Application of Competitive Activities to Improve Students' Participation

Virginia Francisco, Pablo Moreno-Ger, and Raquel Hervás

***Abstract*—Making students become intrinsically motivated to participate in daily class activities is an open challenge that has been addressed in different ways. In this paper, we evaluate the impact of an educational innovation project, named TrivialCV, in terms of student motivation, engagement, and learning outcomes. We analyze the impact of two types of activities: multiplayer team-based competitions created for delivery during a live class session, and single player competitions created to be played asynchronously from home. We deployed these activities in two different computer engineering courses (programming fundamentals and operating systems) and used questionnaires, grades, and activity tracking in the virtual campus to evaluate their impact. After the analysis, we can assert that the use of TrivialCV activities was useful for providing additional motivation to the students and improving their engagement with the courses in which they were deployed. TrivialCV activities were very well received by the students, who considered them fun, engaging, and useful.**

***Index Terms*—Competitive and collaborative learning experiences, engagement, participation, learning outcomes, motivation, single player activities, team-based competition activities.**

I. Introduction

The interest in new teaching methodologies that focus on improving students' individual work and class participation has increased in the framework of the European Higher Education Area. The main objective is to move away from the "master class" model, with unidirectional instruction followed by a final examination, to models where students must actively participate in class and perform individual activities [1].

However, increasing class participation and capturing student attention is not easy since students tend to be passive agents in the classroom. There are various ways of involving students, ranging from punitive approaches (students either take part in or do not pass the course) to reward-based approaches (positive points are given if students are involved in in-class activities). Making students to become intrinsically motivated to participate in daily class activities is an open challenge which has been addressed by different authors in the academic field [2]–[4].

Among the approaches to improving education, there is a growing interest in the possibility of using video games for academic purposes. Since the turn of the century, different authors have consistently defended this approach. Their arguments are based on the importance of using activities that motivate people and the benefits provided by games regarding engagement, participation, and appropriation [5]–[14].

A. Harnessing Games in the Classroom

When considering what kind of elements make video games so attractive and motivating, different authors identify some of the characteristics that make them especially engaging for players [15]. Two of the most commonly referenced features are collaboration and competition [16]–[19]. Therefore, a good approach is to use activities based on digital games (or activities which incorporate some kind of gamified experience). This could stimulate collaboration among students and make use of students' competitive nature to increase their motivation.

The field of education, in fact, usually mentions collaboration and competitiveness as ways to increase intrinsic motivation among students. To make the most of these approaches, many authors consider the possibility of organizing structured competitive and collaborative activities in the classroom [20]–[22], as well as the addition of these activities in the evaluation process [16], in a positive light. In particular, competitive and/or collaborative mechanics designed to be played among peers in a classroom environment have demonstrated significant effects in terms of motivation and engagement [23]–[27]. They can also add value in the form of social interaction, an element which is often missing in game-based learning approaches [28], [29].

In practice, however, organizing collaborative or competitive activities using games or other tools is often in conflict with the reality of everyday teaching activity. These approaches always demand a significant amount of extra work for instructors, who tend to already be overloaded [30].

Fortunately, the actual workload in delivering these activities can be alleviated in digital learning scenarios. In past years, universities have adopted models of *blended learning* [31], which combine regular face-to-face classroom activity with the use of virtual learning environments (VLEs), such as Moodle, Sakai, or BlackBoard. Usually, this adoption is not merely the implementation of an isolated system, but these e-learning systems are integrated into the universities' essential services, thereby creating so-called virtual campuses (VCs).

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P. Moreno-Ger was with the Department of Software Engineering and Artificial Intelligence, Universidad Complutense de Madrid, 28040 Madrid, Spain. He is now with the School of Engineering and Technology, Universidad Internacional de La Rioja, 26006 Logrono, Spain (e-mail: pablo.moreno@unir.net).

V. Francisco and R. Hervás are with the Department of Software Engineering and Artificial Intelligence and with the Instituto de Tecnología del Conocimiento (ITC), Universidad Complutense de Madrid, 28040 Madrid, Spain (e-mail: virginia@fdi.ucm.es, raquelhb@ucm.es).

In this way, it is common to use these tools for communicating with students, collecting work, or assigning grades. Therefore, it is possible to use these digital platforms to simplify the management and delivery of different forms of engaging activities, as well as for storing and processing grades and other learning outcomes obtained through these activities.

This idea is in line with the interest that comes from using a VLE as a connection between regular classroom activity and other activities supported by information technologies, such as the use of virtual worlds [32] or educational video games [33]. In fact, these e-learning environments are some of the most affordable approaches to employ in these types of activities.

We have joined these three notions (the interest in gamified competitive or collaborative activities, the challenge of integrating them in the classroom, and the availability of VLEs) in the development of an educational innovation project named TrivialCV (CV is the Spanish abbreviation for "virtual campus" (*campus virtual*)). The idea behind this project is to increase participation and engagement using simple gamification principles. We approach engagement as a measure of whether the introduction of these experiences results in better and more active student participation in the day-to-day activities of the course. To do so, we intend to help teachers prepare competitive and collaborative learning experiences in which students are asked questions based on the course syllabus while reducing the teachers' workload as much as possible.

B. The TrivialCV Project

TrivialCV is designed based on the mechanics of the popular Trivial Pursuit game, where students answer preformulated questions. As in Trivial Pursuit, some elements of the game are due to chance. For example, questions are selected randomly from a group of categories. This kind of Trivial Pursuit design offers the advantages of being easy for students to understand and, at the same time, the excitement of competitive mechanics in a game [34].

The TrivialCV system, however, is not merely limited to showing questions and answers. It is also designed to facilitate the instructors' task by providing a visual editor to create question groups and, most importantly, to be integrated with a virtual learning environment to manage student lists, team creation and the storage and management of learning outcomes.

The project proposes, in turn, two types of activities: multiplayer team-based competitions created for delivery during a live class session and single-player competitions created to be played asynchronously from home. As we describe in detail, each tool serves a different purpose when deployed in a specific course. In short, the multiplayer version of TrivialCV serves to encourage class participation, while the single player version encourages individual work in complementary activities.

C. Research Questions

In this work, we present our analysis of the impact of both approaches in terms of student motivation, participation, and engagement, and learning outcomes. We have focused on students enrolled in a computer engineering program, an often-targeted audience for serious game approaches [35]. In particular, we deploy the activities in two specific courses: a first-year course on programming fundamentals (PF) delivered in the first semester and a more advanced course on operating systems (OS) delivered in the fifth semester.

Both courses have a strong technical part, which is taught and graded using practical programming assignments. However, both courses also incorporate a share of theoretical content. This is especially the case in the operating systems course, which is graded using a two-part examination which includes short questions about theoretical concepts, and open-ended questions about practical solutions. These courses are nontrivial and are chosen as a vehicle for answering the following three research questions:

- RQ1. *Are these tools effective in motivating students?* This research question studies whether these games and their competitive/collaborative approaches are effective in motivating students by providing an attractive experience. Are they fun to play? Do students spend time improving their results? Do they recommend that their fellow students participate?
- RQ2. *Does the application of these tools result in increased participation and engagement?* We approach engagement as a measure of whether the introduction of these experiences results in better and more active student participation in the day-to-day activities of the course. Typical students tend to decrease their class participation as the course progresses and the examination period approaches, and they tend to procrastinate participating in these activities in favor of the final examination, an attitude which goes against the principles of progressive skills development.
- RQ3. *Is there an increase in student performance after using these tools?* Higher motivation and better student engagement are important goals on their own, although it is desirable for educational intervention to result in a better transfer of knowledge. To answer this research question, we take a threefold approach.

The four main notions covered by these research questions form a cycle (see Fig. 1), in which providing fun and attractive activities should result in higher motivation. In turn, this motivation should result in higher engagement with the content, which is manifested as a higher level of student participation in day-to-day activities. This higher participation should result in increased performance, which in turn can boost motivation in students (even if it is only a perceived increase in motivation).

The rest of this article is structured as follows: In Section II we describe the developed gamified tools, as well as how we structure different teaching and research activities, aimed at answering our three research questions. In Section III, we present the results of the different activities and then discuss their implications in Section IV. Finally, in Section V, we summarize our main conclusions and present some further steps in this line of work.

Fig. 1. Relationship among the proposed research questions.

II. Methods

The aforementioned research questions we established according to typical assesment approaches for serious games [36], with a special focus on the least intrusive methods, especially after-action questionnaires and indirect measurements such as time spent interacting with the games, comparison of activity in the virtual campus or comparison of actual grades.

Aiming for simplicity and low-impact interventions, we opted for direct questions as opposed to using formal evaluation instruments, an approach which is consistent with similar case studies in the literature [36]–[38].

A. Materials

To explore the effect that competitive activities can have on student participation and motivation, multiplayer team-based competition using TrivialCV is carried out in three scenarios: a laboratory session in the programming fundamentals (PF) course, and two theoretical sessions during a course in operating systems (OS). Students are also provided with a single-player version of the game to prepare for their examinations at home. After the competitions and after using the single player version of TrivialCV, the students answered different questionnaires.

1) TrivialCV: The TrivialCV tools were developed as part of a series of teaching innovation projects, funded by the Universidad Complutense de Madrid (UCM) University, aimed at exploring new approaches to engage students and improve their day-to-day involvement as opposed to focusing on a final examination. Two different tools were created (see Fig. 2).

- TrivialCV multiplayer version. In this version, students are divided into four teams and receive points for correct answers to preformulated questions. This version was designed to be used during a classroom session, streamlining the preparation, management, and development of competitive activities in the classroom. In addition to this, the instructors' work is facilitated through integration with an existing virtual campus. The system downloads lists of students from the virtual campus, prepares groups, manages competitions and, finally, uploads the results into the same virtual campus as an additional activity to be included in evaluations.
- TrivialCV single player version. In this version, the player competes against the stopwatch instead of another team of students. Instead of being given a specific time limit for answering each question, the player has 3 minutes to answer as many questions as possible. As the player answers questions correctly and incorrectly, bonuses or penalties are accumulated on the time counter, respectively. The initial time, as well as bonuses and penalties, are designed for a total game time of approximately 10 minutes. The students are expected to play at home, at their own pace, as many times as they wish. In addition to this, the tool can publish rankings on the virtual campus using the scores obtained by all students, tapping into the competitive nature of some students.

The tools were also created with a special focus on lowering the level of instructor effort, who are already overloaded by the new methodologies required in the European Higher Education Area. TrivialCV's questions editor, which generates question sets compatible with both tools, is available to the teachers for these courses. For these experiments, they created two question databases to be displayed in TrivialCV, one per course (programming fundamentals and operating systems).

2) Data collection: The collection of data was aligned with the evaluation of each specific activity, rather than having separate interventions for each research question. The three main approaches to data collection were the use of questionnaires, the statistical analysis of access logs to the virtual campus, and the analysis of participation and performance results during the final examinations of these courses.

Two questionnaires were designed by the researchers: one

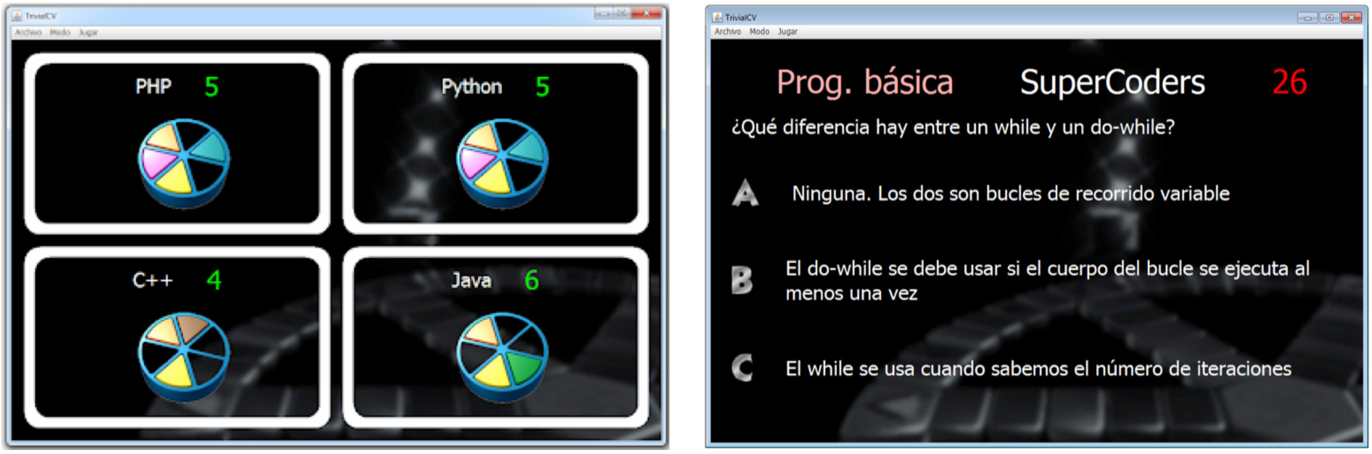


Fig. 2. Screenshots of the TrivialCV tools. (a) Multiplayer version for in-class team competitions. (b) Single-player version designed to compete against the clock.

for the in-class multiplayer team competition and the other for the single player competition.

In the questionnaire for the in-class multiplayer team competition, students were asked about their perceptions of the competition, the tools and their overall experience. The questions, detailed in Table I, all used a 5-point Likert-scale format, where 1 meant "strongly disagree" and 5 meant "strongly agree." In addition to this, information was collected on whether or not the team to which the student belonged was the winner of the competition. A blank space was also provided for students to include additional suggestions for improvement.

In the questionnaire for the single player competition, students were asked about their perceptions and usage of the tool. This questionnaire is shown in Table II. Students rated most questions in a 5-point Likert-scale format, where 1 meant "strongly disagree" and 5 meant "strongly agree." Exceptions were questions Q2.24 and Q2.25, which were answered in a true-false format. In addition to this, information about the time the student was using the tool was collected (Q2.20), and a blank space was available for students to provide additional feedback or suggestions for improvement.

Students filled out both questionnaires anonymously.

B. Participants

Participants were students in the programming fundamentals (PF) and operating systems (OS) courses from the computer engineering program at Complutense University of Madrid. Participation in the experiments was voluntary, and students provided their informed consent.

Regarding the in-class multiplayer team competition, the PF session was attended by 35 students (7 females and 28 males) ranging in age from 18 to 23 years, and the OS session was attended by 25 students (5 females and 20 males) ranging in age from 20 to 32 years old. Participation in PF was above the average class attendance, which was usually between 20 and 30 students, while in OS, it was in line with regular class attendance.

In the single player competition, which was only available in the OS course, 33 students participated (8 females and 25 males), ranging in age from 20 to 32 years old.

Given that the experiments were conducted during computer engineering courses, all participants were university students with an above-average proficiency in using computer systems.

C. Procedure

In one academic year, we performed different teaching and research activities around the two versions of the TrivialCV tool. These activities were scheduled and designed prioritizing a coherent approach for students and teachers, focusing on their learning experience over rigid experimental restrictions.

Therefore, rather than setting up different experiments for each research question, we leveraged each teaching activity to collect data potentially pertaining to different research questions. More specifically, we performed two different types of activities.

1) In-class multiplayer team competitions: Two in-class team competitions with the multiplayer version were organized: one with the students of the programming fundamentals (PF) course in the last week of the first semester (this is a two-semester course) and another in the course of operating systems (OS), halfway through the course.

At the beginning of these sessions, students accessed the laboratory and were asked to organize themselves in teams of 4 to 8 students. Before starting, they were informed of the experimental nature of the session and that at the end of the experience, they would be asked for their opinion through an anonymous questionnaire.

The game session lasted approximately an hour, and after finishing the competition but before leaving the laboratory, all students completed the questionnaire for the in-class multiplayer team competition shown in Section II-A2.

2) Single-player competitions: After the team competition and until the day of the examination, the students in the operating systems course could access the single player version deployed in the virtual campus of the UCM. It was configured so that students could play as many times as they wanted, and the virtual campus would keep the highest score obtained so far. In addition to this, a public ranking was regularly updated in the virtual campus with the scores obtained by all students

TABLE I
CONTENT OF QUESTIONNAIRE 1, WHICH WAS COMPLETED BY STUDENTS CONCERNING THE MULTIPLAYER VERSION OF TRIVIALCV

	Question	RQ
Q1.1	The activity was fun	RQ1
Q1.2	The activity was more fun than a problem-solving class	RQ1
Q1.3	I liked the format of the activity (team competition)	RQ1
Q1.4	I prefer individual competitions	RQ1*
Q1.5	I prefer noncompetitive activities	RQ1*
Q1.6	I liked the mechanics of the game	RQ1*
Q1.7	I liked the appearance of the game	RQ1*
Q1.8	I would prefer a more colorful appearance	RQ1*
Q1.9	I would prefer a more serious appearance	RQ1*
Q1.10	The activity was more useful than a problem-solving class	RQ2
Q1.11	This activity should be done in future editions of this course	RQ2
Q1.12	I would like to do this activity again during this course	RQ2
Q1.13	I would like to do this activity in other courses	RQ2
Q1.14	The activity was effective as a review exercise	RQ3

The RQ column indicates the research question associated with each questionnaire question. The mark * designates specific questions about game design and usability.

TABLE II
CONTENT OF QUESTIONNAIRE 2, WHICH WAS COMPLETED BY STUDENTS CONCERNING THE SINGLE-PLAYER VERSION OF TRIVIALCV

	Question	RQ
Q2.1	The activity was fun	RQ1
Q2.2	The activity was more fun than a theory review class	RQ1
Q2.3	The activity was more fun than an hour of theory study	RQ1
Q2.4	The activity was more fun than a team competition in class	RQ1
Q2.5	The tool was easy to use	RQ1*
Q2.6	I liked the format of the activity (individual competition with public ranking)	RQ1*
Q2.7	I prefer team competitions	RQ1*
Q2.8	I prefer private rankings	RQ1*
Q2.9	I liked the mechanics of the game	RQ1*
Q2.10	I liked the appearance of the game	RQ1*
Q2.11	I would prefer a more colorful appearance	RQ1*
Q2.12	I would prefer a more serious appearance	RQ1*
Q2.13	I would prefer to play only the multiplayer version	RQ1*
Q2.14	I would prefer to play only the single player version	RQ1*
Q2.15	I would prefer that both versions of the tool were offered	RQ1*
Q2.16	This activity should be done in future editions of this course	RQ2
Q2.17	I would like to do this activity in other courses	RQ2
Q2.18	The activity was more effective than an hour of theory study	RQ2
Q2.19	I have studied more than I would have studied without the tool	RQ2
Q2.20	How long do you think you have been playing with the single player version in the virtual campus?	RQ2
Q2.21	The activity was effective as a review exercise	RQ3
Q2.22	The activity was more effective than a theory review class	RQ3
Q2.23	The activity was more effective than a team competition in class	RQ3
Q2.24	Has the tool helped you study?	RQ3
Q2.25	Has the tool helped you refresh your knowledge?	RQ3

The RQ column indicates the research question associated with each questionnaire question. The mark * designates specific questions about game design and usability.

to explore their competitive nature. In this stage, statistical data on access were collected. In addition to this, a message board was opened on the virtual campus to discuss the problems and limitations of the tool with the students.

Students were informed that it was a voluntary activity and that it would have no impact on their final grade. Even so, many students used the application and participated very actively in the message board, providing comments, suggestions, and bug reports.

Immediately before the examinations, students who had used the single player tool were asked to complete the questionnaire for the single player competition shown in Section II-A2.

D. Data Analysis

All the data collected from the questionnaires were analyzed, calculating for each Likert-scale question the mean, the standard deviation, the median, and the quartiles, together with the frequency, for each possible Likert value.

We were also interested in whether having won the team competition would influence the assessment, for which we used the Wilcoxon two-sample test to analyze. To study whether the time spent with the single player version of TrivialCV was related to the answers given by the students to Questionnaire 2, we used Spearman correlation coefficients.

These questionnaires and the other sources of data served in different ways toward reaching the goal of answering each of the three research questions, as detailed below:

1) RQ1—Assessing student motivation: To study motivation, we analyzed responses to questions Q1.1 to Q1.3 from Questionnaire 1 and Q2.1 to Q2.4 from Questionnaire 2. We gathered data from both courses (programming fundamentals and operating systems) separately since different course features could alter student perceptions.

In addition to this, questions Q1.4 to Q1.9 from Questionnaire 1 and Q2.5 to Q2.15 from Questionnaire 2 (marked with an * in both tables) were used to validate the specific game approach, including aspects such as game mechanics, usability, and other design choices within the game. These perceptions are also related to student motivation since an adequate and attractive experience can also be a driver for motivation.

2) RQ2—Assessing student participation and engagement: We measured participation and engagement by studying responses to questions Q1.10 to Q1.13 from Questionnaire 1 and to Q2.16 to Q2.20 from Questionnaire 2.

In addition to this, we collected access logs to the virtual campus during the course and compared them with access data from the previous academic year. An increase in access rates would indicate a higher engagement. To determine whether the difference between the access rates in both years was significant, we used Student's t-test.

3) RQ3—Assessing transfer of knowledge: To assess the transfer of knowledge, we analyzed responses to questions Q1.14 from Questionnaire 1 and to Q2.21 to Q2.25 from Questionnaire 2.

In addition to this, we checked whether students with a high performance while playing the game obtained better grades in their examinations using Spearman correlation coefficients. This approach is informative since this correlation does not necessarily imply causation.

Finally, we compared the average grades of students from the study year with the grades from the previous academic year, checking for significance using Student's t-test.

III. Results

In this section, we present the results of the different questionnaires, tests, and evaluations used during our study. They are presented focusing on each individual activity, while their relevance in answering the different research questions is discussed in Section IV.

A. Questionnaire Results

Questionnaire 1 (see Table I) gathered student opinions about the attractiveness of the multiplayer team competition and the overall game experience, usability and effectiveness. The responses, a total of $N = 35$ for the course of programming fundamentals and a total of $N = 18$ for operating systems, were generally positive and are detailed in Tables III and IV, respectively. The distributions of the responses are presented in Figs. 3 and 4.

We also analyzed whether there were any correlations between winning the team competition and the responses to Questionnaire 1. To do this, we used the Wilcoxon two-sample test. The results are shown in Table V. The only relevant correlation observed appeared in the responses to Q1.14 in the programming fundamentals course. In this case, students who did not win the competition tended to consider the exercise *more useful* as a study activity than those who won.

Questionnaire 2 (see Table II) collected student impressions about the single player version of TrivialCV, which was available to students of the operating systems course. A total of 33 students accessed this single player version, but only $N = 13$ completed the questionnaire. Their responses also indicated a good perception of the tool. The results are presented in Table VI, and the distribution of responses is presented in Fig. 5.

We also analyzed whether the time spent using the single-player version of TrivialCV (Q2.20) is related to the answers given to Questionnaire 2. To do this, we again used Spearman correlation coefficients. The results are shown in Table VII. As can be observed, the only statistically significant relationship was that the greater the time students spent playing TrivialCV was, the lower the value given to question Q2.11 (*I would prefer a more colorful appearance*).

B. Activity in the Virtual Campus

Another relevant measure was whether the presence of the single player tools would attract students to interact more with the virtual campus as a measure of their engagement with day-to-day coursework. This measure was only considered in the operating systems course because it was the only course of the two involved in the study (PF and OS) in which the single-player version was available.

For this, we used the activity logs from the previous year as an informal control group, where a total of 95 students were enrolled in the course and interacted with the virtual campus an average of 140.59 times (SD = 115.6).

In turn, for the year in which the TrivialCV tools were available, a total of 65 students were enrolled in the course and interacted with the virtual campus an average of 176.85 times (SD = 128.37). While there was a 25.8% increase, an independent-sample t-test was conducted to compare the values, demonstrating borderline significance ($p = .06$).

We also measured the number of times that each student interacted with the TrivialCV tools. A total of 46 students registered 515 play sessions during the weeks in which the tool was available, with an average of 11.20 play sessions per student.

C. Student Grades

We also analyzed the relationship between the results obtained in TrivialCV and the grades obtained by the students in

TABLE III
RESULTS OF QUESTIONNAIRE 1 IN THE PROGRAMMING FUNDAMENTALS (PF) COURSE: NUMBER OF RESPONSES, MEAN, STANDARD DEVIATION, MEDIAN AND QUARTILES FOR EACH QUESTION

Question	N	Mean	Std. Dev.	Median	Quartile Range	Lower Quartile	Upper Quartile
Q1.1	35	4.69	0.63	5.00	0.00	5.00	5.00
Q1.2	35	4.57	0.81	5.00	1.00	4.00	5.00
Q1.3	35	4.66	0.59	5.00	1.00	4.00	5.00
Q1.4	35	2.60	1.63	2.00	3.00	1.00	4.00
Q1.5	35	1.80	1.21	1.00	1.00	1.00	2.00
Q1.6	35	4.46	0.74	5.00	1.00	4.00	5.00
Q1.7	35	4.26	0.82	4.00	1.00	4.00	5.00
Q1.8	35	3.26	1.42	3.00	3.00	2.00	5.00
Q1.9	35	1.69	1.08	1.00	1.00	1.00	2.00
Q1.10	35	3.49	1.25	3.00	2.00	3.00	5.00
Q1.11	35	4.89	0.40	5.00	0.00	5.00	5.00
Q1.12	35	4.51	0.78	5.00	1.00	4.00	5.00
Q1.13	35	4.77	0.49	5.00	0.00	5.00	5.00
Q1.14	35	4.31	0.99	5.00	1.00	4.00	5.00

TABLE IV
RESULTS OF QUESTIONNAIRE 1 IN THE OPERATING SYSTEMS (OS) COURSE: NUMBER OF RESPONSES, MEAN, STANDARD DEVIATION, MEDIAN AND QUARTILES FOR EACH QUESTION

Question	N	Mean	Std. Dev.	Median	Quartile Range	Lower Quartile	Upper Quartile
Q1.1	18	4.72	0.57	5.00	0.00	5.00	5.00
Q1.2	18	4.72	0.57	5.00	0.00	5.00	5.00
Q1.3	18	4.39	0.61	4.00	1.00	4.00	5.00
Q1.4	18	2.06	1.21	2.00	2.00	1.00	3.00
Q1.5	18	2.00	1.24	1.50	2.00	1.00	3.00
Q1.6	18	4.00	0.84	4.00	1.00	4.00	5.00
Q1.7	18	4.00	0.97	4.00	1.00	4.00	5.00
Q1.8	18	2.50	1.04	2.50	1.00	2.00	3.00
Q1.9	18	1.78	0.81	2.00	1.00	1.00	2.00
Q1.10	18	3.53	1.07	4.00	1.00	3.00	4.00
Q1.11	18	4.72	0.46	5.00	1.00	4.00	5.00
Q1.12	18	4.56	0.70	5.00	1.00	4.00	5.00
Q1.13	18	4.89	0.32	5.00	0.00	5.00	5.00
Q1.14	18	4.44	0.78	5.00	1.00	4.00	5.00

TABLE V
RESULTS OF THE WILCOXON TWO-SAMPLE TEST FOR EACH QUESTION CLASSIFIED ACCORDING TO WHETHER OR NOT THE STUDENT WON THE COMPETITION IN EACH OF THE STUDIED COURSES: PROGRAMMING FUNDAMENTALS (PF) AND OPERATING SYSTEMS (OS).

	PF	OS
Q1.1	.0699	.7588
Q1.2	.086	.7588
Q1.3	.1682	.9599
Q1.4	.3344	.5727
Q1.5	.4475	.2218
Q1.6	.1476	.3894
Q1.7	.8811	.2249
Q1.8	.572	.1135
Q1.9	.056	.1764
Q1.10	.2822	.3316
Q1.11	.9717	.3088
Q1.12	.2892	.5576
Q1.13	.2111	.8062
Q1.14	.0096 †	.8391

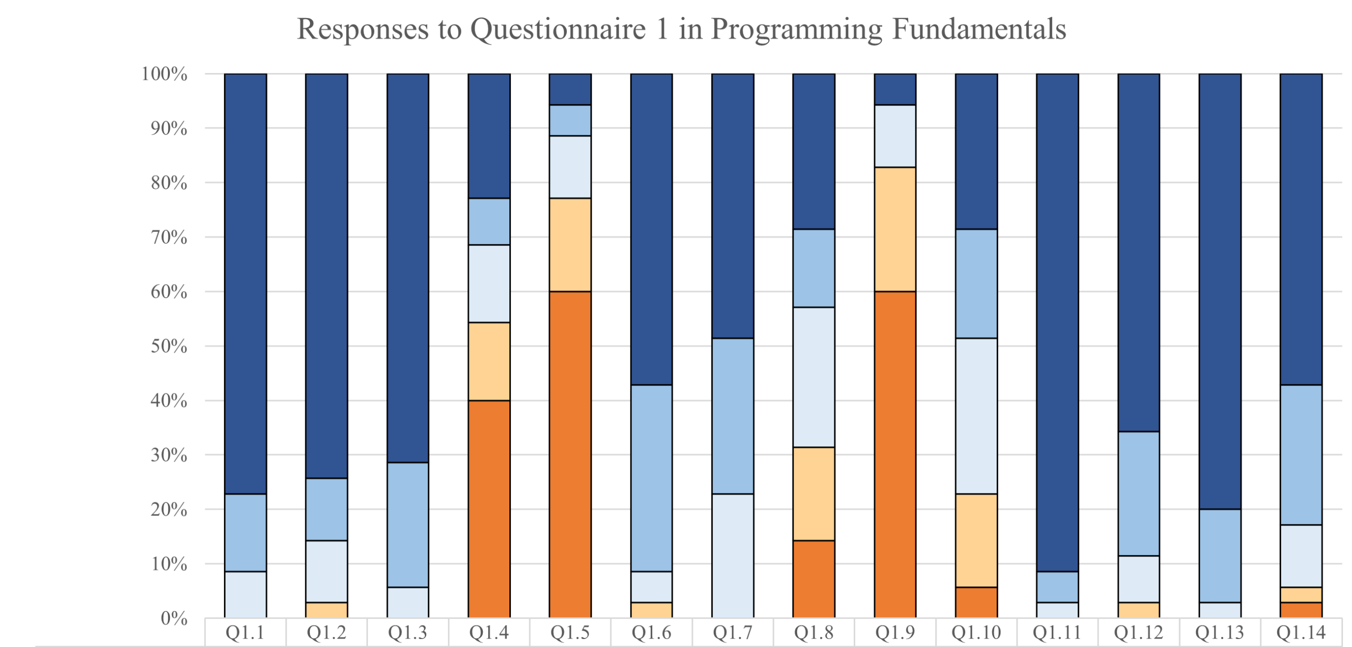
Statistically Significant Results are marked with †.

the operating systems course since this course does include an explicit theoretical evaluation. In fact, the operating systems examination includes two blocks: a theoretical block (accounting for 40% of the examination grade) and a practical block (accounting for the other 60%). Conversely, the programming fundamentals examination is 100% practical.

Additionally, the grading model for the operating systems course also contemplates additional points for "class participation," in which different day-to-day assignments and activities are evaluated.

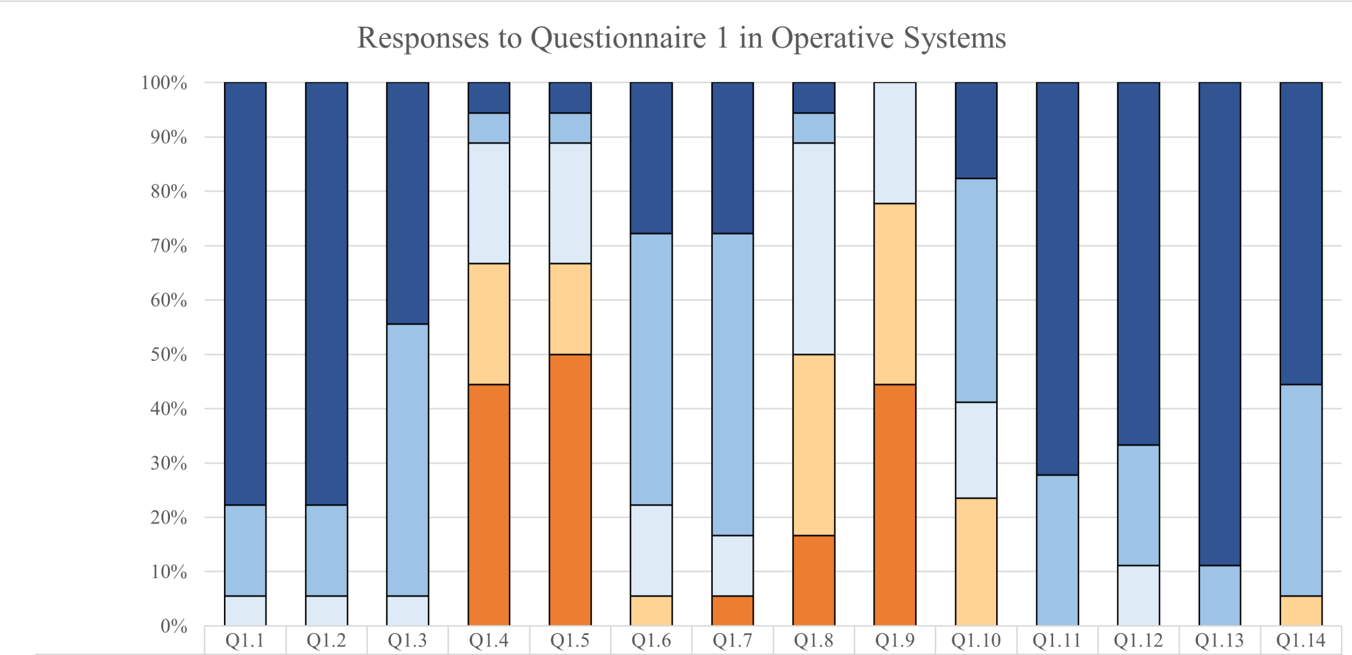
1) Grade correlations: We analyzed the relationship between the results obtained in TrivialCV and the grades obtained in 1) the final examination (distinguishing between the theoretical and the practical part), 2) class participation, and 3) the final grade for the course. For this analysis, we used Spearman correlation coefficients, and the results are shown in Table VIII.

Students took their examinations on two different dates, with similar but not identical examinations. Therefore, we separated the results depending on which examination they took. Most results, especially those in Group 1, were found



	Q1.1	Q1.2	Q1.3	Q1.4	Q1.5	Q1.6	Q1.7	Q1.8	Q1.9	Q1.10	Q1.11	Q1.12	Q1.13	Q1.14
Strongly agree	77%	74%	71%	23%	6%	57%	49%	29%	6%	29%	91%	66%	80%	57%
Agree	14%	11%	23%	9%	6%	34%	29%	14%	0%	20%	6%	23%	17%	26%
No opinion	9%	11%	6%	14%	11%	6%	23%	26%	11%	29%	3%	9%	3%	11%
Disagree	0%	3%	0%	14%	17%	3%	0%	17%	23%	17%	0%	3%	0%	3%
Strongly disagree	0%	0%	0%	40%	60%	0%	0%	14%	60%	6%	0%	0%	0%	3%

Fig. 3. Distribution of responses to Questionnaire 1 in the programming fundamentals course.

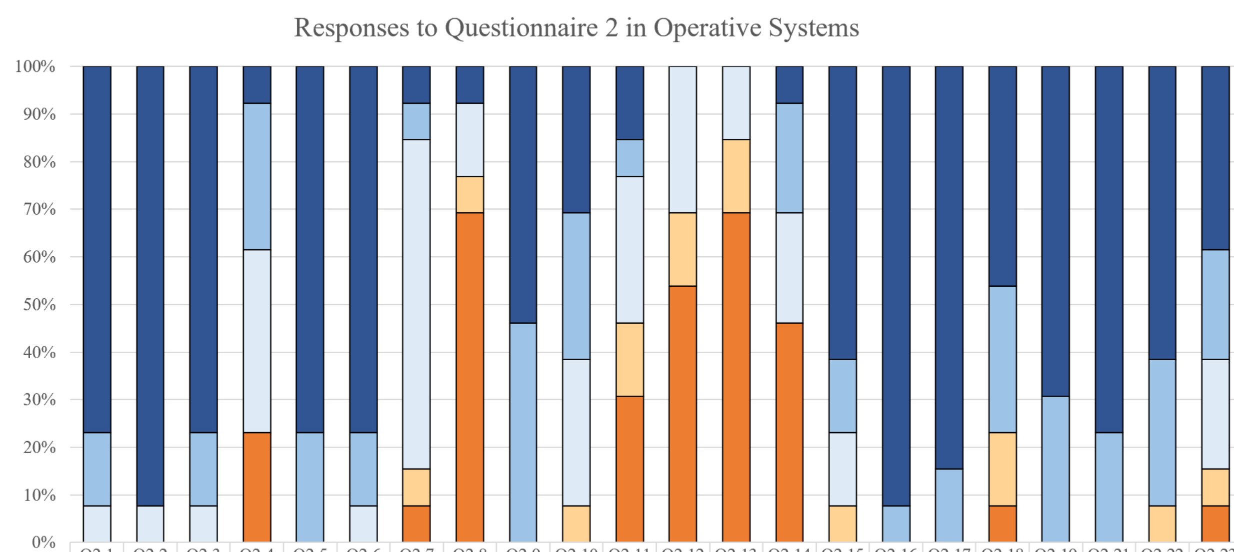


	Q1.1	Q1.2	Q1.3	Q1.4	Q1.5	Q1.6	Q1.7	Q1.8	Q1.9	Q1.10	Q1.11	Q1.12	Q1.13	Q1.14
Strongly agree	78%	78%	44%	6%	6%	28%	28%	6%	0%	17%	72%	67%	89%	56%
Agree	17%	17%	50%	6%	6%	50%	56%	6%	0%	39%	28%	22%	11%	39%
No opinion	6%	6%	6%	22%	22%	17%	11%	39%	22%	17%	0%	11%	0%	0%
Disagree	0%	0%	0%	22%	17%	6%	0%	33%	33%	22%	0%	0%	0%	6%
Strongly disagree	0%	0%	0%	44%	50%	0%	6%	17%	44%	0%	0%	0%	0%	0%

Fig. 4. Distribution of responses to Questionnaire 1 in the operating systems course.

TABLE VI
RESULTS OF QUESTIONNAIRE 2 IN THE OPERATING SYSTEMS COURSE: NUMBER OF RESPONSES, MEAN, STANDARD DEVIATION, MEDIAN AND QUARTILES FOR EACH QUESTION

Question	N	Mean	Std. Dev.	Median	Quartile Range	Lower Quartile	Upper Quartile
Q2.1	13	4.69	0.63	5.00	0.00	5.00	5.00
Q2.2	13	4.85	0.55	5.00	0.00	5.00	5.00
Q2.3	13	4.69	0.63	5.00	0.00	5.00	5.00
Q2.4	13	3.00	1.29	3.00	1.00	3.00	4.00
Q2.5	13	4.77	0.44	5.00	0.00	5.00	5.00
Q2.6	13	4.69	0.63	5.00	0.00	5.00	5.00
Q2.7	13	3.00	0.91	3.00	0.00	3.00	3.00
Q2.8	13	1.69	1.25	1.00	1.00	1.00	2.00
Q2.9	13	4.54	0.52	5.00	1.00	4.00	5.00
Q2.10	13	3.85	0.99	4.00	2.00	3.00	5.00
Q2.11	13	2.62	1.45	3.00	2.00	1.00	3.00
Q2.12	13	1.77	0.93	1.00	2.00	1.00	3.00
Q2.13	13	1.46	0.78	1.00	1.00	1.00	2.00
Q2.14	13	2.46	1.51	3.00	3.00	1.00	4.00
Q2.15	13	4.31	1.03	5.00	1.00	4.00	5.00
Q2.16	13	4.92	0.28	5.00	0.00	5.00	5.00
Q2.17	13	4.85	0.38	5.00	0.00	5.00	5.00
Q2.18	13	3.92	1.38	4.00	1.00	4.00	5.00
Q2.19	13	4.69	0.48	5.00	1.00	4.00	5.00
Q2.21	13	4.77	0.44	5.00	0.00	5.00	5.00
Q2.22	13	4.46	0.88	5.00	1.00	4.00	5.00
Q2.23	13	3.77	1.30	4.00	2.00	3.00	5.00



	Q2.1	Q2.2	Q2.3	Q2.4	Q2.5	Q2.6	Q2.7	Q2.8	Q2.9	Q2.10	Q2.11	Q2.12	Q2.13	Q2.14	Q2.15	Q2.16	Q2.17	Q2.18	Q2.19	Q2.21	Q2.22	Q2.23
Strongly agree	77%	92%	77%	8%	77%	77%	8%	8%	54%	31%	15%	0%	0%	8%	62%	92%	85%	46%	69%	77%	62%	38%
Agree	15%	0%	15%	31%	23%	15%	8%	0%	46%	31%	8%	0%	0%	23%	15%	8%	15%	31%	31%	23%	31%	23%
No opinion	8%	8%	8%	38%	0%	8%	69%	15%	0%	31%	31%	31%	15%	23%	15%	0%	0%	0%	0%	0%	0%	23%
Disagree	0%	0%	0%	0%	0%	0%	8%	8%	0%	8%	15%	15%	15%	0%	8%	0%	0%	15%	0%	0%	8%	8%
Strongly disagree	0%	0%	0%	23%	0%	0%	8%	69%	0%	0%	31%	54%	69%	46%	0%	0%	0%	8%	0%	0%	0%	8%

Fig. 5. Distribution of the responses to Questionnaire 2 in the operating systems course.

to be statistically significant ($p < .05$). Students in Group 2 displayed lower correlations, but they were nevertheless present.

2) Grade improvement: We also checked whether students who had been exposed to the different versions of the game performed better than those who had not, comparing their grades with those of students from the previous academic year.

IV. DISCUSSION

The experiments performed with these students were tailored to suit their learning experience but still provided useful insights and lessons learned for our specific research questions. While the relative power of the experiment was limited due to the population size, the reaction from the students was overwhelmingly positive.

TABLE VII
RESULTS OF THE SPEARMAN CORRELATION COEFFICIENTS FOR EACH QUESTION CLASSIFIED BY THE TIME SPENT ON THE SINGLE-PLAYER VERSION OF TRIVIALCV

	Spearman Correlation Coefficients	p
Q2.1	-.08607	.7903
Q2.2	-.35309	.2602
Q2.3	-.13725	.6706
Q2.4	-.16467	.6091
Q2.5	.25355	.4265
Q2.6	-.06547	.8398
Q2.7	-.06958	.8299
Q2.8	-.32102	.3090
Q2.9	-.36596	.2420
Q2.10	.15691	.6262
Q2.11	-.59585 †	.0409
Q2.12	-.15816	.6235
Q2.13	-.04648	.8859
Q2.14	-.22324	.4855
Q2.15	-.00792	.9805
Q2.16	-.22068	.4907
Q2.17	-.13093	.6850
Q2.18	.09543	.7680
Q2.19	.02588	.9364
Q2.21	-.14086	.6624
Q2.22	-.28002	.3780
Q2.23	.03349	.9177

Statistically significant results are marked with †.

This perception is aligned with the results of the different analyses described in Section III and provides useful insights into our initial research questions, providing support for them to different degrees.

A. RQ1—Are These Tools Effective in Motivating Students?

As shown in Section III-A, the responses to Questionnaires 1 and 2 indicate that students, in general, are quite satisfied with the TrivialCV tool in its two versions (single player and multiplayer). In particular, most of the students were satisfied with the experience (e.g., Q1.1 and Q2.1), and praised the activity when compared with other teaching activities (e.g., Q1.2, Q1.3, Q2.2, Q2.3, and Q2.6).

Regarding the overall game design and usability, questions marked with asterisks in Tables I and II were also valued very highly by students, even though the game design and appearance were relatively simple. These trends were also visible in the questions that were proposed with an inverted scale (e.g., Q1.5, Q1.9, Q2.4, Q2.8, and Q2.12).

Therefore, it seems that the use of these tools increased the students' motivation and was perceived as a positive experience in general. This is consistent with most serious games studies, where students tend to embrace the approach [39] even though this is often connected to the novelty effect of the intervention [40].

B. RQ2—Does the Application of These Tools Result in Increased Participation and Engagement?

While motivation or student acceptance are relatively straightforward terms, engagement and participation are far more elusive [41]. Different studies have targeted the evaluation of participation in terms of interactions with the game itself [42], [43], while others focus on whether the interventions result in behavioral changes [44], [45]. Our goal was two-fold, seeking an active engagement of the students with the games, but also with the courses and day-to-day classroom activities in general.

Increased engagement and participation were measured in different ways. Regarding responses, students were willing to repeat the activities in this and other courses (Q1.11 to Q1.13, Q2.16, and Q2.17) and considered the activity more relevant than other forms of study (Q1.10 and Q2.18). Perhaps most importantly, all students reported in Questionnaire 2 that with the tool, they spent more time studying than they would have without it (Q2.19).

In turn, it is also remarkable that once the single player game was made readily available, 46 out of 65 students accessed the game at least once, and a total of 515 sessions were completed, for an average of 11.20 play sessions per student.

Finally, when measuring the difference in overall virtual campus activities, the average access rate per student to the virtual campus increased more than 25%, although the difference was barely statistically significant at $p = .06$.

Regardless, we consider that the results indicate a positive attitude toward the game. Many students used it frequently, and the overall assessment of the tool was that it was an interesting addition to their set of study resources. The game also drove them to pay more attention to the course during day-to-day activities, as opposed to the traditional approach of only assigning importance to the course as the final examinations draw near.

C. RQ3—Is There an Increase in Student Performance After Using these Tools?

The transfer of knowledge proved to be the most elusive measure in all our experiments. The perception of students was positive in general. All students considered these activities to be effective as review exercises (Q1.14 and Q2.21) and even more effective than traditional classes (Q1.10 and Q2.22). As their instructors, it was surprising (and humbling) to identify that our students considered a one-hour gameplay session more useful than a one-hour lecture.

It is also worth mentioning the inverse correlation between the answers to Q1.14 (*The activity was effective as a review exercise*) and performance during team competitions. Students who did not win the competitions found the exercise more effective. We believe that students on the losing side realized that they still needed further effort to be on par with their classmates, and therefore, it had a deeper impact on them than on the winning students, who probably were already performing well in the classroom. This is very relevant for our research since it may have more deeply impacted students needing further support, which is a very positive outcome.

Most remarkably, the students generally perceived the tools as helpful in their examination preparations, especially the single player version which could be used from home (Q2.24 and Q2.25).

TABLE VIII
RESULTS OF THE SPEARMAN CORRELATION COEFFICIENTS (SCC) FOR EACH GRADE ACCORDING TO THE PREVIOUS RESULTS IN THE SINGLE-PLAYER VERSION AND THE MULTIPLAYER TEAM COMPETITION PERFORMED DURING THE COURSE

			Theoretical Part	Examination	Class Participation	Final Grade
Group 1	Single-player	SCC	.62128 †	.70327 †	.78574 †	.75410 †
		p	.0005	$< .0001$	$< .0001$	$< .0001$
	Multiplayer	SCC	.48055 †	.42511 †	.54916 †	.45701 †
		p	.0112	.0271	.0030	.0166
Group 2	Single-player	SCC	.32083	.40578	.47913	.43503
		p	.1678	.0759	.0207	.0552
	Multiplayer	SCC	.29453	.49386 †	.63147 †	.55591 †
		p	.2075	.0269	.0012	.0109

Statistically significant results are marked with †.

In addition to this, we did observe in Section III-C significant correlations between the time spent playing the game and the grades obtained on the examination, as well as other graded activities such as assignments. These are, however, correlations. It could be argued that good students simply performed better in the game and then naturally performed better on the examination.

Finally, we tried to compare their average grades with those of students from the previous academic year. However, we did not find statistically significant differences in the performance of either group. This is consistent with other existing analyses, where the learning outcomes of using serious games tend to be less significant in higher education [46].

This does not mean that the tools were not useful since there is no way to measure the extra examination preparation work which students in different years and groups required. Students might have needed less traditional study effort having the TrivialCV tools available but still achieved the same result.

However, since we could not measure this, the argument about learning outcomes relies exclusively on the self-perception of students when they reported how useful the tools had been during their study efforts.

V. CONCLUSION

As stated above, in this work, we have presented a summary of different game-based interventions in two different computer science courses taught at a university level: programming fundamentals and operating systems. The addition of these game activities was useful in providing additional motivation for students and improving their engagement with the courses. These interventions were very well received by the students, who considered them fun, engaging, and useful.

In this work, we measured the impact according to three specific research questions, as stated in the introduction. Each research question was addressed through different research activities, including questionnaires, analysis of interaction logs provided by the virtual campus and statistical analysis of the impact on student grades. The research questions, research activities and main findings are summarized in Fig. 6.

We first explored whether these tools were effective in *motivating* students. We found very positive attitudes toward these game activities and a desire to increase their frequency and availability in other courses. This is aligned with first-person observations and feedback during the interventions, which were undeniably highlights in their respective courses.

We then explored whether this motivation translated into an increase in student *participation* in day-to-day activities, a cornerstone of the instructional design of these two courses. Higher motivation should naturally result in higher engagement, and we observed clear indications of increased engagement through our questionnaires and through our analysis of the frequency of interactions with the virtual campus. Remarkably, the balance between competition and collaboration was also positive, given the concern that some students may naturally prefer either competitive or collaborative approaches [47].

Finally, this additional participation should have resulted in better student performance. The students reported that this had impacted their study and performance very positively, although we did not observe significant variations in their final examination grades. As discussed above, this does not mean that the tools failed to produce any significant transfer of knowledge, but we cannot consider that it demonstrated that the use of the TrivialCV tools leads to an increase in student performance.

In addition to this, we must acknowledge the relatively small sample size and further intervening factors, such as the impact of the specific instructors or other effects local to specific teaching groups (e.g., whether the impact changes in a first-year course).

In fact, these two factors represent our main future line of work; more studies and interventions are needed to support the idea that this type of game-based activity increases motivation, therefore increasing participation and student performance.

Thus far, we can confidently assert that we have demonstrated the first two steps for our experimental groups. However, we consider that this does not diminish the value of the interventions. If we managed to increase the motivation of the students and their participation in class while achieving similar academic performance, then we can be satisfied with the impact of these kinds of activities.

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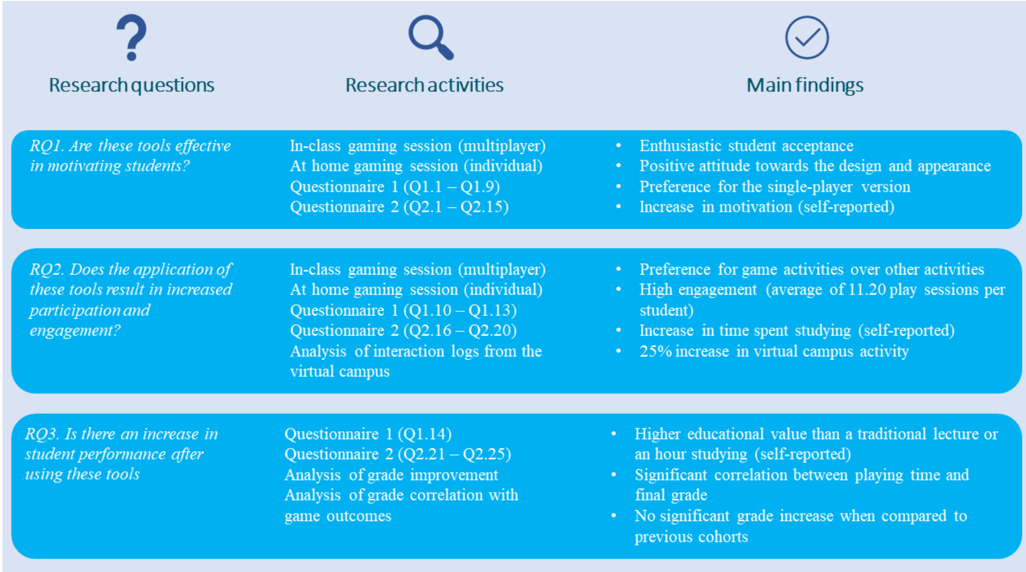

Fig. 6. Summary of research questions, research activities and main findings.

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