Investigating the Impact of an Immersive Computer-based Math Game on the Learning Process of Undergraduate Students

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***Abstract* — Although Mathematics is a fundamental subject for many STEM related areas, undergraduate students find Mathematics a challenging and difficult subject, and they face difficulties in developing logical thinking and problem solving skills. This research-to-practice paper introduces *Count With Me!,* a novel immersive computer-based educational game that teaches counting principles. The paper analyses and discusses the impact of the game on the learning process and knowledge gain. Twenty-four 1st year undergraduate students took part in the case study. Knowledge tests were employed before and after the students interacted with the educational game. Although addition, multiplication, factorial, and permutation topics were already studied by the students in the high school, the pre-test results showed that some students face difficulties with these topics. The post test results analysis showed a statistically significant knowledge improvement and a high student engagement in playing the game and learning about the Mathematics concepts.**

Keywords—STEM education, computer-based Maths game, learning performance.

I. INTRODUCTION

Mathematics continues to be considered a challenging subject by many undergraduate students [1]. In general, undergraduate education needs an overall improvement in terms of the pedagogical approaches taken however, Mathematics needs special attention. A study conducted by Freeman [2] raises questions on traditional learning and recommends active learning approaches. Further to this there are barriers in Mathematics learning and teaching and a number of different type of actions are needed including suitable pedagogical approaches to reduce the barriers [3].

Mathematics is a fundamental subject and a lot of research has been done in how it should be taught including presentation of material, engagement and transfer of learning for the student [4, 5]. Despite various pedagogical approaches were proposed such flipped classroom, problem-based learning, game-based learning, hand-on practical projects, practice testing, a lot more needs to be done to improve Mathematics teaching. An immersive and interactive game-based learning is the pedagogical approach is investigated in this research paper.

Game based learning can help improve student learning and achievement in Mathematics by improving engagement [7]. The large number of people, including an overwhelming number of teenagers, who play video games almost every day is driving the growth of game market. Part of this growing market focuses on game-based learning. This is due to the fact that educational games engage students, encourage them to get involved in live projects or real-time activities, support learning by experimenting and not at last boost learners' attraction to and confidence in STEM subjects [8]. Recent research on Mathematics education shows that many students perceive Mathematics as a difficult subject and face difficulties in developing logical thinking and problem solving skills. In this context, mixing up technology in the learning and teaching process can be beneficial. This paper presents a case study that involved the use of educational game for teaching some Mathematic concepts.

The pedagogy applied so far in *Introduction to Mathematics* module part of a Computing degree at National College of Ireland has been a culmination of a number of strategies such as flipping the classroom and practice testing. Flipping the classroom has been effective [1] and so has been the practice testing [5] however, the lecturers found that certain concepts like counting, permutations and combinations were still difficult for students to comprehend and apply. Although the undergraduate students have studied these concepts in the high school, they still lack the skills to apply the concepts on a real-life problem The module team discussed that there is a need for to include in this module the elements of game based learning which may help to improve the student knowledge, engagement and performance further. With this in mind the pedagogical design for the game and the associated face-to-face teaching started and the immersive game-based educational content (*Count With Me*!) was designed and developed.

The *Count With Me!* educational game has a number of pedagogical innovations that support its introduction in the module. The game brings the real world learning into classroom. The students feel like they are learning the concepts

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sitting in the canteen eating something or making pizza. Real world learning is then cemented by connecting what they have learned to mathematical terminology and concepts. The game is played by students at home, in advance of the class session, and the engagement and collaboration is further sustained in a classroom based environment by discussing the same concepts and additional problem solving. The students learn best when they can connect their existing knowledge to the new concepts they are learning which is the key pedagogy for this game. This incorporation of new knowledge into their existing conceptual framework supports further development of the subject area and skills [9].

This research-to-practice paper presents a study of the impact of *Count With Me!,* a novel immersive computer-based educational video game on undergraduate students' learning process. *Count With Me!* introduces learners to counting principles such as addition, multiplication, factorials and permutations. A real life case study involving twenty-four first year undergraduate students, enrolled into the *Introduction to Mathematics* module part of a Computing degree in an Irish third level institution that played the game was run. The analysis of learning outcome (through pre-tests and post-tests) and learner satisfaction (via questionnaires) showed that using the game was beneficial to the students.The paper is organized as follows. Next section presents current research work on game-based learning and teaching approaches used in STEM with focus on Mathematics. Section 3 introduces the design methodology for the *Count With Me!* educational game. Section 4 describes the case study methodology and presents an analysis of the results Last section concludes the paper, and presents future perspectives.

II. STATE OF THE ART

Research work in the area of educational games has shown the positive impact of game based teaching method on students' motivation [15, 23] and engagement [20], knowledge construction, learning performance [16, 22], fostering students' science learning [17,18, 21].

Some studies investigated the use of educational games to learn mathematics concepts in particular. [10] developed a game that aims in training basic arithmetic skills. The educational content of the game covers basic arithmetic with a particular focus on conceptual understanding of base-10 and the arithmetic operations. The game was evaluated in a study with 153 participants, consisting of 3rd and 5th grade students. The results indicated that the game helped students improve their math performance and self-efficacy beliefs.

Lee developed "Tower Trap", an educational math game on fractions [11]. The learning objective of this game is to order fractions with like and unlike denominators from the smallest to the largest and vice versa. The game was evaluated in a study conducted on 168 students (11 to 13 years old) from 3 intermediate schools (i.e., middle schools) in a New Zealand town. Results showed that students' understanding and performance has improved for the fractions topic through the game play.

Zavaleta et al. introduced NumerAmigos, an educational game for elementary school [12]. The game has a friendly interface and covers concepts required for learning the basic arithmetic and algebraic operations. The game was evaluated in a study conducted on 128 students between the second and third grade, aged between 7 and 10 years. The study showed that the use of NumerAmigos helped students and teachers in the learning of algebra.

Elliott presented AquaMOOSE, a 3-D educational game to help students learn about behavior of parametric equations [13]. An underwater theme which allows the players to swim like a fish in 3 directions is used in the game environment. The design was based on constructionism philosophy. The evaluation took place during an after-school program at a local high school on 14 students. The results showed that the game provides a powerful learning experience that augments standardized educational activities by giving students opportunities to fully employ their imagination and creativity.

Kebritchi *et al.* examined the effects of Dimenxian, a computer game on students' mathematics achievement and motivation, and the role of prior mathematics knowledge, computer skill, and English language skill on their achievement and motivation as they played the game [14]. A total of 193 students and 10 teachers participated in this study. The results showed a significant improvement of the achievement for the experimental group versus control group. No significant improvement was found in the motivation of the groups. Prior knowledge, computer and English language skill did not play significant roles in achievement and motivation of the experimental group.

This analysis of previous research on educational games for Mathematics confirms that the use of educational game increases students' learning, motivation and interaction with the content. However, no research work was identified that investigated the use of an educational game to teach counting principles at 3rd level education. Our previous teaching experience with *Introduction to Mathematics* module has shown that counting, permutations and combinations are difficult topics for undergraduate students to comprehend and apply. Therefore, we designed, developed and applied *Count With Me!,* game in *Introduction to Mathematics* module at the National College of Ireland.

III. A NOVEL INTERACTIVE GAME

Count With Me! is an immersive interactive computer-based educational game developed with the aid of two math lecturers based on both the syllabus of the Irish leaving certification curriculum for Mathematics (K-12 level) and the Introduction to Mathematics module descriptor part of the first year of the BSc in Computing undergraduate degree at National College of Ireland. The game teaches the counting principles in particular addition, multiplication, factorials, and permutations.

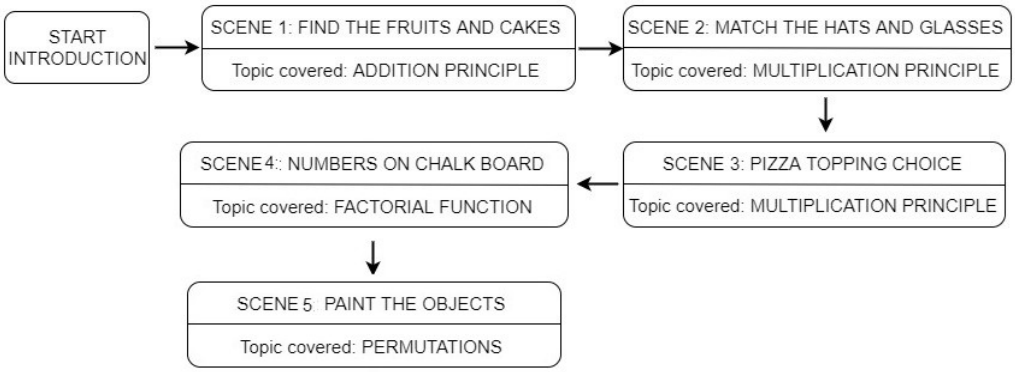

Fig. 1. *Count With Me!* game flow

The reason for this choice of topics is the fact that students find these topics difficult to grasp and it would be very easy to explain these concepts in a game environment.

The game style chosen was a "visual novel" style, that mostly consists of static graphics, minimal gameplay and an interactive story. It would also suit the objective of teaching the Mathematics syllabus as it involves giving a lot of information, explaining concepts without interrupting the flow of the game. During the gameplay the player takes a role of a student in a class and a teacher avatar brings the player to different real life scenarios and talks to the student describing the tasks to be solved but also introducing the math concepts.

The flow of the game is illustrated in Fig. 1. First, the player is brought to a scene that presents a real life scenario and asked to do a mini game that involves a task linked into the mathematical concept to be covered. For example, Scene 1, the player is placed in a classroom where some fruits and cakes are hidden. The task is to collect all the fruits and cakes. Once the player completes the mini game they are prompted with a multi choice question that is related to the task they just completed. If the question is answered correct the avatar teacher explains the mathematical concept (e.g. addition). Next, one more question on the same mathematical concept is presented to the player that aims to check information recall. Once the player answers correct this question too, the game progresses to the next scene and a new mini game covering another mathematical concept is presented (e.g. Scene 2 Match the hats and glasses, covering the multiplication principle). This cycle is repeated until all the mathematical concepts have been covered. Feedback is also provided to the student for each question answered correct through a brief explanation of the answer. Otherwise, if incorrect answer was chosen, the player is allowed to try again to answer the question.

TABLE I MINI-GAMES DESCRIPTION

No.	Mini game	Description	Math concepts
1	Fruit and cakes	There are fruits and cakes scattered in the scene of the game. The player must find them and click on them	Addition
2	Hats and glasses	There are two types of glasses and three types of hats. The player must do all the possible combinations of the hats and glasses. There are 6 total combinations that the player must generate by dragging the hats to the boxes underneath the glasses.	Multiplication
3	Pizza toppings	The player must choose the toppings for their pizza, the topping choices are presented on screen as an option of 3, then 3 again and then 2 items. The player must click one of the topping choices each time.	Multiplication
4	Numbers on chalk board	There are some numbers scattered on the chalk board. The player must drag them into the boxes and put them in the right order	Factorial Function
5	Painting objects	The player has three colour paints, pink, blue and green and two objects a fence and a door to be painted. The player must exhaust all the possible combinations, without doing the same combination of colours twice. There are 6 total permutations. There is a chart on the top left of the screen that shows the previous matches the player has done.	Permutations

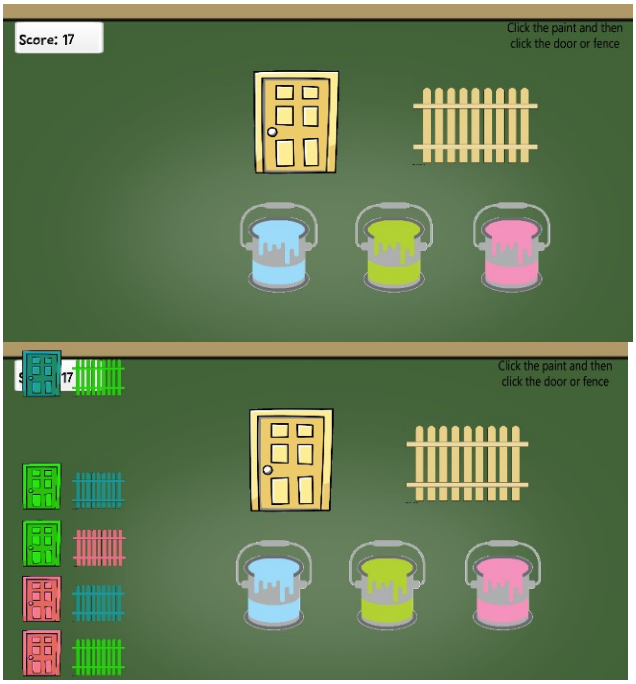

Fig. 2. Painting mini-game

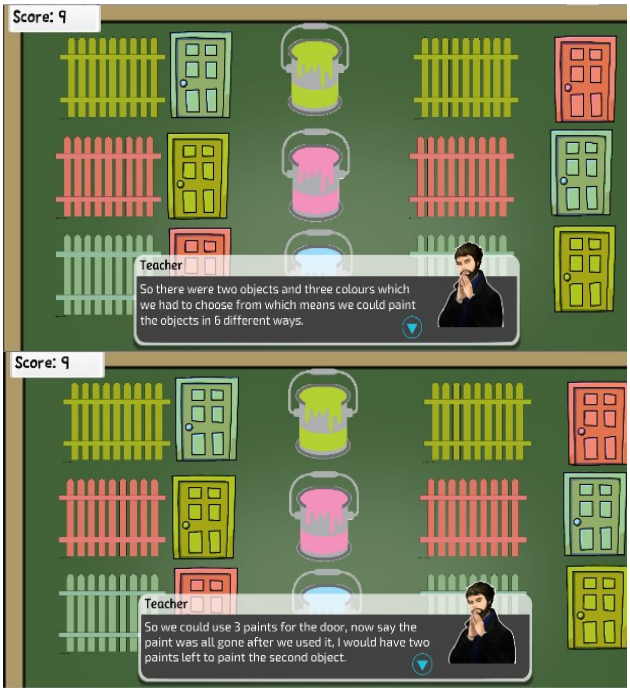

Fig. 3. Explanation of permutation principle in the painting mini-game.

Table 1 presents the five mini-games and the associated math concepts. These types of mini-games have been chosen as they help the player to understand the basic of the math concept through a real-world example. The 3rd mini-game reinforces concepts relating to the Multiplication Principle through a game in which the player must decide on a number of toppings for a pizza. In the 4th mini-game, the player is introduced to the factorial function and the standard mathematical notation associated with this function.

The painting objects mini-game related to the permutation concept is illustrated next. Fig. 2 shows the mini game activity the player has to complete: paint the door and fence with different colours. The player will click on a paint pot and then he/she will choose the fence or door to be painted. Based on his/her choice the door or fence will be colored. The player can then repeat the process and if the combination is correct, a checklist will appear on the left-hand side of the screen showing the different combinations. Once the painting mini game was completed, the permutation principle is explained by the avatar teacher using the door and fence as exemplification purpose (see Fig. 3).

Building on the player's knowledge of the Multiplication Principle, the teacher avatar proceeds to explain how a mathematical expression is derived (using the factorial function) to solve the problem posed by the painting mini-game. This expression is presented in the form that is typically used when computing permutations. In order to progress in the game, the player must answer one more question (short recall knowledge question) related to the permutation concept. Then, the teacher avatar explains the correct answer. The aim of this question is to reinforce the player understanding of the presented concept. Fig. 4 provides some illustration as to how this process is presented in the game. A detail description and illustration of the other mini-games is provided in [19].

IV. CASE STUDY RESULTS

A. *Set-up desciption*

The Moodle LMS was used to provide access to resources and activities supporting the learning experiment. The case study consisted of students completing an ordered sequence of staged activities. These activities were:

i) completion of a quiz (pre-test) that consists of four multiple choice questions covering key concepts that will be taught through the use of the educational game

ii) downloading and playing the *Count With Me!* game to completion

iii) taking note of a code-word that is generated at the end of the game,

iv) completion of a quiz (post-test) consisting of another four multiple choice questions covering the four concepts introduced in the game.

v) answering a questionnaire that assesses satisfaction and engagement

It was necessary that students completed all of the experiment's activities prior to the counting principles being covered in more details in class via lecture and tutorial sessions. Class delivery of lecture and tutorial sessions further developed and explored the key topics that had been introduced in the game. The Moodle based LMS activities to support the experiment were configured in such a way so that access to

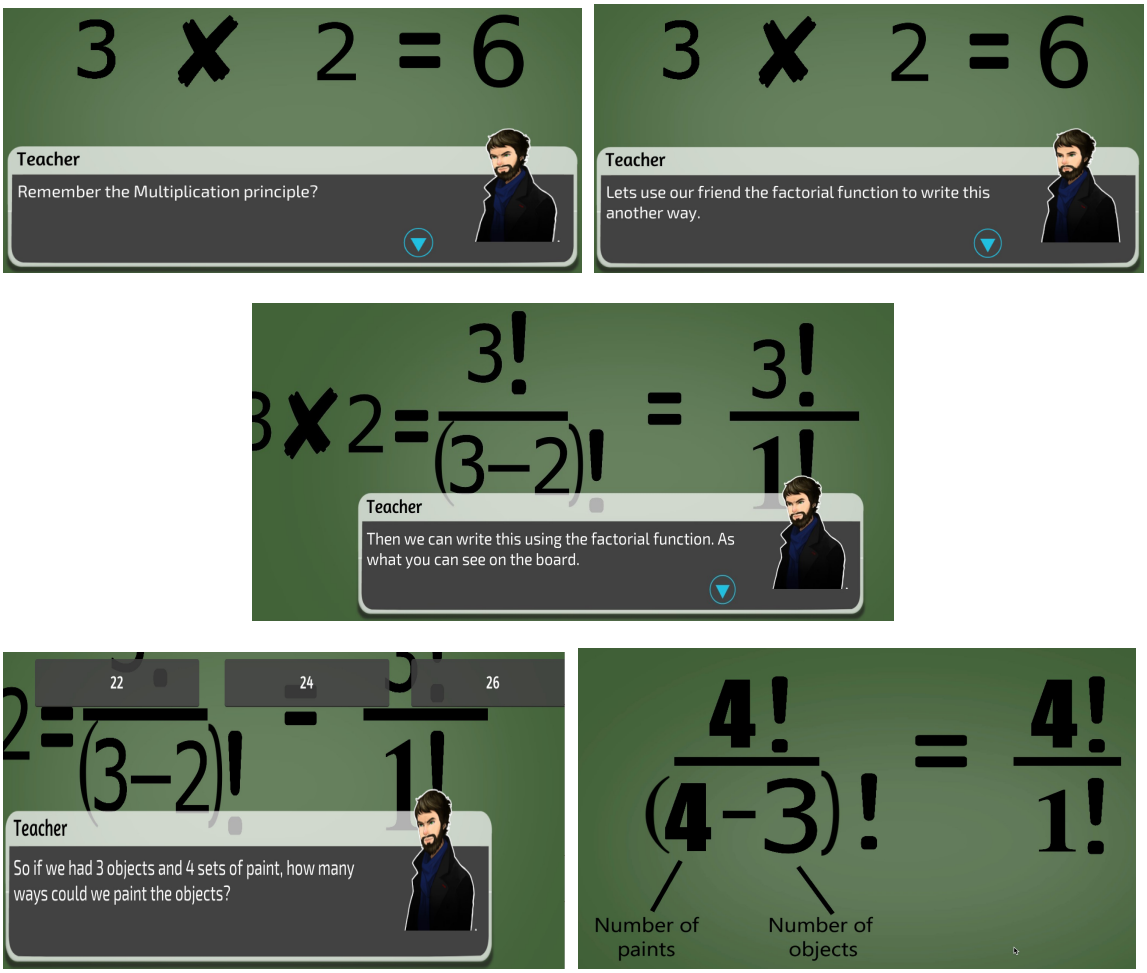

Fig. 4. The recall question in the painting mini-game.

those activities was provided to participants in an ordered manner. Participants were initially given access solely to the first quiz (pre-test) activity. On completion of this initial quiz activity the link to download the *Count With Me!* game became active. It was necessary to ensure that participants actually played the game to completion prior to progressing through the remaining activities. The game was developed to provide a code-word to the player at the end of the game. Participants were instructed to record this code-word. Once the mathematics game had been downloaded an activity to enter the generated code-word became available. Only on successfully entering the generated code-word was the second quiz (post-test) activity made available to participants. Participants were provided with a maximum of eight minutes to complete the quiz activities. For each of the multiple choice questions in the initial quiz activity there was a corresponding similar multiple choice question in the final quiz activity.

Additionally, access to a survey questionnaire which contained a number of questions related to game based learning experience was also provided through the Moodle LMS. Participants were instructed to complete this survey questionnaire after having taken part in the game based learning activities and attending in-class lecture and tutorial sessions on the topic of counting principles. The survey was used to gather and evaluate participant feedback with respect to the perceived usefulness of game based learning for mathematics.The evaluation of the educational game included a group of twenty-four 1st year undergraduate students from National College of Ireland that used the *Count With Me!* game. The game-based learning activity took place at home in advance of the class session. 16.7% of students were female and 83.3% of students were male. 70.8% of students were less than 21 years old, 12.5% of students were between 21-24 years old and 16.7% of students were mature students older than 24 years old.

The pre-test and post- test quizzes (see Table II and Table III) were designed and validated by the module academic team involved in the delivery of *Introduction to Mathematics* module to undergraduate students enrolled in different courses. The quizzes were designed by the team which consisted of researchers and faculty members to reduce the gender and background bias. The common problems in single group, pre-post-test research designs are maturation and test effects [18]. In this study problem of maturation does not apply as the time

TABLE II. PRE-TEST QUESTIONS

Pre-Test Questions	Answer Choices
Q1. How many ways are there to order a meal consisting of one sandwich and one beverage at a restaurant that serves 3 different sandwiches and 4 different beverages?	a) 7 **b) 12** c) 6 d) 5 e) e. I don't know
Q2. How many ways to eat a single food item from a restaurant that has 3 different sandwiches and 3 different types of pizza?	a) 3 **b) 6** c) 1 d) 4 e) e. I don't know
Q3. What is the value of 5! (factorial of 5)?	a) 5 b) 15 c) 80 **d) 120** e) e. I don't know
Q4. There are 3 pots of paint which are of different colour. There are 2 boxes that needs to be painted, each with a single distinct colour. How many different ways can we paint the 2 boxes with different colours given that we have 3 different colours to choose from?	a) 3 **b) 6** c) 5 d) 2 e) e. I don't know

TABLE III. POST-TEST QUESTIONS

Post-Test Questions	Answer Choices
Q1. How many ways are there to order a meal consisting of one pizza and one beverage at a restaurant that serves 5 different pizza and 3 different beverages?	a) 7 **b) 15** c) 6 d) 5 e) e. I don't know
Q2. How many ways to eat a food item from a restaurant that has 5 different sandwiches and 3 different types of pizza?	a) 3 **b) 8** c) 1 d) 4 e) e. I don't know
Q3. What is the value of 4! (factorial of 4)?	**a) 24** b) 12 c) 10 d) 7 e) e. I don't know
Q4. There are 4 pots of paint which are of different colour. There are 2 boxes that needs to be painted with a single colour. How many different ways can we paint the 2 boxes with different colours given that we have 4 different colours to choose from?	a) 10 **b) 12** c) 20 d) 22 e) e. I don't know

difference between pre and post-test was very short (weekend). It is possible that the scores can improve just by taking the pre-test as the students are then more focussed to play the game and obtain the knowledge (testing effect) and the authors acknowledge that.

The *Count With Me!* game evaluation process meets all ethics requirements. Prior to running the case study, the ethical approval was obtained from the College Ethics Committee and all required forms were provided to the students, including informed consent form, informed assent form, plain language statement and data management plan. These documents include a detailed description of the testing scenario, as well as information on study purpose, data processing and analysis, participant identity protection, etc.

TABLE IV. PRE-TEST QUESTIONS ANALYSIS

	Q1 (Multiplication)	Q2 (Addition)	Q3 (Factorial)	Q4 (Permutations)
Correct Answers	83.3%	79.2%	79.2%	58.3%
Incorrect Answers	16.7%	20.8%	20.8%	41.7%
Mean	1.67	1.58	1.58	1.17
STD	0.58	0.69	0.69	1.01

TABLE V. POST-TEST QUESTIONS ANALYSIS

	Q1 (Multiplication)	Q2 (Addition)	Q3 (Factorial)	Q4 (Permutations)
Correct Answers	100%	95.8%	100%	87.5%
Incorrect Answers	0%	4.2%	0%	12.5%
Mean	2	1.92	2	1.75
STD	0	0.17	0	0.46

The game-based learning outcome was evaluated by analysing the answers provided to the four questions part of the pre-test and post-test. Q1 in the pre-test and the post-test were related to the Multiplication principle, Q2 to the Addition principle, Q3 to the Factorial function, and Q4 to the permutation principle. Each question answered correct was marked with 2 points while an incorrect answer was marked with 0 points.

B. Pre-Test Results

This section presents the pre-test results achieved by the students (see Table IV). A quiz consisting of 4 questions, each question covered one of the 4 topics was answered by the students before using the educational game. The purpose of this quiz is to assess the prior knowledge level of the students.

Although addition, multiplication, factorials, and permutations have already been studied by the students in the high school, the pre-test results show that some students have knowledge gaps. The main difficulty that some students experience with the Addition Principle is in discerning when this principle should be applied. Based on in-class student remarks made subsequent to performing the tests, the difficulty lies not in the addition of numbers per se, but with correctly recognising when to apply the Addition Principle if presented with a problem that is stated in natural language rather than in direct mathematical terms. We notice from these results that the Multiplication principle (related to Q1) is the most known concept: 83.3% of students answered correct Q1. On average, the students have the same level of knowledge on the Addition principle (related to Q2) and the Factorial function (related to Q3): 79.2% of students answers correctly Q2 and Q3 respectively. However, students are less familiar with the Permutations principle (related to Q4). Only 58.3% of students answered correct Q4.

C. Post-Test Results

The post-test results achieved by the students in the quiz run after they have completed the game are presented in Table V. The quiz consisting of four questions, each question covered one of the four topics. These results show that the Multiplication principle and the Factorial function (related to Q1 and Q3) are the most known concepts. All students have answered correct both Q1 and Q3. The students have also demonstrated that they achieved a very good level of knowledge on the Addition principle (related to Q2) and the Permutations principle (related to Q4): 95.8% of students provided correct answers to Q2 while 87.5% of students provided correct answers to Q4.

D. Discussion and statiscial analysis

The learning impact of the game was evaluated through an analysis of the pre and post test results achieved by the students.

Table VI shows the impact of the *Count With Me!* game on the students' learning. The *Count With Me!* game increased students knowledge level on Multiplication principle and the Addition principle by 16.7%, the Factorial function by 20.8%, and the Permutation principle by 29.2%.

An analysis on how many students answered correct all or almost all questions in the pre-test is presented in Table VII, were the percentage of correct answers and the corresponding number of students are provided. 33.3% students answered correctly all the pre-test questions and 41.7% of students provided correct answers to 3 out of 4 questions. Worth to be highlighted is that 25% of students were not able to answer correctly more than 50% of the questions and 8.3% of students answered correctly only one question out of 4.

An analysis on the number of questions answered correct by the students in the post-test is presented in Table VIII. A significant increase in the number of students that answered correctly all post-test questions was obtained (87.5% of students in post-test vs 33.3% in pre-test). Also, the number of students that were able to answer correctly only up to half of the questions has significantly dropped from 25% in pre-test to only 4.2 % in the post-test. This analysis demonstrates that the *Count With Me!* Game has increased the knowledge level of the students on all the four topics. The biggest jump of 13 students, or 54.2% was obtained in terms of number of students that demonstrated that they are able to master all the four topics related to counting principles.

TABLE VI. PRE-TEST VS POST-TEST QUESTIONS' ANSWERS

	% of correct answers in the pre-test	% of correct answers in the post-test	Δ(%)
Q1 - Multiplication	83.3%	100%	16.7%
Q2 - Addition	79.2%	95.8%	16.7%
Q3 - Factorial	79.2%	100%	20.8%
Q4 - Permutations	58.3%	87.5%	29.2%

TABLE VII. NUMBER OF QUESTIONS CORRECT ANSWERED IN THE PRE-TEST ASSESSMENT

	Number of students	Percentage of students
4 out of 4	8	33.3%
3 out of 4	10	41.7%
2 out of 4	4	16.7%
1 out of 4	2	8.3%
None	0	0.0%

TABLE VIII NUMBER OF QUESTIONS CORRECT ANSWERED IN THE POST-TEST ASSESSMENT

	Number of students	Percentage of students
4 out of 4	21	87.5%
3 out of 4	2	8.3%
2 out of 4	1	4.2%
1 out of 4	0	0.00%
None	0	0.00%

TABLE IX. T-TEST TESULTS BETWEEN THE PRE-TEST AND THE POST-TEST

	Pre-Test		Post-Test		t-Test Results		
	Mean	*STD*	*Mean*	*STD*	*t*	*Df*	*p*
Q1	1.67	0.58	2.00	0.00	-2.15	23	0.043
Q2	1.58	0.69	1.92	0.17	-1.77	33.50	0.087
Q3	1.58	0.69	2.00	0.00	-2.46	23.0	0.022
Q4	1.17	1.01	1.75	0.46	-2.36	40.21	0.023
All Qs	6.00	3.47	7.67	0.93	-3.88	34.45	0.0004
Significance levels: $p < .001$; $p < .01$; $p < .05$; $p < .1$							

Table IX presents the mean and standard deviation ratings for the four questions in the pre-test and post-test, as well as the results of statistical analysis using a t-test. The results show that the post-test had statistically significant higher rating than the pre-test for Q1, Q3 and Q4 at 95% confidence level, and a weaker difference for Q2 at 90% confidence level.

The class average total scores in pre- and post- tests and the t-test analysis are also presented in Table IX. The results show an increase of 27.8% in the average total score. This increase is statistical significant with a 99% confidence level.

V. CONCLUSION

A case study that involved the use of an immersive educational game (*Count With Me!*) in the *Introduction to Mathematics* module delivered to twenty-four 1st year undergraduate students enrolled into a Computing degree was presented. The game introduces learners to counting principles such as addition, multiplication, factorials and permutations by brings real world scenarios that require problem solving and Mathematics knowledge into the learning process. A description of the game and its educational content focusing on counting principles were provided.

The game was played by the students at home in advance of the class session. The aim of the game was to help the students to fill in the knowledge gaps on the four concepts prior coming to the class and learning advance Mathematics concepts.

A quiz based pre-test analysis has shown that the students did not master well the 4 topics and they were the least familiar with the Permutations principle. Although addition, multiplication, factorials, and permutations have already been studied by the students in the high school, the pre-test results showed that some students face difficulties with these topics.

A quiz (post-test) was run at the beginning of the lecture session, after the students have played the game at home. The post-test results analysis has shown that *Count With Me!* game significantly increased the knowledge level and students achieved better results. It was also noticed that the biggest jump of 13 students, or 54.2% was obtained in terms of number of students that demonstrated that they are able to master all the four topics related to counting principles. The number of students that were able to answer correctly only up to half of the questions has also significantly dropped from 25% in pre-test to only 4.2 % in the post-test.

Learner engagement and satisfaction have also been analysed through a survey that was run at the end of the case study and more details were presented in [19]. Overall, 82.82% of students liked self-pacing themselves through the educational, 78.78% of students agreed that the *Count With Me!* game has improved their knowledge and 81.81% of students were satisfied with their achievements in the game. The contribution of this research is using game-based learning methodology (Game) to fill the gaps that students have in their maths education so that they can participate in the class. This approach can be generalized to create a more comprehensive game that can be used prior to the classroom event. This will not only help with the pass rate but also with the engagement and satisfaction.

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