Implementing Neuroscientific Principles in Gamified Software Engineering Courses

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***Abstract*— This research-to-practice full paper describes the intersection between gamification and neuroscientific indicators of learning in an introductory software development course. We implemented an action research approach, using weekly questionnaires and concept maps to assess the acquisition of new concepts and the enrichment of students' neural connection networks. The gamification was structured with the Octalysis framework, promoting an interactive and engaging learning experience. The results indicated improvements in academic performance and student engagement. Gamification increased motivation and facilitated the assimilation of new knowledge. Neuroscientific indicators showed that students were able to integrate new knowledge with pre-existing information, enriching their neural networks. Gamification activated the brain's motivation and reward mechanisms, promoting deeper and more interconnected learning. Real-time data analysis allowed for continuous adjustments in pedagogical strategies, improving the methodology's effectiveness. We concluded that the combination of gamification and neuroscience can transform the learning experience, making it more engaging and effective. Educators can adopt these strategies to create curricula that not only transmit technical knowledge but also continuously motivate and engage students. Future research will explore the application of this approach in different educational contexts and more diverse populations.**

Keywords*— *Gamification, Educational Technology, Computing Skills, Active Learning, Neuroscientific Learning Indicators

I. Introduction

Engaging students in the ever-evolving landscape of higher education, especially in programs like Software Engineering, requires innovative approaches. Digital natives with different cognitive demands, today's students need strategies that impart technical knowledge and stimulate motivation [1]. Introductory courses in software development, typically offered in the first year of Software Engineering undergraduate programs, are at the forefront of this challenge. These courses aim to provide a fundamental understanding of software development practices and principles, demanding high levels of engagement and practical application from students right from the start of their academic journey.

The use of gamification [2], [3] emerges as a powerful strategy to address these educational challenges. By incorporating game design elements into the learning environment, gamification offers a dynamic and interactive approach to education, enhancing student motivation and engagement. This modern teaching methodology aligns well with the characteristics of today's students, providing them with a familiar and stimulating context to learn complex concepts and skills.

Furthermore, integrating neuroscience into educational strategies presents a frontier for improving learning outcomes. Neuroscientific indicators, which measure cognitive functions and learning processes, provide valuable data into how students learn best [4]. Specifically, these indicators can assess the effectiveness of gamification in stimulating cognitive and emotional responses that promote better engagement and performance in learning.

In this context, our work explores the intersection of gamification and Neuroscientific indicators in an introductory software development course. We propose that the motivational boost provided by gamification, when combined with information from Neuroscientific indicators, can significantly enhance student performance. This approach not only meets the unique profiles of modern students but also aligns with the essential competencies required for future software engineers, such as problem-solving, critical thinking, and collaborative teamwork. Through a detailed examination of this innovative educational strategy, our study aims to contribute to the broader discourse on effective teaching methodologies in software engineering education, highlighting the potential of gamification and neuroscience to transform the learning experience.

The structure of this paper is organized as follows: In the second section, we present the necessary background, examining previous work on gamification, student engagement, and the role of neuroscience in learning. Our methodology, described in the third section, details how we integrated gamification into the software development course and applied Neuroscientific indicators. The fourth section presents our findings on the effects of this integration on student outcomes. We discuss these results and their implications for educational practice in the fifth section. The paper concludes in the sixth section, where we summarize our contributions and outline directions for future research.

II. Background

A. Course context

The course analyzed is a component of the Software Engineering curriculum at a Brazilian public university. It is offered to first-year students. The course aims to provide a broad understanding of the software development process, covering everything from requirements to implementation and project management.

Since the second term of 2021, the course has adopted a gamified approach using the Octalysis framework [3] to structure gamification. The goal of this approach is to increase student engagement and motivation. Gamification transforms the learning experience, making it more interactive and engaging.

Students are organized into teams and assume specific roles within a feudal-themed scenario. Team leaders coordinate the activities of team members. This structure promotes the development of leadership and teamwork skills, essential for success in the field of software engineering. Advanced term students offer guidance and support, facilitating the integration of new students into the academic environment.

The course is now offered in person. Historical data is shown in Table I.

TABLE I: DATA FROM THE ACADEMIC TERMS.

Term	**Modality**	**Approach**	**Number of Students**
2023/2	In-person	Gamification	72
2023/1	In-person	Gamification	70
2022/2	In-person	Gamification	70
2022/1	In-person	Gamification	60
2021/2	Remote	Gamification	70
2021/1	Remote	Expository	70

The objective of the course is for students to develop a software product, such as an application, portal, or game, in teams, applying software development principles. This practical approach facilitates the understanding of theoretical concepts and prepares students for the real-world challenges of the job market.

Since 2023, continuous weekly data collection has been implemented on student indicators that allow the evaluation of neuroscientific indicators. Using a PowerBI dashboard, the data is imported from the course application (built in PowerApps). The monitoring of the data allows tracking student progress, particularly performance and engagement, and adjusting pedagogical strategies during the course.

B. Gamification in education

Gamification, defined as the application of game design elements and techniques in non-game contexts, aims to increase user engagement and motivation [2]. In education, this strategy transforms learning into a more engaging and interactive experience, encouraging students to actively participate in the educational process [5].

The implementation of gamification in the course demonstrates how this approach can enhance student motivation and engagement. By using mechanisms that promote active and continuous participation, gamification not only makes learning more enjoyable but also offers recognition of achievements through rewards, collaboration, cooperation, and visible progress [6], [7].

Studies indicate that gamification can increase student motivation. A systematic review conducted by Hamari et al. [5] highlighted that gamification significantly improves engagement and learning outcomes. Caponetto et al. [8] reinforce this perspective, indicating that a well-planned application of gamification transforms the educational environment, making it more dynamic and suited to the needs of modern students.

C. Framework Octalysis

We used the Octalysis framework [3] by Yu-kai Chou, which analyzes and applies human motivation to interactive systems. It is structured around the eight core drives that influence human behavior. These core drives are:

CD1 - Epic Meaning & Calling: People are motivated by a cause or mission that they believe is bigger than themselves.

CD2 - Development & Accomplishment: The drive for progress, skill development, and achieving goals.

CD3 - Empowerment of Creativity & Feedback: Encouraging creative freedom and experimenting with regular feedback to guide progress.

CD4 - Ownership & Possession: The motivation that comes from owning something and wanting to improve.

CD5 - Social Influence & Relatedness: Involvement with social elements like mentorship, social acceptance, social feedback, companionship, and competition.

CD6 - Scarcity & Impatience: The need to have something because it is rare, exclusive, or immediately unavailable.

CD7 - Unpredictability & Curiosity: A drive related to the enjoyment of experiencing surprises and the thrill of finding out what will happen next.

CD8 - Loss & Avoidance: The motivation to avoid negative outcomes, including fear of loss and a desire for consistency.

The Octalysis framework allows the creation of interactive experiences that motivate users to achieve their goals in various areas, such as learning [9], health improvement [10], and productivity increase [11], among others.

D. Neuroscience in learning

The acquisition of new concepts is a vital process in learning, especially in educational contexts. From a neuroscientific perspective, learning involves the formation and consolidation of memories, which occurs through the processes of encoding, storing, and retrieving information. Studies demonstrate that the encoding of new concepts in the human brain is associated with the activation of specific regions, such as the hippocampus and prefrontal cortex, which are responsible for integrating new information with pre-existing knowledge [12].

Neuroplasticity, or the brain's ability to reorganize its connections in response to new information, is central to the acquisition of new concepts. During learning, synapses between neurons are strengthened, and new connections are formed, facilitating the retention of new information. This process is influenced by factors such as repetition and emotion, which help consolidate long-term memories [13]. For example, the study by Mason et al. [14] demonstrated that the brain organizes scientific concepts into new dimensions of neural representation, suggesting that learning involves decomposing concepts into meaningful components and integrating these components into existing neural networks.

In an educational context, applying indicators to measure the acquisition of new concepts can involve assessing students' prior knowledge and measuring learning throughout the course. Tools such as questionnaires and pre- and post-course assessments allow educators to identify which concepts have been assimilated and which require further reinforcement [4].

The enrichment of the connection network refers to the increase in complexity and density of neural connections as new knowledge is integrated with pre-existing knowledge. This process creates robust and accessible memory. In neuroscientific terms, the enrichment of connection networks is related to the concept of engrams, which are lasting memory traces formed by structural changes in synapses [13].

To measure the enrichment of the connection network, educators can use techniques such as concept mapping and information recall exercises, in which students list the connections, they can make between different learned concepts. This type of assessment helps identify the degree of interconnection of new information with existing knowledge and can guide pedagogical interventions to strengthen these connections [4].

E. Gamification, neuroscience, and learning indicators

The interconnection between gamification, neuroscience, and learning indicators is central to the educational approach used in the course. Gamification, by transforming the learning experience into an engaging and interactive activity, activates the brain's motivation and reward mechanisms, facilitating the retention of new concepts and the enrichment of neural networks.

The neuroscientific indicators used in this work allow for measuring the effectiveness of this approach. The two indicators applied were the acquisition of new concepts and the enrichment of the neural connection network.

Acquisition of new concepts: This indicator assesses how well students can assimilate new knowledge throughout the course. Using questionnaires and continuous assessments, it was possible to measure students' progress and identify which concepts were effectively assimilated. The encoding of new concepts involves the activation of brain regions such as the hippocampus and prefrontal cortex, which are essential for integrating new information with pre-existing knowledge [12], [13].

Enrichment of the connection network: This indicator measures the complexity and density of neural connections formed as students assimilate new knowledge. During learning, not only are new concepts acquired, but they are also associated with already established information networks, creating robust and accessible memory. Studies show that this process of interconnectivity is vital for the efficient and accurate recall of memories [15]. Techniques such as concept mapping and information recall exercises were used to assess the enrichment of connection networks [4].

III. Methodology

The methodology of this study was designed to evaluate the impact of gamification on learning. Using an action research approach, the study followed an iterative cycle of planning, action, observation, and reflection, allowing for continuous adaptation of the gamification design based on feedback and data collected throughout the phases.

A. Study Design

The study followed an action research approach [16] with specific objectives: designing a gamification strategy aligned with educational goals and student motivations, measuring the impact of gamification through neuroscientific indicators (such as the acquisition of new concepts and the enrichment of the neural connection network), and analyzing collected data to identify patterns and trends.

1) Study Phases

Phase 1 - Audience Identification with the Octalysis Framework: The study began with identifying student motivations and behaviors using the Octalysis framework. This phase helped understand the needs and preferences of the students.

Phase 2 - Personalization of Gamification Design: Based on the information obtained in the previous phase, a gamification strategy was designed that aligns with the educational objectives of the course and student motivations. Gamification elements such as points, badges, restricted leaderboards, challenges, and narratives were selected to create an engaging educational experience within a feudal theme.

Phase 3 - Pilot Test Without the Application: Before integrating technology, a pilot test was conducted without the support of the gamified application. This phase established a baseline for student engagement and learning outcomes, providing reference data for subsequent phases.

Phase 4 - Testing with the Application: The first version of the gamified application (PowerApps) was introduced to evaluate its initial impact on student engagement and learning outcomes. Based on observations from the first version of the application, a second version was developed incorporating all information related to neuroscientific indicators. Analyzing these data identified trends and areas for improvement.

Phase 5 - Evaluation of Engagement and Measurement of Learning Outcomes: Finally, all data collected via the application were used for visualization through a dashboard created in Microsoft Power BI. This allowed various real-time comparisons between student performance before and after the activities, as well as comparisons between terms, providing a conclusive assessment of the methodology's effectiveness.

B. *Participants*

The participants in this study were undergraduate students enrolled in the course offered in the Software Engineering program at a Brazilian public university. Participant selection was based on their enrollment in the course during the terms the study was conducted, ensuring a representative sample of the target audience. There were no exclusions based on age, gender, or academic background, ensuring diversity among participants.

The study covered a total of 72 students in the 2023/2 term, 70 students in the 2023/1 term, and 70 students in the 2022/2 term. These numbers reflect robust and consistent participation across terms, allowing for comparative and longitudinal analysis of the collected data.

Participants were primarily first-year Software Engineering students, aged 18 to 25. Most participants had little or no prior experience in software development, making them ideal for evaluating the impact of gamification in an introductory learning environment.

The students were organized into teams and actively participated in the various study phases. Each team had a leader who coordinated activities and facilitated communication among members, promoting a collaborative and dynamic environment.

C. *Procedures*

The study, conducted over several terms, followed structured procedures to implement and evaluate gamification. The steps were carefully planned to ensure the effectiveness of the intervention and the collection of relevant data.

Phase 1: Audience Identification with the Octalysis Framework

Initially, we used the Octalysis framework to understand student motivations and behaviors. Interviews were conducted to collect data on student preferences and motivations.

Phase 2: Personalization of Gamification Design

With the obtained information, we developed a gamification strategy aligned with the course's educational objectives. The selected gamification elements enabled the creation of a gamification project, which was subsequently implemented and tested.

Phase 3: Pilot Test Without the Application

To establish a baseline, we implemented gamification without application support in the 2021/2 and 2022/1 terms. We observed student interactions, engagement, and learning outcomes, collecting data that served as a reference for future comparisons. This phase was essential to identify which aspects of the course would benefit most from gamification.

Phase 4: Testing with the Application

We introduced the first version of the gamified application, incorporating gamified features in the 2022/2 and 2023/1 terms. We monitored changes in student engagement and learning outcomes, comparing them with the baseline data. Based on feedback, we developed a second version of the application, integrating a more immersive feudal theme and additional gamification features, as well as a more intense data collection process. This second version was applied in the 2023/2 term. It is worth noting that various data have been collected since the start of gamification in 2021/2, and all data are tabulated in the same database.

Phase 5: Evaluation of Engagement and Measurement of Learning Outcomes

The final phase involved evaluating student engagement levels and measuring the educational impact of gamification. We used application data and performance comparisons before and after gamification implementation to assess the methodology's effectiveness.

D. *Tools and Materials*

The implementation of gamification in the software development course utilized various tools and materials carefully selected to support design, data collection, and result analysis.

The main instrument used was a gamified application developed specifically for the course using Microsoft's PowerApps platform. The application underwent two versions during the study. The first version incorporated basic gamification elements, such as points, badges, and leaderboards. To better monitor students throughout the course, a more sophisticated second version was developed. The application is essential for tracking student interactions, recording achievements, and providing continuous feedback.

For detailed data analysis, we used a PowerBI dashboard. This tool enabled direct data import from the gamified application, providing a comprehensive and progressive view of student performance and engagement. The dashboard was configured to track learning indicators and facilitated the visualization of trends and patterns throughout the term, allowing for adjustments to pedagogical strategies as needed.

Various resources were incorporated into the application and dashboard, including questionnaires applied at different times during the course, evaluating aspects such as:

- Student knowledge of the concepts used (weekly frequency),
- Weekly meetings (duration and content) held outside the classroom,

- Performance of all team members (cross-evaluation).

Additionally, collaboration tools such as Microsoft Teams, GitHub, and Trello were used to facilitate communication and collaboration among team members.

The course-specific educational materials included study guides, tutorials, and reading resources that complemented the course content. These materials were integrated into the course webpage or the gamified application, allowing students to easily and quickly access relevant information while participating in gamified activities.

E. Data Collection

Data collection in the 2023/2 term was carried out entirely through the application. Previously, we also used questionnaires via Microsoft Forms. However, even when using Forms, all data were incorporated into the same database, allowing for term comparisons.

1) Data Collection Methods

Student Prior Knowledge Questionnaires

Objective: Assess students' prior knowledge and measure learning acquired throughout the term.

Procedure: Questionnaires were applied weekly. The questions covered self-assessment (on a 5-point Likert scale) of fundamental software development concepts used individually by each team, such as programming languages, databases, development platforms, team management methodology, among others. This allowed for a direct and continuous comparison of student and team knowledge throughout the term.

Concept Maps in Out-of-Class Meetings

Objective: Visualize the network of connections formed by students between different learned concepts.

Procedure: All out-of-class meetings were recorded through forms within the application. The leaders of each team documented these meetings, providing the theme, duration, date, and a brief description of what was discussed. These meetings allowed us to map how concepts were being reinforced within each team.

2) Data Processing and Analysis

The collected data were centralized and analyzed through the PowerBI dashboard, including neuroscientific indicators.

F. Neuroscientific Indicators

1) Acquisition of New Concepts

This indicator assessed students' ability to assimilate new knowledge throughout the course. The Acquisition of new concepts was measured weekly.

Method: Structured questionnaires were applied weekly to evaluate the fundamental concepts of software development. The responses were analyzed to identify progress in understanding and retaining new concepts.

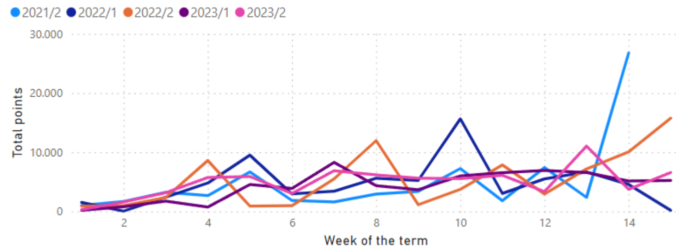

Fig. 1. Comparison between academic terms and their weeks.

Objective: Measure the effectiveness of gamification in facilitating the assimilation of new knowledge, observing how students evolved in their understanding of the course topics.

2) Enrichment of the Neural Connection Network

This indicator evaluates the complexity and density of neural connections formed as new knowledge is integrated with pre-existing knowledge. The enrichment of the connection network was measured using concept maps and information recall activities.

Method: From the out-of-class meetings conducted and recorded, we analyzed the themes and duration of each meeting, evaluating how the concepts were being reinforced and interconnected within each team.

Objective: Assess the depth and interconnectivity of the acquired knowledge.

G. Study Limitations

Although this study can provide valuable information about the effectiveness of gamification in learning and student engagement in software development, it is important to recognize its limitations. These limitations provide context for interpreting the results and highlight areas for future research.

1) Confounding Variables

There are several external variables that may have influenced the results and were not fully controlled. Factors such as individual leadership styles, workload in other courses, and differences in students' technological resources could have affected engagement and performance.

2) Generalization of Results

Another limitation of the study is its generalizability. The research was conducted at a single Brazilian public university, with a specific group of software engineering students. Therefore, the results may not be directly applicable to other disciplines, institutions, or cultural contexts.

3) Sample Size

Although the number of participants was sufficient for the analyses conducted, the sample size can still be considered a limitation. Studies with larger samples could provide more robust results and increase the reliability of the conclusions.

H. Academic Performance

The study results indicated improvements in student performance with the use of gamification. The analysis of Fig. 1 shows the sum of points accumulated over the weeks of each academic term, highlighting the variations in student performance. Analyzing the gains from the 2023/2 term compared to the other periods, a consistent increase over time is observed, indicating a better cadence in the learning process.

IV. Results

The increase in points in the 2023/2 term, especially in the last weeks, suggests continuous improvement in engagement. This better performance in the 2023/2 term may indicate the effectiveness of the new approaches adopted to stimulate student learning and motivation.

A. *Neuroscientific Indicators*

The neuroscientific indicators, specifically the Acquisition of new concepts and the enrichment of the connection network, showed positive results.

1) *Acquisition of New Concepts*

Fig. 2 shows students' self-assessment throughout the 2023/2 term, indicating the average knowledge level in major areas, including backend frameworks, databases, frontend frameworks, game engines, programming languages, and project management tools. The assessment began in the fourth week of the term and continued until the 16th week.

Backend Framework and Game Engine show a steady growth trend, with a significant peak around the 10th week. Database and Programming Language exhibit moderate growth throughout the term. Frontend Framework and Project Management Tool remain relatively stable, with slight variations.

In week 5, there is a decrease in the average knowledge level in all areas. This phenomenon can be explained by a recalibration of students' self-assessments as they become familiar with the depth and complexity of the content to be learned and used in the software development project. Initially, students underestimated the difficulty of the topics, leading to a more realistic and critical evaluation of their knowledge as these concepts were effectively employed in the software development project.

Regarding growth over the term:

- Database (Blue line) shows gradual and steady knowledge growth, peaking around week 14 and showing a slight decline in the final weeks.
- Game Engine (Orange line) shows rapid initial growth until week 6, followed by significant fluctuations, with peaks and troughs throughout the term, and a decrease in the final weeks.

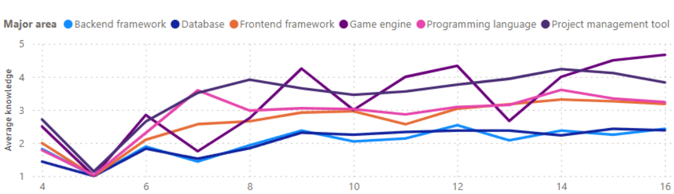

Fig. 2. Evolution of the acquisition of new concepts per week in the 2023/2 term (5-point Likert scale).

- Project Management Tool (Purple line) shows constant and linear growth, remaining one of the areas with the highest average knowledge level during the term. Backend Framework (Pink line) grows irregularly with several peaks and troughs but shows a general upward trend in knowledge over time.
- Frontend Framework (Red line) maintains relatively stable growth, with slight variations, reaching a stable level from week 8. Programming Language (Light blue line) grows gradually, with fluctuations, peaking in week 14 and then declining.

Students' self-assessment throughout the 2023/2 term reflects a pattern of new concept acquisition, with initial challenges followed by increasing assimilation and stabilization of knowledge. The possibility of real-time monitoring of the graph's evolution in 2023/2 was essential to understand how gamification influenced learning and helped form new pedagogical strategies.

2) *Enrichment of the Connection Network*

Fig. 3 shows the total number of out-of-class meetings per week during the 2023/2 term.

Note that the number of meetings starts at 33 in the first week and shows a fluctuation pattern until week 17. Peaks occur in weeks 7, 11, and 13, with a maximum of 68 meetings in week 17. Week 6 shows a drop to 23 meetings, reflecting a phase of re-evaluation or adaptation within the teams.

Fig. 4 details the frequency of out-of-class meetings conducted by different teams (such as Sunflower Yellow, Dark Violet Blue, etc.). Meetings were documented by team leaders, providing data on the theme, duration, and content of discussions.

Note that teams show variations in meeting frequency throughout the term. There are meeting peaks at critical moments of the term, indicating concentrated efforts in certain weeks, usually related to each team's internal schedules and periods of greater complexity in learning activities.

When analyzed together, the three graphs (Fig. 2, Fig. 3 e Fig. 4) provide a comprehensive view of the enrichment of connection networks:

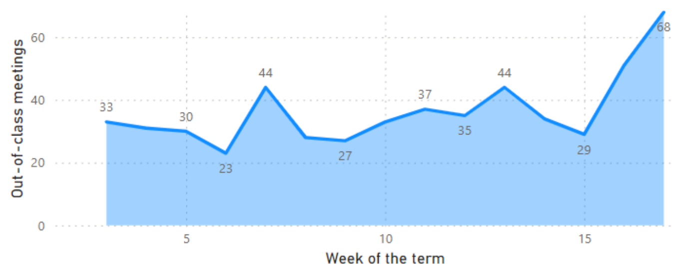

Fig. 3. Total number of weekly out-of-class meetings in the 2023/2 term.

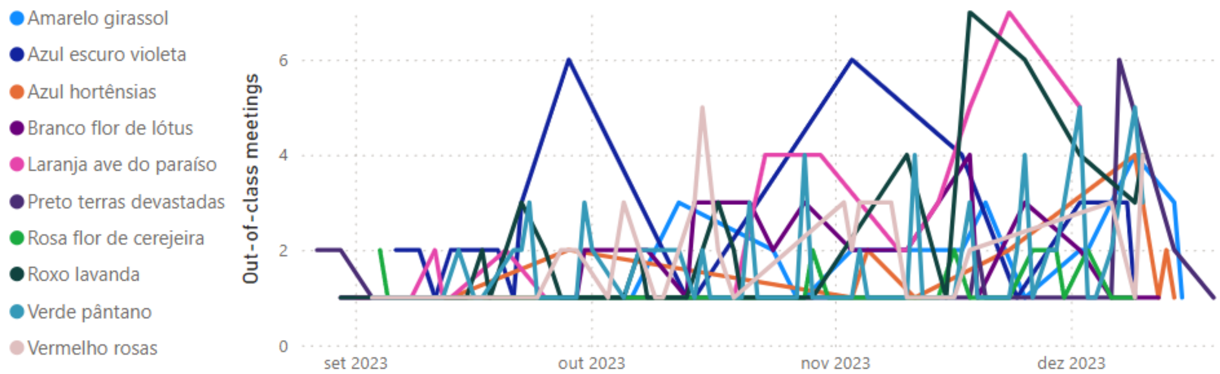

Fig. 4. Number of weekly out-of-class meetings per team in the 2023/2 term.

- Knowledge Growth: Fig. 2 indicates how students acquired new knowledge throughout the term. The general growth in knowledge averages, despite fluctuations, suggests that the gamified approach was effective in promoting continuous learning.
- Team Activity: Fig. 3 shows that teams had varying levels of activity, with some teams holding meetings more frequently than others. This reflects different work dynamics and collaborative approaches within the teams.
- Meeting Patterns: Fig. 4 reflects the continuous and concentrated efforts of teams to reinforce learned concepts. The increase in meetings during critical weeks indicates that students were engaged in reinforcing and interconnecting concepts outside the classroom.
- Correlation Between Meetings and Learning: Teams that met more frequently exhibited better indicators in concept acquisition and higher scores in peer evaluations. This suggests that these teams not only reinforced their learning more effectively but also achieved a deeper understanding of the concepts.

Real-time analysis allowed for the adjustment of pedagogical strategies as needed. Out-of-class meetings played an important role in reinforcing concepts and enriching neural connection networks, providing a collaborative and dynamic environment that facilitated continuous and interconnected learning.

In the 2023/2 term, there was an improvement in students' self-assessment scores compared to the 2023/1 and 2022/2 terms. The general growth in knowledge averages, despite fluctuations, suggests that the gamified approach was increasingly effective in promoting continuous learning. Specifically, the Backend Framework and Game Engine categories showed steady growth with significant peaks around the 10th week, indicating a robust assimilation of new concepts.

The 2023/2 term showed improvements in both student performance and engagement compared to the 2023/1 and 2022/2 terms. The continuous and interactive nature of the gamified approach, supported by real-time data analysis, proved to be effective in promoting continuous learning and deepening students' understanding of complex concepts.

V. Discussion

A. Impact of Gamification on Learning

The results demonstrate the positive impact of gamification on the learning of software development students. The application of game design elements, such as challenges, rewards, and narratives, contributed to increased student engagement and motivation. These findings align with previous studies highlighting the benefits of gamification, such as increased student motivation [5], [8].

The improvement in academic performance, evidenced by the increase in self-assessment questionnaire scores, indicates that the approach facilitated the assimilation of new concepts. This result supports the theory that gamification can make learning more appealing and effective, transforming educational tasks into interactive and engaging activities [2], [17].

B. Student Engagement

The increase in student engagement, measured by the number of interactions with the application and participation in gamified activities, suggests that the approach is an effective strategy for keeping students involved. Gamification elements, such as partial leaderboards and other game techniques, encouraged participation and promoted a sense of healthy competition and cooperation among students. This result is consistent with existing literature pointing to the potential of gamification to increase student engagement and satisfaction [18].

C. Neuroscientific Indicators

The neuroscientific indicators used, such as the acquisition of new concepts and the enrichment of the neural connection network, provided an objective and detailed assessment of the impact of gamification on learning [4]. The improvement in these indicators suggests that gamification not only increases engagement but also promotes deeper and more interconnected learning. The analysis of concept maps showed that students were able to integrate new knowledge with pre-existing information, indicating an enrichment of neural networks. These findings are supported by studies highlighting the importance of neuroplasticity and memory encoding in learning [14].

D. Study Limitations

Despite the positive results, this study has some limitations. The generalization of results is limited because the study was conducted at a single university with a specific group of students. Additionally, external variables, such as individual teaching styles of leaders and workload in other courses, may have influenced the results.

To address these limitations, future research should expand the study to include multiple universities with diverse student populations. This will enhance the generalizability of the findings across different educational contexts. Increasing the sample size will also provide more robust data and more reliable conclusions. Controlling for external variables can be achieved by standardizing teaching methods across different classes and balancing course workloads to minimize their impact on engagement and performance. Future studies should also consider longitudinal approaches to assess the long-term effects of gamification on learning outcomes and student motivation.

E. Implications for Educational Practice

The findings of this study have several implications for educational practice, particularly in the context of Software Engineering education. The integration of gamification with neuroscientific indicators offers valuable insights into how to create more effective and engaging learning environments.

1) Enhancement of Motivation and Engagement

Gamification has proven to be a powerful tool for increasing student motivation and engagement. By transforming educational tasks into interactive and engaging activities, game design elements can help maintain student interest and promote active participation in the learning process. Educators can use this approach to design curricula that not only convey technical knowledge but also keep students motivated and engaged throughout the course.

2) Skill Development

The gamified methodology, especially when applied in a themed scenario like the feudal one, facilitates the development of essential skills for future software engineers, such as leadership, teamwork, problem-solving, and critical thinking. Structured gamification activities encourage collaboration and communication among students, better preparing them for the challenges of the job market.

3) Personalization of the Learning Process

Neuroscientific indicators, such as the acquisition of new concepts and the enrichment of neural connection networks, allow for detailed monitoring of student progress. By using real-time data to adjust pedagogical strategies, educators can personalize the learning process according to individual student needs.

4) Promotion of a Collaborative Learning Culture

The gamification structure encourages a collaborative learning culture in which students work together to achieve common goals. This not only improves the understanding of concepts but also promotes a sense of community and mutual support among students. Such collaborative experiences are essential for developing interpersonal skills and building support networks that extend beyond the academic environment.

VI. Conclusion

This study investigated the impact of gamification and neuroscientific indicators on the learning of Software Engineering students, specifically in an introductory software development course. Using an action research approach, we implemented and evaluated a gamified strategy integrated with indicators of the acquisition of new concepts and the enrichment of neural connection networks.

The results indicated that gamification increased motivation and engagement. Weekly self-assessments showed steady growth in average knowledge despite fluctuations. Real-time analysis of the collected data, facilitated by tools like PowerApps and PowerBI, allowed for continuous adjustments to pedagogical strategies, improving the methodology's effectiveness.

The neuroscientific indicators used provided a detailed view of how students assimilate and connect new concepts, highlighting the importance of neuroplasticity in the learning process. Gamification, by activating the brain's motivation and reward mechanisms, facilitated the retention of new knowledge and the development of more complex and interconnected neural networks.

In terms of implications for educational practice in Software Engineering and related fields, this study demonstrates that combining gamification and neuroscience can transform the learning experience, making it more engaging, effective, and measurable. Educators can adopt these strategies to create curricula that not only convey technical knowledge but also motivate and engage students continuously. Personalizing the learning process and using continuous feedback are essential to meet individual student needs and promote a collaborative learning culture.

Future research will explore the application of gamification in different educational contexts and with more diverse student populations. Longitudinal studies that follow students over more extended periods would be valuable to assess the long-term effects of gamification on learning and engagement.

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