Control (SIDRA)	86	6,437	6.730	1,781

A pretest was administered to participants to determine the equivalence of the group control and experimental group in terms of their understanding and knowledge of anatomy before the intervention. A t-test for unpaired samples revealed no statistically significant difference in pretest mean scores between the experimental and control groups (T(157) = 0.375; p = 0.705). A t-test for unpaired samples for the

Performance variable was applied. The results revealed that with the usual 95% confidence interval, there was a statistically significant difference when the students used G-SIDRA versus the students employing a non-gamified CRS such as SIDRA (T(157) = 3.992; p = 0.044). The data therefore suggests that the incorporation of G-SIDRA allowed the students to gain knowledge, thus confirming hypothesis H1.

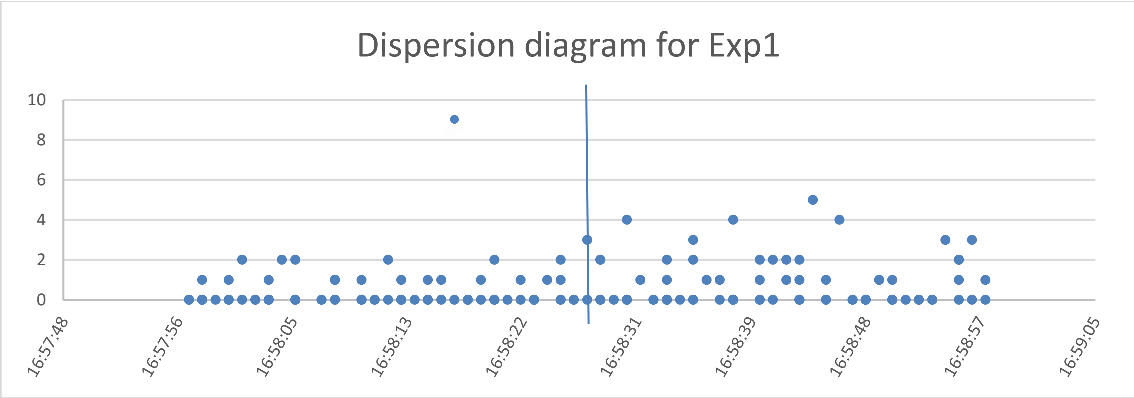
4.2 Effect of the gamification elements in students when using G-SIDRA

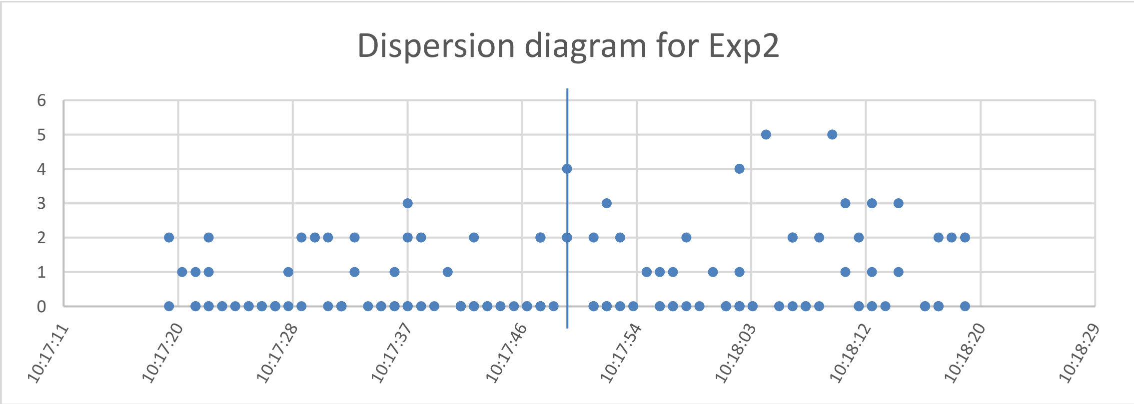
The rise in the pulse increases for two events in the four experiments was studied in order to check the impact of the gamification elements on the students. From the statistical results shown in Table III, it can be concluded that the pulse increases after the badge event was statistically significantly higher than the pulse increases before this event in the four experiments (U = 2.484,00, p = 0,038 for Exp1; U = 2.109,50, p = 0,046 for Exp2; U = 1.790,50, p = 0,025 for Exp3; U = 1.557,0, p = 0,048 for Exp4). However, there are not statistically significant differences between the pulse increases after and before the ranking event in the four experiments. These data suggest that only the badge event encouraged students, thus leading us to accept partially hypothesis H2.

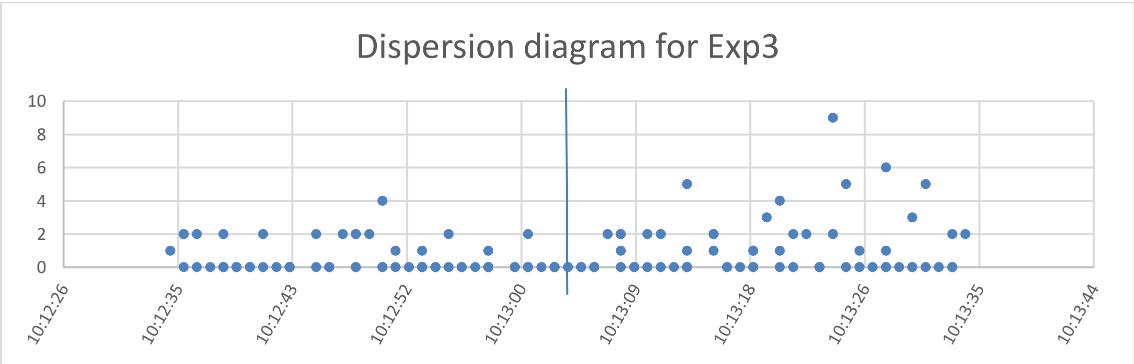
Table III. Descriptive statistics and Mann-Whitney U Test results for PulseIncreases in four experiments. "N": Sample size; "M": Mean; "SD": Standard deviation; "U": Mann-Whitney U Test; "P": p value.

Time point	N	M	SD	U	P
VariationsBeforeExp1RE	55	1,309	2,062	1.853,00	0,073
VariationsAfterExp1RE	57	,824	1,477		
VariationsBeforeExp2RE	48	1,25	1,494	1.154,00	0,988
VariationsAfterExp2RE	48	1,145	1,184		
VariationsBeforeExp3RE	40	,775	1,025	763,00	0,334
VariationsAfterExp3RE	43	1,162	1,541		
VariationsBeforeExp4RE	34	,882	1,148	564,50	0,543
VariationsAfterExp4RE	36	1,222	1,79		
VariationsBeforeExp1BE	77	,454	1,164	2.484,00	0,038
VariationsAfterExp1BE	77	,805	1,214		
VariationsBeforeExp2BE	71	,450	,806	2.109,50	0,046
VariationsAfterExp2BE	71	,887	1,304		
VariationsBeforeExp3BE	66	,484	,898	1.790,50	0,025
VariationsAfterExp3BE	67	1,104	1,759		
VariationsBeforeExp4BE	60	,55	1,32	1.557,00	0,048
VariationsAfterExp4BE	63	,952	1,372		

Fig. 7 displays graphically the pattern in the distribution of data after and before the badge event in the four experiments. The times of the badge event in each experiment were 16:58:27, 10:17:49, 10:13:04 and 10:09:42 for Exp1, Exp2, Exp3 and Exp4, respectively. Notice that students were excited when the three award-winning individuals and groups were published and the awards were handed out.


Dispersion diagram for Exp1
10
8
6
4
2
0
16:57:48
16:57:56
16:58:05
16:58:13
16:58:22
16:58:31
16:58:39
16:58:48
16:58:57
16:59:05


Dispersion diagram for Exp2
6
5
4
3
2
1
0
10:17:11
10:17:20
10:17:28
10:17:37
10:17:46
10:17:54
10:18:03
10:18:12
10:18:20
10:18:29


Dispersion diagram for Exp3
10
8
6
4
2
0
10:12:26
10:12:35
10:12:43
10:12:52
10:13:00
10:13:09
10:13:18
10:13:26
10:13:35
10:13:44

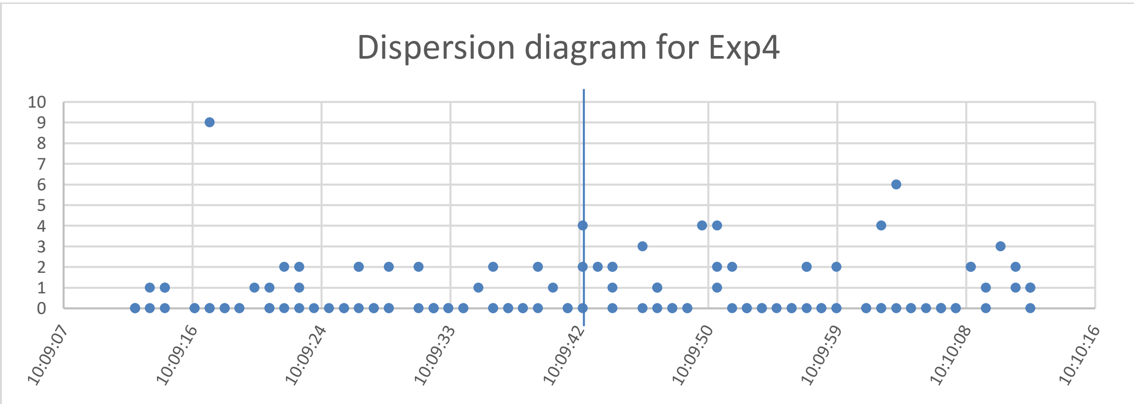

Dispersion diagram for Exp4
10
9
8
7
6
5
4
3
2
1
0
10:09:07
10:09:16
10:09:24
10:09:33
10:09:42
10:09:50
10:09:59
10:10:08
10:10:16

Fig. 7 – Dispersion diagrams of PulseIncreases for badge event in the four experiments. The y-axis represents the pulse increments; the x-axis represents the time.

4.3 Survey

A questionnaire concerning participation in the experiment was filled by students. The aim of this survey was to collect feedback about the students' perceptions in respect of their experience with G-SIDRA. A total of 10 questions were administrated employing a five-point Likert-type scale (5 = very high; 4 = high; 3 = medium; 2 = low; 1 = very low). **¡Error! No se encuentra el origen de la referencia.** shows the means, standard deviations and medians obtained as regards the students' answers. A total of 87 students took part in the survey. This high participation is remarkable taking into account the workload of the students at the end of the semester. The use of G-SIDRA was positively evaluated by the students (median: 5 in Q1, Q2, Q4, Q7, Q9 and Q10), confirming that hypothesis H3 is supported. Moreover, the students expressed satisfaction with the gamification elements used when learning about anatomy (median: 4), acting as a motivating factor in class (median: 5). Particularly, students cited in discussion group sessions comments such as "*What I found most interesting was how G-SIDRA helps you and invites you to keep up to date with the subjects*."; "*I loved it. In addition, G-SIDRA forced me to study and keep up to date on the subject*". Students think that the G-SIDRA allows them to better understand both theoretical and practical concepts (median: 4), and most of them found that working in groups on gamification helps them to improve their learning (median: 4). One student commented "*It helps me enormously to fix ideas with this more than regular examination*". Note that these perceptions confirm the findings obtained in previous sections, in which the scores and final exam grades obtained by the students in four tests were significantly improved after using G-SIDRA. Fig. 8 shows the results of the survey.

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

Id	Question	M	SD	Md
Q1	You are satisfied with the use of G-SIDRA in the classroom?	4.552	0.605	5
Q2	Does G-SIDRA help/motivate you in your learning process?	4.414	0.771	5
Q3	Do you think the system has helped you to better	4.092	0.923	4

	understand both theoretical and practical concepts?			
Q4	Do you think the teacher's immediate explanations (direct feedback) help you in your learning?	4.419	0.901	5
Q5	Do you think that the system has helped you to better understand both theoretical and practical concepts (regardless of the 10% of the grade just for participating)?	3.828	1.059	4
Q6	Do you think the time spent on the activity throughout the course is adequate?	4.149	0.922	4
Q7	Do you think that the gamification award system adds incentives/motivation for class participation?	4.345	1.010	5
Q8	Do you think that working in a group on gamification helps you to improve your learning?	4.218	0.908	4
Q9	Do you think classes are more dynamic, improve the climate in class, are more fun... when using G-SIDRA?	4.655	0.662	5
Q10	Your assessment of the use of the G-SIDRA platform is:	4.471	0.628	5

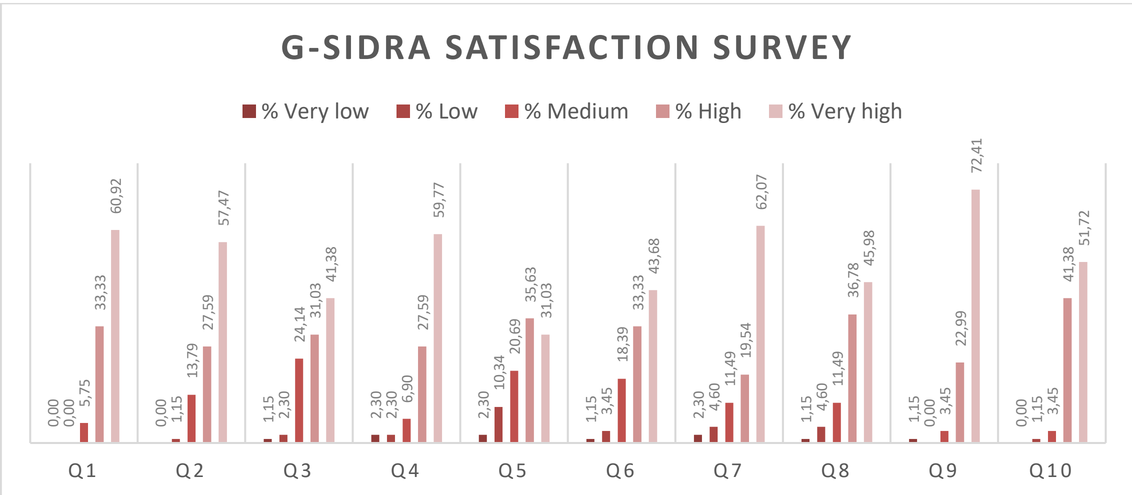


Fig. 8 – Distribution of answers employing a five-point Likert-type scale (from 1 = very low to 5 = very high) considering the use of G-SIDRA.

5. Discussion

5.1. Improving learning outcomes

Gamification has been identified as a promising enabler in education which has a positive effect on students' knowledge retention and is independent of age and gender [16]. This invaluable resource has been successfully used in health sciences education [33] , in general, and anatomy education, in particular [34]. The hypothesis testing in our study has revealed that the experimental group obtained significantly better marks than the control group in the final exam of an anatomy course. These findings confirm previous research on the use of gamified systems [35] [36] [37]. Furthermore, previous experiment examining the effects of points and leaderboard on users' performance showed a significantly increase [38], confirming the effectivity of the gamifications elements employed in our experiment, although no statistically significant differences were obtained in the case of the ranking event. Scientific evidence on the impact of the gamification in anatomy teaching was found in another study [39]. Students achieved significant statistically highest scores in post-test versus pre-test, compared with other two groups using non-gamified approaches. This can be attributed to the fact that gamification can foster intrinsic motivation [40]. Moreover, studies shown that a fun learning environment can reduce psychological distress inherent to medical learners [41]. Students perceived a sense of freedom in his/her actions, feelings of effectiveness when performing activities in G-SIDRA, and the desire to feel connected with other individuals, thus increasing intrinsic motivation [42]. Nevertheless, a study on the effects of gamification in a communication course reported negative effects in the final exam grades [43]. In particular, in the case of rankings, the stress of competition and the stress from inferior performance can produce a poorer sense of competence and autonomy [42], which can a negative impact on the student’s performance. Learners who do not ascend in the rankings may perceive a lack of competence, leading them to discouragement [44]. Therefore, lower performing students do not benefit from the gamified format [45]. This fact was confirmed in our experiment in which no statistically significant differences were found for the ranking event. To mitigate this problem, G-SIDRA showed this event at the end of each test. Moreover, the points were restarted at the beginning of each test. Notice that there are confounding variables which can change the effect of the gamification on students’ motivation. Specifically, students who play video games are more motivated by gamification elements [46].

5.2. Implications of the variations in heart rate

Heart rate and rhythm are largely under the control of the autonomic nervous system. Personal heart rate is an effective tool for measuring the physiological response of students to classroom activities [22]. Previous studies have shown that when playing computer games, emotional arousal may raise the heart rate [47]. Therefore, we can draw from our experiment that the increase in pulses has its origin in the emotional excitement produced by the interaction with the gamification elements. Nevertheless, heart rate variability can also be caused by the release from stress after test [48], when ranking was published, as compared to before and during the examination. Another explanation of the result is that student attention rises during the last minutes of class [49], supported by heart rate measurements which showed a rise at the end of the class period [24].

Therefore, our conclusions need to be taken with a degree of caution and more research is required. Moreover, heart rate has been shown to be an objective measure of engagement [24]. Particularly, attentional engagement may lower heart rate. In fact, no conclusive findings were obtained for the impact of the stress identified by heart rate on the improvement of the student's skills and performance during the training [50]. Low heart rate variations were observed in most events where questions are asked. Students needed to concentrate in order to respond correctly [51]. In our study, this rule was not satisfied in questions 5, 6, 8 and 9 from Exp1 and question 4 from Exp3, where high heart rate variations were achieved. Notice that, increased heart rate correlates with higher cognitive effort and higher-order problem solving [52] [53]. In questions 5 (Exp1) and 4 (Exp3) the lowest success rates were obtained, 50.1% and 46.9%, respectively. Moreover, the highest number of blank answers were achieved, with 20.2% and 28.9%, respectively. These findings can be attributed to the fact that students perceived these questions as very difficult, which was confirmed by medical instructors. Despite the great effort made during lectures or in the discussion group, the large number and complexity of the anatomical structures involved (the inguinal canal, posterior wall of the axilla or supra or infra-piriform foramen) and their complicated language caused a low success rate in questions 5 (Exp1) and 4 (Exp3). Moreover, these questions were difficult to agree on in a group. In contrast, questions 6, 8 and 9 (Exp1) achieved the highest success rates, 83.9%, 85.1 and 91.9% even if these questions referred to non-trivial concepts. The high hit percentage may be due to the topics involved being explained in depth during the classes.

5.3. Survey

The students reported satisfaction with G-SIDRA (Q1) with a similar average mean (4.552) to that obtained in two previous surveys performed by: 114 employees in companies from different countries using Habitica (mean 4.330) [54] and 150 medical students using Kahoot [41]. Students also showed motivation (Q2, mean 4.414) obtaining similar results in other surveys: 67 functional anatomy students with a 50% of participants feeling motivation to put forth a greater effort in preparing for their exams [35], 215 medical and dental histology students using Kahoot (mean 3.000 out of 4) [55], and 65 computer architecture students using Kahoot with a 49% of participants responding “Quite a lot” as regards with Kahoot motivated them to learn [56]. Regarding Q3, G-SIDRA gave students support to better understand theoretical and practical concepts (mean 4.092). However, previous studies [55] obtained a mean of 2.900 out of 5, and a 21% of participants [56] responded “It helps me a lot” considering that the gamified system reinforced what have been learned. Involvement of instructors reported in literature [55] with a mean of 3.5 out of 4 is also confirmed by our study (mean 4.419 in Q4). The answer of our students with regards to improvement of the dynamic and the climate in class (mean 4.655 in Q9) confirmed previous findings with a mean of 4.30 [54] and a percentage of 81.5% [35] informing that participants enjoyed taking part in the tournament. Notice that working in a group on gamification was valued positively as a learning enhancer, confirming a previous experience with Kahoot [41]. To conclude, 96.5% of students indicate that they would like G-SIDRA to be used in other subjects, a similar percentage was found in a previous experience with Kahoot [35].

5.3.1. Participation and interactivity

Learner engagement is one of the most commonly identified benefits which can be achieved using gamification [57] [37] [41]. Our heart rate analysis has shown that the use of a gamified CRS is an effective means to increase student attention. Similar findings for polling technologies were obtained by using brainwave [58]. The high turnout of students in overcrowded classrooms is a highlighted feature of CRS lecture delivery [59], which can be boosted with gamification elements [60]. Gamified polling technology is an invaluable resource to help students maintain attention and motivation during the learning process [35] [61]. In particular, students spend more time studying and gaining more badges, which ultimately increase their performance [62]. Leaderboards have also shown to produce higher interaction with their projects [63]. Previous research showed that students have feelings of efficiency and success while interacting with the gamified environment in using leaderboards and badges [17]. Nevertheless, frequent feedback and personalized guidance is needed to improve utility of badges [62]. Concerning leaderboards, competition brings benefits to students when competitors are of roughly equal ability [63]. Under these circumstances, success at the competition depends on effort.

In our experiment, G-SIDRA was used in the anonymous mode to alleviate anxiety and feelings of embarrassment and intimidation [64]. The students’ anxiety or jealousy is one of the two main reasons for their dislike of gamification based on meta-analysis of 32 qualitative studies [18]. Moreover, tests were accompanied by dialogues in addition to in-depth and broad-ranging discussions, in such a way that students felt connected to their other classmates, specially in student teams sharing common goals.

In the experimental group, the number of students involved on each test was 80, 83, 85 and 86 which shown the increasing interest of the G-SIDRA. This increasing participation can be attributed to gamification, despite the high workload of the students in the form of practices, lectures, and a final examination, which could stop them from going to class. Notice that the dropout rate of the experimental was relatively low (19%). In contrast, 22% of the students in the control group dropped out the final exam. The experimental group students were more encouraged and had more enthusiasm to complete the course.

5.3.2. Satisfaction

A systematic review on gamified e-Health applications found evidences pointing that game mechanics can foster user's satisfaction [65]. Students' satisfaction with gamified CRS use is positively documented in related literature [60]. The reason for this phenomenon may be explained by the fact that game mechanics greatly improves students' satisfaction with a course [43]. In contrast, other studies found less satisfaction in gamified class, and empowerment over time, than those using non-gamified tools [43]. Studies reported that the effect of gamification can be diluted in time, likely due to a novelty effect [45].

Students positively viewed the use of G-SIDRA into lectures (Q1, mean, 4.552). In our opinion, the instructors' experience in CRS approaches had an important impact on the students' perceived satisfaction. Previous studies have identified pedagogical difficulties reported by teachers in using gamified tools: short time to use gamification, lack of student preparedness, and disinterest for preparing gamification [66]. To overcome these drawbacks, our tool provides both students and teachers with a CRS integrated with gamification elements, with minimal student participation in selecting their teams. Furthermore, G-SIDRA has a user-friendly interface and instructors had previously used non-gamified SIDRA. The use of technology is not enough to promote reflection in the classroom, deep knowledge on how to use it is a key factor to benefit from it [67].

Notice that the instability of communication facilities can produce disruptive learning process and have a negative impact on the flow of lectures and discussions [68]. Frustration feelings and distraction are common consequences of a poor communication. Moreover, cyberloafing [69], overload of learning methods [34] and distraction from the academic content due to entertainment features [70] are other problems reported in literature. To prevent communication problems, a computer science technician was always present to cover any eventuality in our experiments. Moreover, the teachers overcame their lack of technical knowledge with great willingness and showed interest in exploiting the approach. The medical instructors were actively aware of what students were doing or thinking in their classroom to stimulate their cognitive processes and avoid cyberloafing.

6. Conclusions

Human anatomy is a key pillar of the medical curriculum. The subject GAHMS is one of the great difficulties that first year medical students have, since it incorporates new concepts not related to previous knowledge of other subjects, and also requires the acquisition of a new, more clinical language. This work reported the benefits of a gamified CRS versus a non-gamified CRS in terms of student scores and academic performance in an anatomy of the locomotor system course. This is especially important in the teaching of human anatomy. As suggested recently [71], human anatomy should be modernized in its learning techniques by making use of 21st century technology (e.g. interactive lectures [72] and virtual reality [73]. Our work may contribute to fill this gap in the teaching of human anatomy.

Heart rate measurements collected by smart bracelets can be used to compare the usefulness and efficacy of different gamification elements. Positive emotions may elicit an increase of heart rate [74]. Empirical research suggests that positive-activated emotions (e.g., enjoyment) are positively related with cognitive elaboration and effort (as behavioral engagement process) [75]. Therefore, heart rate can be considered as a predictor of behavioral and mental effort [22] [76] [77]. Based on these cause-effect relations, we can draw from our experiment that:

- Of the three gamification elements used in the study, only the badge produced an increase in heart rate. The increase in pulses can have its origin in the emotional excitement produced by the interaction with this gamification element [47]. Therefore, the badge can have a positive effect on student in terms of motivation to study and participation in class which was confirmed in our survey. The use of G-SIDRA allows students to know their evolution in the subject of human anatomy during the course of a class, both individually and collectively, working in groups, and gives them the opportunity to be rewarded (gamification elements) which undoubtedly motivates them to improve their learning. Our perception is that the theoretical and practical classes were made more enjoyable, and attendance and participation in the classes increased.

- High variations in heart rate were observed in events involving difficult questions, which required students to concentrate especially hard to respond correctly. Therefore, our study validates the use of heart rate variations as a means of measuring changes in cognitive load in human anatomy students.

Gamification can arouse both negative and positive emotions in students [78]. Although there seems to be evidence in the scientific literature of the positive effect of gamification on student academic performance, the conclusions are not definitive. Educators should have a clear understanding of the advantages and disadvantages of gamification in curriculum design, adopt a reflective approach when integrating game design elements, and taking into account the types of learners and players as well as the overall learning objectives.

More research is required to evaluate the impact of the gamification elements on the motivation, engagement and performance of students, especially in health sciences. The combination of a CRS with gamification elements is a promising approach to address overcrowded classrooms which is one of the traditional issues in education. Moreover, these systems are expected to gain importance, since they enable more enjoyable and sustainable education in the face of the new reality caused by COVID-19. A gamified CRS can be part of a learning management system (LMS) to reduce the number of visits to the education center when teaching does not really require the learner to attend in person.

LMS can also collect and analyze data from learners' on-line activity, including physiological measures for gamification elements evaluation. These data can be used to improve and assure an accurate assessment of the student. On the one hand, the use of educational standards can ease integration of gamified CRS into LMS. On the other hand, educational standards can be used to share and exploit data, easing the collaboration between learning analytics and LMS.

In future work, we also plan to extend the analysis to other gamification elements to finally have a comparative framework in which the most appropriate gamification elements can be selected in each teaching context. Variables such as the type of player, the type of content explained, and the student's mood should be taken into account, since they can have an effect on the effectiveness of gamification elements. We also intend to integrate G-SIDRA into a LMS such as Sakai in order to facilitate the adoption of this type of environment in other disciplines.

Conflict of interest

The authors have no conflict of interest.

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Highlights

- Gamified classroom response increase student's performance
- Badge events in gamified Classroom Response System (CRS) produce heart rate increases
- Students are satisfied using gamified CRS