

COLOSSUS FROM ALGEBRON – GAMIFICATION AS A TOOL TO ENGAGE STUDENTS IN LEARNING MATHEMATICS

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Abstract: Gamification is a tool that allows for high engagement in performing tasks that have been previously considered difficult or uninteresting. It works exceptionally well in education as it supports students in developing habits of learning and provides them with a visual representation of their progress in acquiring knowledge and skills. Skillful design of gamified academic courses enables the achievement of the educational goals set by both the students and the academic teachers. Gamification is helpful for subjects that seem challenging, require a significant amount of effort, or are simply perceived by students as uninteresting or useless. The purpose of this paper is to discuss various aspects of engaging students in the process of learning mathematics by the gamification of linear algebra.

Keywords: gamification, linear algebra, teaching mathematics, learning outcomes, students' engagement.

1. INTRODUCTION

Gamified classes offer the opportunity to set different goals than just grades; they create motivation for self-improvement, knowledge acquisition, and skill development. As a result, they spark interest in the subject itself. It is an imaginative journey into a fictional world where learning becomes a source of pleasure and adventure. Student-players achieve a state of flow, familiar from games, leading to better outcomes and greater satisfaction from their efforts. They take responsibility for their own education, charting their development path, exercising autonomy in decision-making, and strategically pursuing their goals. This approach teaches self-management of time, allowing for learning from setbacks and turning them into valuable lessons.

Gamification offers students an adventure filled with challenges, sprinkled with a bit of mystery. Positive emotions accompany this journey, and the relationships formed create a safe space for effective work of individuals and teams. The traditional roles of teacher and students blur as the teacher becomes part of the new game world, supporting the students in their quest to reach their goals. The most crucial role of the teacher in this course-game is designing the individual stages and the purpose of this journey, as well as accompanying the student-players and providing feedback on their progress.

2. GAMIFICATION AS A TOOL

Gamification is not about turning routine activities into a game, but about redesigning the process with game mechanics to provide an enjoyable experience. It is using gamified elements in a non-game environment to increase motivation and engagement in the process. It is designing experiences that build excitement and motivate people to perform activities that seem boring or difficult, using mechanisms that function in games [Deterding et al. 2011]. The definition draws from several disciplines, from psychology and behavioral science to game theory. McGonigal [2014] calls it "a game you play in your real life"). Zichermann and Cunningham [2011] say it is "a process that uses the thinking found in games, their mechanics, for the purposes of engaging people and solving problems" and that it is "engaging users and changing their behavior using concepts from games, loyalty programs and behavioral economics" [Zichermann 2012].

According to Werbach and Hunter [2012], gamification is "the process of making an activity more like a game" and "the combination of various components that drive a sequence of desired mechanisms to develop interactive behavioral dynamics with the intent of supporting key business processes", and Kapp [2012] states "the process of using some of the elements of a game to improve an individual's problem-solving skills, performance, commitment and motivation".

Studies conducted on player behavior conducted for a long time in the field of ludology [Huizinga 1949] indicate that most participants in games (games in the broad sense of the word) manifest far-reaching optimism, willingness to cooperate, very high involvement and positive emotional investment during the game. Engaging in playful activities is deeply rooted in human nature.

Play is a prerequisite for acquiring cultural skills [Panksepp 2005; Gray 2013], a recognized way for children to learn and generally serving basic evolutionary purposes [Ryan and Deci 2000]. The potential inherent in players is enormous, they completely voluntarily invest countless hours in developing their skills that help them pass levels in the game. It is almost total commitment, a kind of "trance". Players then lose track of time, can work more, better, longer, and their motivation is extremely high. They enter a state of full immersion (flow) in the game

environment. It is a psychological state where work is combined with play [Csikszentmihalyi 1990; Csikszentmihalyi, Abuhamdeh and Nakamura 2005; Hamari et al. 2016].

3. LINEAR ALGEBRA COURSE

The 2021/2022 academic year was the first time the gamified Linear Algebra course was offered to first-semester students majoring in Automatic Control, Cybernetics and Robotics and Biomedical Engineering (hereinafter referred to as ACCR and BE, respectively) at the Faculty of Electronics, Telecommunications and Informatics (FETI). It is one of the three mathematics courses included in the curriculum for these majors during the first semester, alongside Fundamentals of Mathematics and Mathematical Analysis.

The course of Linear Algebra consists of 15 hours of lectures and 15 hours of classes (equivalent to 3 ECTS credits). The course content can be categorized into four main areas: matrices and determinants, linear equations, analytical geometry in space, and complex numbers. The introduction of these topics does not require extensive knowledge of mathematical concepts going beyond the secondary school level, allowing the course to be conducted from the beginning of the semester, alongside the Fundamentals of Mathematics. Linear Algebra classes are entirely conducted during the first 8 weeks of the winter semester.

The topics covered in Linear Algebra are significant for students pursuing these majors, as they are utilized in other subjects in the subsequent semesters, such as Circuits and Signals and Fundamentals of Image Processing.

Successful completion of the course in Linear Algebra concludes with a passing grade. In previous years, students could earn up to 90 points in the final test and 10 points for participation in exercises, with their final grade determined by the accumulated points. Gaining 50% of the available points was the required minimum for a pass. Additionally, students had the option of completing two thematic courses on the e-learning platform, covering Elements of Linear Algebra and Complex Numbers.

The main challenge in conducting the course was the lack of consistency in students' work, and the points awarded for participation were not motivating enough. Another significant issue was the absence of real-time feedback for students regarding their current progress and understanding of various topics. This feedback was only provided through self-assessment quizzes in the two e-learning courses. Moreover, students perceived the subject as less relevant, especially in the context of their future studies.

The primary objective of introducing gamification was to create conditions for consistent work for all students, increase their engagement in solving problems (exercising this skill independently), and emphasize the importance of the discussed

topics in terms of their practical applications. Real-time feedback on students' understanding of the covered topics and the ability to monitor their ongoing progress were also essential aspects. All tasks in the gamification platform, except for attending and task solving during the classes, were optional, and students could attempt the final assessment without completing the tasks.

In the 2021/2022 academic year, a total of 155 students from the ACCR and BE programs participated in the gamified Linear Algebra course. The results were compared with those achieved by students in previous years in the same programs (ACCR and BE) and studying under the same conditions with the same academic teachers.

The gamified classes were the same as the non-gamified classes: every week there were lectures in which the lecturer explained the theory and exercises for the students to practice algebra tasks and take the tests covering the material. However, gamification gave students the opportunity to be better prepared for classes, it increased motivation to learn and gave them the opportunity to do creative supplementary tasks.

The successful implementation of gamification in Linear Algebra was made possible through the collaborative efforts of five instructors from the Mathematics Center and the Center for Innovative Education, including a methodologist, a programmer / game and gamification specialist, and a graphic / user interface designer.

4. COLOSSUS FROM ALGEBRON

Colossus from Algebron is a web application in which each of the students, instructors, and testers (senior students) created their individual accounts. After registering their accounts, the student-players created their in-game nicks and could personalize their avatars (selecting the character, color scheme etc.) and share information about themselves. Instructors were authorized to send messages to players (individuals, groups, or all).

In the first year of implementing the subject in a gamified format this web application was prepared in two versions: a narrative version (the basic version) and a non-narrative version (toggleable in the menu bar); however that version was later discontinued due to low student interest.

The game's narrative unfolds in the Undergrounds of Algebron, where all students, acting as Searchers, are trapped by a dark force. To escape from the Undergrounds, each Searcher must traverse four corridors filled with mathematical challenges. Dreadful Monsters which symbolize the four thematic sections hide at the end of each corridor. To defeat them, Searchers need dexterity points and coins, which they can collect in the game by completing tasks.

During their journey, Searchers can train and prepare themselves thoroughly for their encounters with each of the four Monsters. In the Undergrounds of Algebron, there are also the Spirits of the Sages, who are the guides, supporting Searchers with their knowledge during lectures, exercises, and consultations.

To escape from the Undergrounds, the Searchers must collect four parts of an amulet guarded by the Monsters. Once the amulet is complete, it grants invisibility, protecting Searchers from a confrontation with the Colossus from Algebron and allowing them to be exempt from the final test.

Searchers have the option to train and prepare for battles with Monsters through magical and strength training (these tasks are optional). By completing these tasks (also called quizzes), Searchers earn coins, which they can use to purchase magical attributes from the market.

Magical training consists of brief multiple-choice quizzes based on lecture content. These training sessions are initiated directly after the lectures and can be attempted only once. Strength training involves similar multiple-choice quizzes but can be attempted multiple times. These quizzes are launched immediately after lectures and are valid for two weeks. Their purpose is to prepare Searchers for their training with the Sages and to be better equipped for the confrontation with the Monsters. Searchers earn 5 coins for each correctly answered task in magical and strength training, which can be used for purchasing magical attributes from the market.

Among the items offered in the market, the most valuable is the healing elixir (worth 300 coins), which, in case of failing a confrontation with a Monster, allows Searchers to regain their strength and face the Monster again. One can gain the healing elixir, which means the possibility of revising a failed confrontation, by learning how to solve quizzes and successfully completing a sufficient number of tasks. Around 22% of students took advantage of this option during the gamification in the 2021/2022 academic year.

In addition to coins, Searchers can earn dexterity points (DPs), which they receive for battles with Monsters, focus tests, and pictograms.

Focus tests are associated with the completion of two thematic courses available on the e-learning platform. Dexterity points are awarded to Searchers based on their final quiz scores upon completing each course.

Pictograms are tasks that involve searching for practical applications of the discussed mathematical concepts in other scientific disciplines, particularly those related to their fields of study and daily life. However, these tasks primarily require a creative approach to present work in any form, such as infographics, mind maps, podcasts, videos, blog posts, comics, graphic work, voice presentations, stories, memes, interviews, games, etc. Searchers also have the option to collaborate on pictograms with another Searcher.

Battles with Monsters are assessments conducted during classes a week after each thematic section has been completed. Each battle is worth 20 DPs and

a fragment of the amulet. In total, Searchers can earn 80 DPs and the entire amulet, which allows them to pass unnoticed by the Colossus and escape from the Undergrounds of Algebron. However, to obtain a fragment of the amulet from a Monster, Searchers must earn at least 10 DPs in the battle. Avoiding a confrontation with the Colossus of Algebron guarantees a minimum of 70 (approximately 58%) out of the possible 120 DPs and the acquisition of the complete amulet.

5. RESULTS

Launched in October 2021, the game was a prototype, and the students who participated in it were testers for a new learning solution for mathematics. After the classes ended in January 2022, a survey (21 questions) was conducted to collect feedback on the game's playability, the functionality of the web application, the level of student engagement in solving mathematical tasks, and the assessment of individual game elements and gamification as a concept for enhancing motivation for systematic work and, consequently, improving the skill level specified for the Linear Algebra subject.

The survey involved 43% (67) of students enrolled in the Linear Algebra course in the 2021/2022 academic year. Almost 70% of the respondents reported that the applied tool (gamification) increased their motivation to learn. 77% of the respondents stated that they learned more from the gamified classes and absorbed more knowledge. 87% expressed a desire to gamify the other two mathematical subjects offered in the 1st semester. 83% of respondents noted that they worked more systematically during the Linear Algebra classes compared to other (non-gamified) subjects.

5.1. Students' engagement in the game

The prepared web application of "Colossus from Algebron" allowed a detailed analysis to be created of students' activity and engagement at various stages of the implemented gamification.

In the database of tasks prepared for the gamification, there were a total of 240 quizzes. The maximum number of coins to be obtained was 1200. On average, players (160 students) completed around 93 quizzes, earning an average of 466 coins. The most engaged player solved 198 quizzes and earned 990 coins.

Figure 1 illustrates how many students participating in the game obtained the number of coins indicated on the horizontal axis. Most players (57) earned from 401 to 600 coins for solving quizzes. Disappointingly, 16 players earned no more than 200 coins, thus, they did not have the possibility of purchasing the healing elixir. On the other hand 14 players earned over 800 coins.

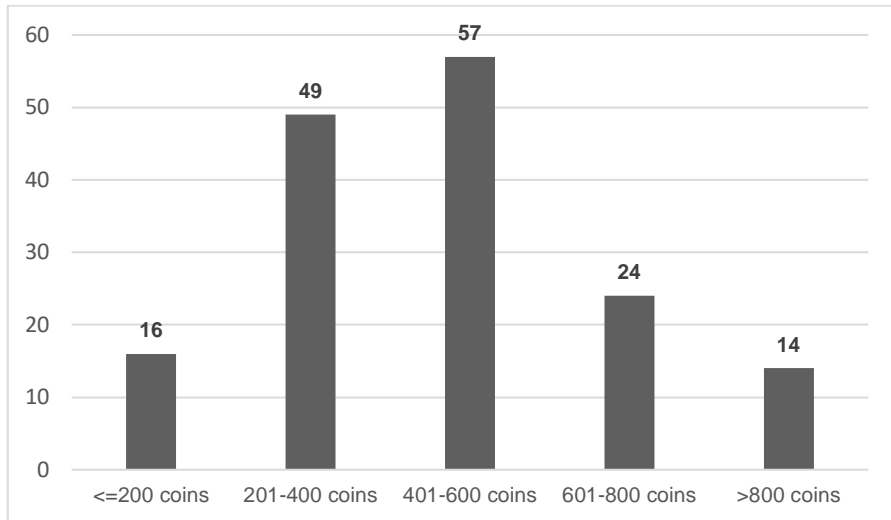


Fig. 1. Number of coins the players earned

Next, Figure 2 shows the number of quizzes solved by the students in the game. Most players, as many as 73, solved from 51 to 100 quizzes; 23 of them solved fewer than 50 quizzes, while 16 players solved over 150 quizzes.

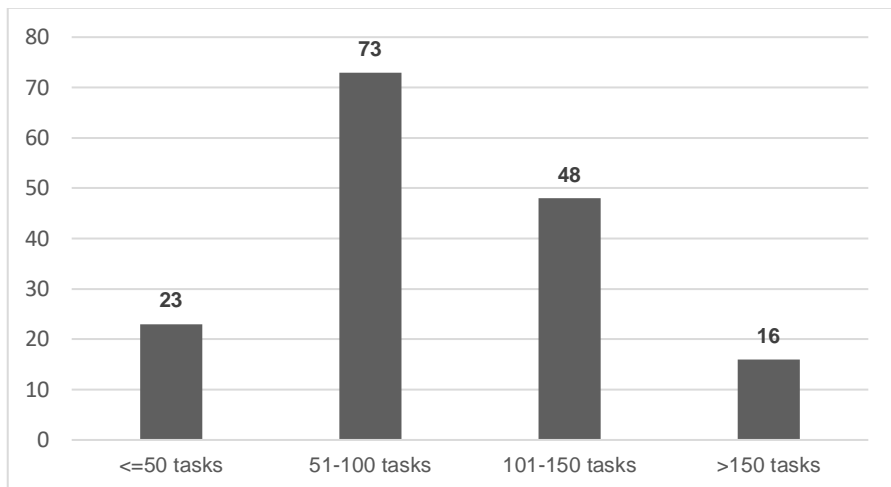


Fig. 2. Number of tasks the players solved

Having the required number of coins (300) allowed players to purchase the healing elixir at the market. 92 students decided to make this purchase. Other products in the market received much less interest from players, although they were still purchased, even though they did not translate into additional benefits related to passing the subject.

The chart in Figure 3 presents the record of market purchases.

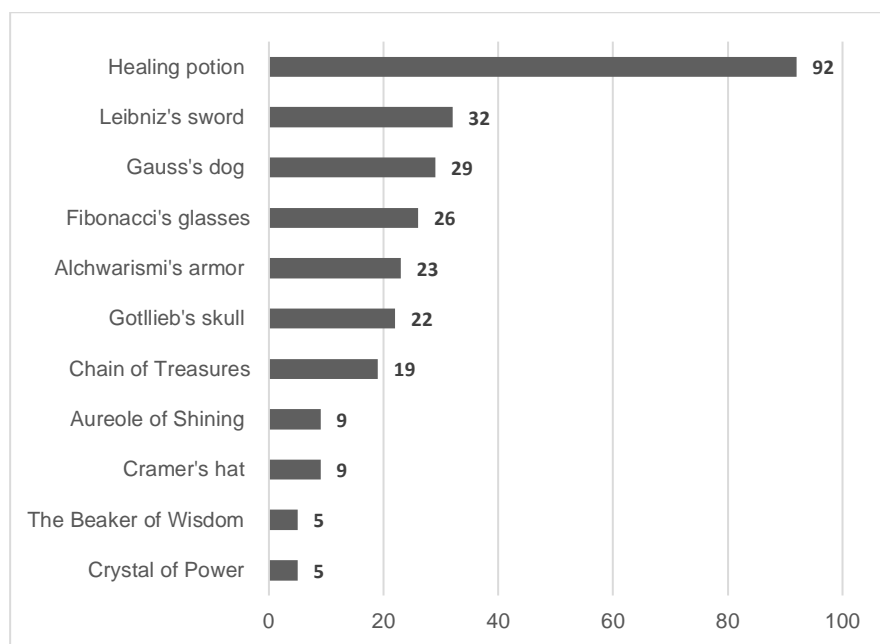


Fig. 3. Number of items purchased at the market

Additional benefits for purchases in the market were introduced to maintain student engagement throughout the duration of the "Linear Algebra" course in the following 2022/2023 academic year, when gamification was still being implemented.

The average number of players participating in various magic and strength training sessions was also analyzed.

The relevant statistics are shown in Figure 4 and Figure 5. The charts indicate that while students were very engaged in solving quizzes in both types of training during the first two weeks of the course (up to 151 in strength training and 143 in the magic training, in the first week). Their engagement gradually decreased as the semester progressed.

In the 2022/2023 academic year, the introduction of additional benefits associated with the market purchases helped to sustain student engagement in the game.

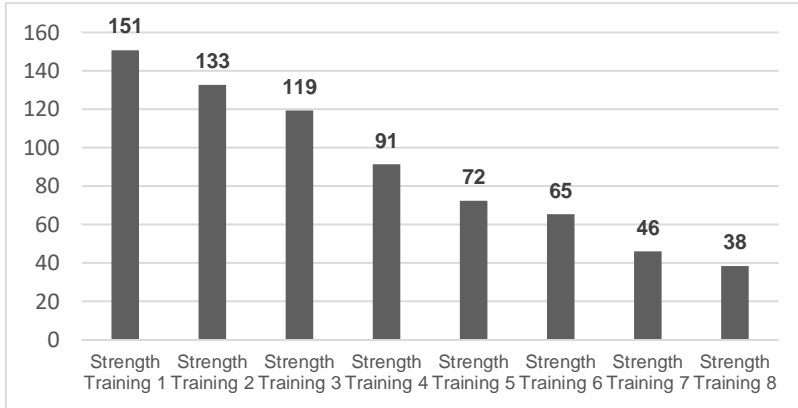


Fig. 4. Average number of participants in each Strength Training session

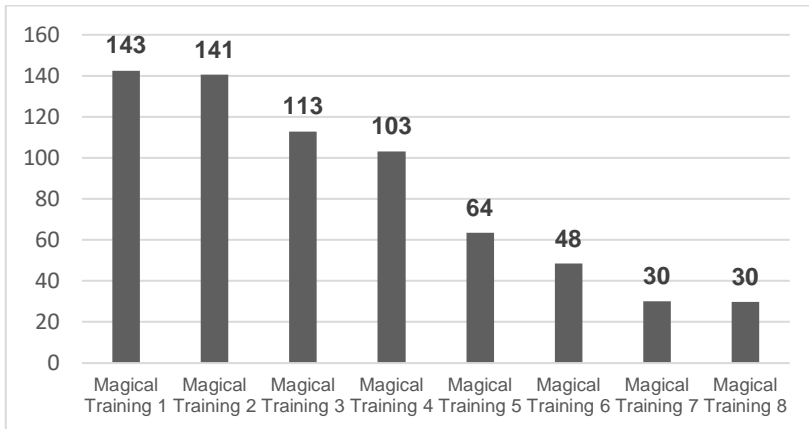


Fig. 5. Average number of participants in each Magical Training session

It was also worth examining the average time the players needed to complete a single quiz in each magic training (a set of tasks based on lecture content, which could be attempted by the players only once) and strength training (a set of tasks that could be attempted multiple times).

The relevant data is presented in Figure 6 and Figure 7.

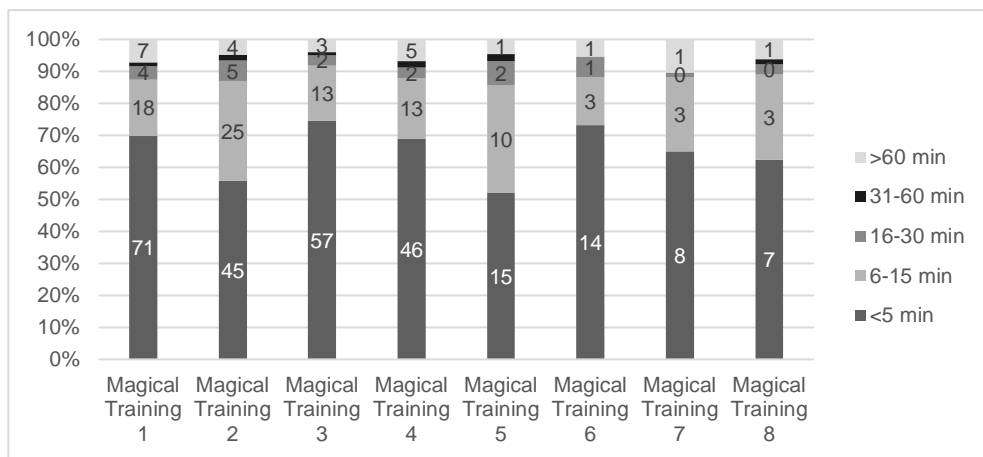


Fig. 6. Average time the players needed to solve a task in each Magical Training session

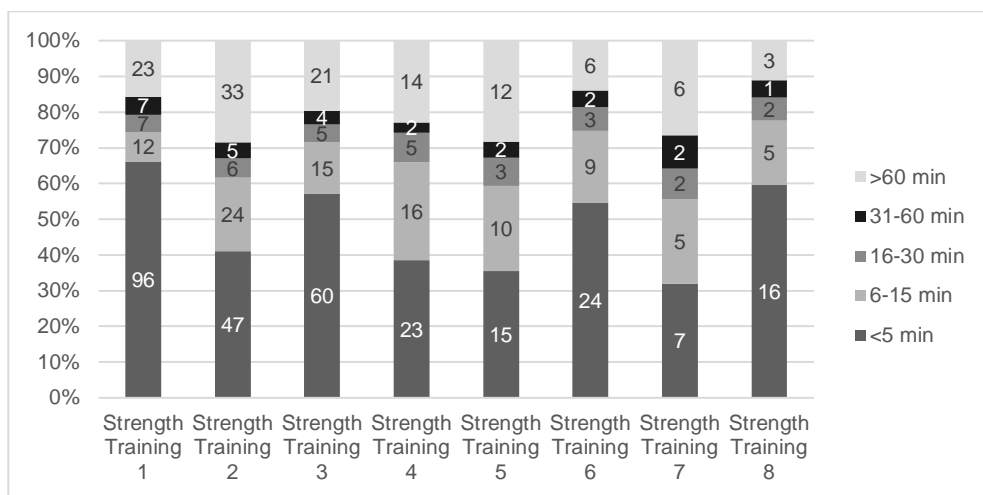


Fig. 7. Average time the players needed to solve a task in each Strength Training session

In analyzing the level of difficulty of the presented problems and the task complexity, it was crucial to investigate how many players correctly solved tasks in each of the Magic and Strength Training sessions and how many solved them incorrectly or not at all. In the Magic Training sessions, 36% to 71% of players solved tasks correctly, while in Strength Training sessions, this range was from 50% to 96%.

5.2. Students' creativity

An incredibly important aspect of building students' motivation for learning Linear Algebra was emphasizing the practical applications of the topics covered in the course through the creation of pictograms, encouraging independent study and exploration by students. The proposed creative form of preparing pictograms was aimed to stimulate students' creativity and motivate them to take on the challenge.

A total of 81% of students from both majors engaged in creating pictograms, with 65% of students preparing more than one pictogram. Students from the ACCR and BE programs demonstrated significant creativity and showcased the applications of various elements of Linear Algebra in diverse ways.

Common forms of presentation included infographics, graphics with animations, or mind maps. An interesting idea was a comic strip (about Matematikano, the Math God) and a concert tour poster (Complex Numbers Tour). There were also thematic websites, blogs and podcasts. However, among the works prepared, there were literary pieces, including stories (e.g. Screens of Addiction, Complexly, Analytical Geometry in Geometropolis) and poetry (such as a mathematical variation on Mickiewicz's invocation, A Jest about Uncle Google, a poem about complex numbers), as well as musical compositions (a song about matrices on the ukulele).

To demonstrate the applications of various topics in Linear Algebra, students created their own computer programs (e.g. an anti-aircraft defense system) and animations (Matrix-like, a meeting between a GUT student and Einstein). Short films were also produced (e.g. about industrial robots). However, the biggest surprise was a series of YouTube videos, featuring interviews as part of Breaking News with such "personalities" as Mr. Matrix and Mr. Vector, to name a few.

As a result, the implementation of the Linear Algebra course revealed additional talents among FETI students, particularly in acting, writing, arts, music and vocals. Most importantly, based on their own work, students had the opportunity to genuinely increase their awareness of the presence and usefulness of the mathematical concepts covered in the course in fields related to their majors, other areas of study, and in daily life. This directly contributed to building motivation for studying the subject and generating interest in the subject itself.

5.3. Teaching assessment

In recent years, when students from the ACCR and BE programs needed to pass the Linear Algebra course, they did it in a final exam conducted at the end of the classes. The threshold for a passing grade was achieving 50% of all available points. In the 2021/2022 academic year, when gamification was introduced, this threshold was raised to approximately 58% (achieving 70 out of 120 possible points). This decision was driven by the knowledge of the positive impact of gamification on user

motivation (based on personal experiences and research results). Additionally, to be exempted from the final exam, students were required to pass each of the discussed course sections with a minimum of 50%. In this way, the authors of the gamification aimed to motivate students to further engage in creative tasks related to applying knowledge in practice.

Analyzing the pass rates in the academic years 2020/2021 and 2021/2022 (both conducted under the same pandemic conditions, with remote lectures), we can see that in the current academic year, after the final exam, 78.06% of students received a passing grade (compared to 51.72% in the previous year), with 70.32% of students exempted from the final exam. An additional 9.03% of students passed the first retake exam (compared to 25.52% in the previous year), resulting in an overall pass rate for the final exam in the current academic year of 87.01% (compared to 77.24% in the previous year).

According to FETI practice, an additional retake exam took place in the summer session of the previous academic year, which, in the annual summary, increased the pass rate for this course to 82.76%. Already at this stage, after the first retake exam, the number of students who passed the course was higher (87.01%) than the number of students after the second retake in the previous academic year (82.76%).

6. CONCLUSIONS

An increase in both learning effectiveness and satisfaction with work has been observed, along with a simultaneous rise in the requirements set for students. However, there was a decline in the average number of participants in various magic and strength training sessions as the course progressed. While the students were highly engaged in solving quizzes in both types of training during the first two weeks of the course, later the number of engaged students gradually decreased.

It might have been due to the lack of additional motivators needed to keep players engaged in the game as the semester progressed. Students had increasingly more assignments in other courses and tended to let go of training sessions.

From the surveys, it appears that some of the students regretted not practicing as intensively in the training sessions as they had done at the beginning. They were aware that it would have helped them to achieve better results. Therefore, in the next edition of the game, we introduced additional incentives related to market purchases to help maintain high levels of students' engagement.

Furthermore, the following observations were made on the basis of the course results and the conducted survey:

- 70% of students reported an increase in the motivation to learn;
- 76% believe that gamification has helped them derive more benefits from the classes;

- 87% would like other mathematical subjects to also be taught in a gamified format;
- 82% felt that they worked more systematically in this gamified course compared to other non-gamified subjects;
- 81% of students from both programs took on the most challenging tasks, namely the pictograms, with 65% preparing more than one pictogram;
- 79% are satisfied with the results they achieved;
- 78% passed the course during the regular term;
- The pass rate for the course during the regular term increased from 52% in the 2020/2021 academic year to 78% in the 2021/2022 academic year.

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