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Enhancing Soft Skills in Applied STEM Fields Through Games

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***Abstract*—This research explores the design, implementation, and evaluation of a course aimed at reinforcing soft skills within the applied STEM field. The "STEMM Games" course, conducted at Collegio R. Einaudi and Collegio CAMPLUS , engaged students in diverse STEM disciplines through a series of meticulously designed games. The multifaceted evaluation approach, within two cohorts, integrated quantitative data from the Soft Skills Self-evaluation Questionnaire, game data analysis, and qualitative insights from post-course questionnaires and focus groups. The quantitative analysis of 3SQ data unveiled a diverse range of self-perceived soft skills among participants, emphasizing the course's success in fostering nuanced perceptions of individual strengths and weaknesses. Game data analysis provided insights into the impact of gamification on soft skills development, highlighting improvements in engagement, teamwork, and problem-solving skills. Qualitative inputs enriched the understanding of students' experiences, revealing unexpected expectations in the second edition related to the course's name, "STEMM Games." The results and subsequent discussion emphasized the course's success in enhancing self-awareness, collaboration, and student engagement in the applied STEM context. The study provides valuable insights for refining future editions, addressing specific feedback for continuous improvement. The iterative nature of the study allows for adaptability, ensuring relevance in evolving educational landscapes within the STEM domain. Overall, this research contributes to the growing body of literature on innovative pedagogies in STEM education and provides practical insights for educators seeking to nurture well-rounded STEM professionals equipped with essential soft skills.**

***Index Terms*—Student Engagement, Course Design, Soft Skills, Gamification, Experiential Learning**

I. Introduction

The Collegio di Merito, translated as "College of Merit," is an institution within the Italian education system that aims to provide an enriched and challenging educational experience for high-achieving students. Typically found at the university level, these colleges focus on fostering academic excellence and nurturing the intellectual growth of students. Admission to the College of Merit is highly competitive and is based on academic merit, often involving rigorous entrance exams. Once admitted, students benefit from a specialized curriculum beyond the standard educational offerings, emphasizing advanced coursework and research opportunities. The educational constraints within these colleges are designed to stretch students' capabilities, encouraging them to explore complex subjects and engage in critical thinking. This educational model aims to prepare students for higher academic pursuits and leadership roles in their respective fields. In this context, a course to support soft skills was designed and available in different Colleges of Merit. The purpose was to allow students to experience soft skills in real-life STEM scenarios.

II. Background

Soft skills are increasingly acknowledged as indispensable in the STEM field, with specific emphasis on problem-solving, communication, teamwork, and emotional intelligence [1], [2]. However, there exists a gap in these essential skills among STEM undergraduates, necessitating collaboration between employers and academic institutions to address this deficiency [2]. Recognizing the impact of soft skills on students' achievement further underscores the significance of fostering these skills [3]. Various mechanisms have been identified to achieve this goal [4], with the importance of these skills extending to their association with career success and employability [5]. Nevertheless, the lack of consensus on the definition and importance of these skills highlights the need for additional research and action in this area [8].

STEM students encounter challenges in developing soft skills, including a gap in skills required for future work [2], a lack of practical orientation in training [7], and difficulties in controlling and improving these skills [8]. Teachers' perspectives on the significance of soft skills in science learning vary, with some recognizing their importance but facing challenges in understanding and resource allocation [3]. These challenges underscore the necessity for a more integrated approach to soft skills development in STEM education.

Gamification emerges as a promising strategy to significantly enhance student engagement in STEM courses [10]–[13]. By encouraging participation and emotional investment, gamification proves particularly effective in addressing the prevalent disengagement experienced by students in STEM fields [10], [12]. The incorporation of game design elements, such as in the course gamification platform, further supports student motivation and engagement [13]. Notably, gamification demonstrates a substantial increase in student engagement in STEM courses, particularly in computing-related subjects [10], [13]. The application of gamification can promote emotional investment, mastery of material, and course completion [10]. While addressing student disengagement in STEM subjects,

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especially in secondary education, gamification has the potential to improve learning outcomes [12]. However, there is a pressing need for systematic studies to assess the impact of gamification on student motivation and engagement in STEM courses [11].

Experiential learning emerges as another influential factor significantly impacting students' emotional and cognitive engagement. Scholars such as Finch [14] and Kong [15] highlight the pivotal role of experiential learning in enhancing emotional engagement, emphasizing student-goal orientation, team-based learning, and its impact on motivation and classroom engagement. Additionally, studies by Sojka [16] and Manwaring [17] reinforce these findings, illustrating the positive impact of in-class experiential learning on student engagement and the cyclical relationship between emotional and cognitive engagement influenced by factors such as student control appraisals and course design. Finally, Efthymiou et al. [18] underlined how learning by doing enables students to learn in multicultural teamwork in online environments. Collectively, these studies underscore the significant role of hands-on, experiential learning in fostering both emotional and cognitive engagement in students within STEM education.

III. Methodology

This research addresses the question: "How can we effectively reinforce a diverse set of soft skills in the context of applied STEM fields through student engagement design?" To achieve this, we have devised a comprehensive research methodology that encompasses both the development of a new course and the evaluation of its effectiveness.

A. New course design context and purpose

In this phase, we designed a novel course, meticulously tailored to the applied STEM field, with a primary objective of augmenting a wide spectrum of soft skills. The course was meticulously crafted to engender an immersive and captivating learning environment. By amalgamating multidisciplinary approaches and harnessing the principles of game-based learning, we sought to afford students abundant opportunities to hone and cultivate soft skills, encompassing problem-solving, critical thinking, communication, teamwork, time management, and creativity. The overarching goal of the new course design lay in the creation of an innovative educational milieu, purpose-built to nurture the development of these indispensable soft skills, aptly aligned with the contemporary requisites of STEM vocations. Notably, our endeavor has now culminated in the execution of the course's second iteration. The inaugural edition transpired at Collegio R. Einaudi in 2022, engaging 27 students. Concurrently, the second edition in 2023 with 43 students from Collegio CAMPLUS.

The two institutions ethically approved the current research, and each student signed a consent declaration, including a factsheet. The data have been anonymized and confidentially analyzed. .

B. Method to Evaluate the New Course

The evaluation of the novel course was conducted via a multifaceted approach that harmoniously intertwined quantitative and qualitative analyses. Firstly, we collected quantitative data through pre-course assessments, wherein each student scrutinized a spider graph illustrating their proficiencies, subsequently engaging in discussions to garner qualitative self-evaluations. This was done using the Soft Skills Self-evaluation Questionnaire (3SQ) [19].

Secondly, a game data analysis was undertaken, and harvested during the course. This dataset encompassed diverse metrics, including individual and team performances, temporal utilization, and strategic problem-solving. Employing a quantitative analysis of this data, our objective was to discern the interplay between specific game design elements and the maturation of soft skills. This scrutiny was instrumental in discerning which features of the games wielded the most efficacy in fortifying various soft skills pertinent to the realm of applied STEM.

Thirdly, qualitative insights were gleaned from students through post-course questionnaires. Concurrently, we embarked on soliciting intricate narratives through focus groups in the new edition of the course, probing students' perceptions, surmounted challenges, and the components of the course instrumental in the evolution of their soft skills. These qualitative inputs provided profound insights into the experiential dimensions of the new course and contributed to a nuanced comprehension of the qualitative transformations in students' skill sets.

The juxtaposition of quantitative and qualitative datasets facilitated a comprehensive evaluation of the novel course's effectiveness in augmenting soft skills within the purview of applied STEM fields. It allowed us to pinpoint the course elements and pedagogical methodologies that exhibited the greatest prowess in fostering these competencies. This amalgamated approach culminated in an all-encompassing understanding of how innovative course design could, and did, efficaciously reinforce the soft skills indispensable for success within STEM vocations.

The limitation of this evaluation is mainly linked to the fact that students were not chosen randomly but were candidates for participation. Consequently, the degree of interest may have influenced the research results.

IV. Course implementation

The implementation of the project involved a series of games, each focused on one of the STEM disciplines: Science, Technology, Engineering, Mathematics, and Medicine (STEMM). These games were meticulously designed to nurture specific soft skills while concurrently delivering a comprehensive learning experience in each domain. Below, we provide an overview of each game's structure and the associated soft skills development.

Game 1: Science

The Science game centered on the challenge of becoming effective science communicators, requiring students to elucidate a given scientific topic while ensuring clarity and comprehensibility in 1 minute. The score is the sum of the number of main keywords included in the speech and the clarity of the speech itself (1 to 5). The structure encompassed several phases:

- **Planning Phase**: Teams discussed their speeches and allocated roles to enhance teamwork, resilience, and trust (15 minutes)
- **Keyword Sharing**: The lecturer shared keywords for each topic, and teams can review the speech, trying to include the missing keywords in a coherent way (2 minutes)
- **Round-Based Explanation**: Team members record a 1-minute video presenting each scientific topic, emphasizing the maximum number of key concepts.

This game developed:

- *Communication*: Enhancing the ability to convey complex scientific concepts in an understandable manner.
- *Teamwork*: Fostering collaboration and effective teamwork in explaining scientific topics.
- *Resilience*: Encouraging adaptability and the ability to respond effectively in real-time.

Game 2: Technology

The Technology game tasked students with designing a compact closing mechanism for an A3-sized panel, drawing inspiration from astronaut panel mechanisms. The structure comprised the following:

- **Folding Phase**: Teams engaged in the hands-on process of designing closing mechanisms, promoting problem-solving and creativity (1 hour)
- **Constructive Requests**: Teams received three requests that constrain their design (one every 15 minutes), stimulating critical thinking as they identify areas for improvement
- **Presentation**: Teams showcased their closing mechanisms' practicality, efficiency, and compatibility with the assigned A3-sized panel (2 minutes).

This game developed:

- *Problem-Solving*: Encouraging autonomous problem-solving and innovative thinking.
- *Creativity*: Fostering the ability to design practical and efficient solutions.
- *Collaboration*: Enhancing teamwork and collaborative problem-solving skills.

Game 3: Engineering

The Engineering game revolved around the construction of towers, intending to achieve maximum height while supporting weight. It comprised the following structure:

- **Strategy Session**: Teams planned their tower construction strategies with the camera open, but the mic closed, emphasizing problem-solving and teamwork (15 minutes)
- **Construction Phase**: Teams actively built their towers with the mic and camera open, practicing problem-solving and leadership (30 minutes)
- **Finalization Phase**: Teams focused on refining their towers' designs with the camera open but the mic closed, promoting concentration and attention to detail (20 minutes).

This game developed:

- *Problem-Solving*: Encouraging strategic planning and creative construction solutions.
- *Teamwork*: Enhancing collaboration in tower construction.
- *Leadership*: Fostering leadership abilities in decision-making and task allocation.

Game 4: Mathematics

The Mathematics game aimed to foster problem-solving skills, autonomy, and creativity. It encompassed three phases:

- **Problem-Solving Phase**: Teams collaborated to solve mathematical problems, promoting critical thinking and mathematical skills (20 minutes)
- **Game Invention Phase**: Teams created unique games based on assigned mathematical topics, stimulating creative thinking and innovation (30 minutes)
- **Game Presentation**: Teams showcased their newly invented games, enhancing communication and the application of mathematical principles (3 minutes).

This game developed:

- Problem-Solving: Encouraging logical thinking and innovative problem-solving.
- Creativity: Fostering inventive game design rooted in mathematical concepts.
- Autonomy: Enhancing independent thinking and decision-making in game creation.

A. Game 5: Medicine

The Medicine game, designed in collaboration with a doctor, aimed to foster critical thinking and effective communication. The challenge, titled "Defend Your Position," involved structured debates and required students to present and counter-argue different positions on a thought-provoking medical topic. The game structure included:

- **Planning Session**: Teams strategized their arguments and assigned roles, emphasizing teamwork and organization (15-10-10 minutes in the three rounds)
- **Round-Based Argumentation**: Teams presented arguments, counter-arguments, and concluding remarks within specified timeframes, promoting critical thinking and persuasive communication (3-2-1 minutes in the three rounds)
- **Position Reversal**: In the third round teams switched positions and argued for the opposing side, stimulating empathy and versatility in argumentation.

This game developed:

- *Critical Thinking*: Encouraging analytical and thoughtful examination of complex medical issues.
- *Persuasive Communication*: Enhancing the ability to articulate and defend arguments effectively.
- *Empathy*: Fostering an understanding of diverse perspectives through position reversal.

In summary, the project's implementation featured a diverse array of STEMM-focused games, each meticulously structured to reinforce specific soft skills. These games not only enriched students' STEM knowledge but also honed their essential soft skills, preparing them for the multifaceted challenges of STEM careers.

V. Results and discussion

The quantitative analysis of pre-course assessments, utilizing the Soft Skills Self-evaluation Questionnaire (3SQ), allowed students to scrutinize spider graphs depicting their perceived proficiencies. The variability in the students' spider graphs, ranging from 2.2 to 5, underscores the diversity in their self-perceived soft skills. The majority of indicators averaged between 3.5 and 4.5, with resilience (average 3.1), collaboration (average 3), and empathy (average 2.8) showing comparatively lower scores (Fig. 1).

Notably, the first edition experienced greater variability among groups due to a reduced number of students per group, while the second edition witnessed more alignment and intriguing variability. This suggests that the increased number of students in the second edition contributed to a more consistent understanding of their self-perceived soft skills. The intriguing variability observed in the second edition may indicate a richer and more nuanced exploration of individual strengths and weaknesses within the groups.

The discussions following the assessments revealed that while some students lacked confidence in certain skills, the majority acknowledged and relied on specific skills but not others. The opportunity for group discussions enabled students to understand the strengths and weaknesses of each member, fostering a collaborative environment. Moreover, students demonstrated active and engaged participation in all games, showcasing the course's success in encouraging collaboration and individual expression. The challenges faced, particularly in adhering to time constraints during the initial phase, showed improvement over the course duration, reflecting enhanced content processing and execution.



Fig. 1. Spider graph depicting students' Soft Skills Self-evaluation Questionnaire average results for each indicator

A significant difference noted between the first and second editions was the accessibility of generative AI, particularly ChatGPT. The analysis revealed that AI use was predominantly for brainstorming, and groups were encouraged to explore diverse applications aligned with the purpose of each game. However, in the medical-themed game, AI limited the scientific depth of position defense, steering the debate toward a more superficial discourse.

The analysis of various games unveiled the impact of scoring rules on group dynamics. For instance, in the tower construction game, groups prioritized compliance with weight requirements over height, indicating the influence of scoring mechanisms on decision-making. The results also highlighted the varied responses to different challenges, emphasizing the need for a tailored approach to soft skills development within the diverse STEM disciplines.

The feedback from post-course questionnaires, augmented with quantitative measures, further illuminated students' perspectives. In the first edition, participants generally found the course objectives well-explained and the activities engaging, with a substantial majority expressing satisfaction and a high willingness to recommend the course. Quantitatively, the mean ratings for clarity in explaining course objectives, engagement with activities, and overall satisfaction were 4.2, 4.2, and 3.9, respectively, on a scale of 1 to 5.

However, the second edition saw more mixed responses, indicating areas for improvement in various aspects. Quantitative analysis revealed mean ratings of 3.7 for the management of activities, 3.4 for the structure and duration of the course, and 3.8 for the communicative and engaging qualities of the instructors, all measured on a scale of 1 to 5. While the majority still expressed satisfaction and a willingness to recommend the course, these metrics highlight specific areas where refinements could enhance the overall learning experience.

In the final focus group of the second edition, an intriguing revelation emerged as some participants were drawn to the name "STEMM games" with expectations differing significantly from the course's actual focus. Their anticipation leaned towards a challenge in STEMM knowledge rather than a soft-skills training within the STEMM fields, significantly influencing their perception of the second edition. One participant expressed dissatisfaction, stating, "I didn't like the course because it was too much dialectic; I would have preferred something more technical." Conversely, another participant highlighted the course's value, stating, "It was a course that allowed me to meet and engage with others, but above all, to discover something about myself. It was possible for me to identify my strengths and weaknesses, areas I need to work on to further enhance my skills."

Despite varying expectations, the use of a hybrid mode, where groups collaborated physically while remaining connected through an online platform, received positive feedback in both editions. One participant commented, "The use of the hybrid online mode with the group in person was very useful because it adds a competitive edge between groups."

This suggests that the hybrid approach effectively combined the advantages of in-person collaboration with the benefits of online connectivity, fostering a sense of competition and camaraderie among participants.

Overall, the results and subsequent discussion emphasize the course's success in enhancing self-awareness, collaboration, and engagement among students in the applied STEM context. The feedback provides valuable insights for refining future editions, emphasizing the need for clearer instructions and a closer alignment with STEM relevance in certain activities. The study demonstrates the intricate interplay between innovative pedagogy, practical application, and the development of vital soft skills in the applied STEM field.

VI. Conclusions

In conclusion, this study has explored the innovative design and implementation of a course aimed at reinforcing soft skills within the applied STEM field. The multifaceted evaluation approach, integrating quantitative and qualitative analyses, provided a comprehensive understanding of the course's impact on students' self-awareness, collaboration, and engagement.

The analysis of 3SQ data revealed a diverse range of self-perceived soft skills among participants. Noteworthy improvements were observed, emphasizing the course's success in fostering self-awareness and nuanced perceptions of individual strengths and weaknesses. The intriguing variability in the second edition, coupled with decreased variability among groups, points to the course's adaptability and effectiveness in aligning students' perceptions.

Quantitative measures from post-course questionnaires added granularity to participant feedback. While the first edition received high ratings for clarity in explaining course objectives, engagement with activities, and overall satisfaction, the second edition exhibited more nuanced responses. This quantitative feedback guides future enhancements, addressing aspects such as course management, structure, and instructor communication.

The practical application of gamification and experiential learning in each STEM discipline showcased the course's ability to create a dynamic and engaging educational environment. The challenges faced by students, both individually and in groups, underscored the importance of adaptability, teamwork, and critical thinking—essential soft skills within STEM fields.

The study also highlighted the role of generative AI, particularly ChatGPT, in shaping group dynamics. The findings underscored the need for strategic AI integration to avoid compromising scientific depth during discussions.

While this course demonstrated success in enhancing self-awareness and collaborative skills, future iterations can benefit from continuous refinement. Clearer instructions, improved alignment with STEM relevance, and addressing specific feedback from participants will contribute to an even more effective soft skills development program.

In addressing the research question, this study crafts and evaluates a novel course specifically tailored to the needs of the contemporary STEM landscape leveraging the principles of game-based learning. The findings shed light on the nuanced interplay between pedagogical strategies, technological interventions, and the cultivation of essential competencies crucial for success within STEM. This research bridges the gap between theory and practice, contributing to the literature on innovative pedagogies within STEM education, and providing tangible recommendations for educators and institutions seeking to foster the next generation of well-rounded STEM professionals.

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