Fostering Employability Skills for Engineers With Serious Games: A Gamified GBL Concept

Paul Varney, Vanessa Mai and Valerie Varney
Cologne Cobots Lab - TH Köln, Germany

paul.varney@th-koeln.de
vanessa.mai@th-koeln.de
Valerie.varney@th-koeln.de

Abstract: The world is becoming increasingly complex, and as a result, the demand for individuals with strong employability skills is growing rapidly. It is essential for engineering education to adapt to this reality and provide opportunities for students to develop critical thinking, problem-solving, communication, teamwork, adaptability, and leadership skills. By doing so, engineering graduates will be well-equipped to navigate the complex challenges of the modern world and make meaningful contributions to society. Engineering education needs to adapt to this reality by incorporating more opportunities for students to develop their employability skills. This can be done through a variety of methods, such as experience- or project-based learning, internships, co-op programs, and industry partnerships. Game-based learning offers an engaging and immersive experience that can promote the development of these skills in a fun and interactive way. Within the Game-based learning approach implemented in our lecture the students play two subsequent game modules in which they first plan and build a factory building together and then put it into operation in the second part. The players are confronted with problems and situations that can only be overcome through communication and cooperation. This paper presents the self-developed online platform that uses gamification aspects such as micro-achievements for each student to represent the progress with the learning materials as well as within the gaming parts. The platform aims to provide students with an engaging and interactive way of learning, while also assessing their performance through collected data.

Keywords: Game-based learning, Engineering education, Employability skills, Gamification, Serious games

1. Introduction

Engineers are facing the demand for a holistic comprehension of the digital transformation, encompassing intricate contexts such as companies, technologies, and markets. They need to integrate technical and methodological competencies rooted in STEM fundamentals with specialized skills from disciplines like mechanical engineering, computer science, and more. Additionally, cross-functional competencies, often referred to as future skills, are crucial for engineers to navigate this evolving landscape successfully. (VDI 2019; VDMA 2019; Stifterverband 2018, 2021). In order to facilitate this, universities are urged to adopt a perspective of being open learning systems. This entails fostering co-creation processes among all stakeholders within the university and establishing a conducive environment for personalized study designs, intelligent systems-based personalized learning, and enhanced integration of research and teaching. Embracing the concept of universities as digital learning ecosystems has implications for shaping graduate profiles, curricula, learning environments, and assessment methods. In this regard, digital and hybrid teaching and learning formats hold great potential for enabling co-creation processes within the framework of open learning ecosystems.

The Faculty of Process Engineering, Energy, and Mechanical Systems at TH Köln/University of Applied Sciences welcomes approximately 800 first-year students every winter semester. The engineering education at TH Köln emphasizes competence and project-based learning, which places significant emphasis on students' methodological skills (e.g., project management) and their ability to work effectively in interdisciplinary teams. These skills need to be nurtured right from the beginning of their studies. However, the expectations of first-year students regarding the content of their engineering studies may not align with the compulsory modules focused on methodological and interdisciplinary competencies, such as the module "work techniques and project organization" worth 5 ECTS. To address these challenges, the FutureING mixed-reality game was specifically developed (Richert et al. 2019). This paper presents the self-developed online platform that uses gamification aspects such as micro-achievements for each student to represent the progress with the learning materials as well as within the gaming parts. The platform aims to provide students with an engaging and interactive way of learning, while also assessing their performance through collected data at a later point.

2. Game Based Learning and Online Laboratories

The concept of FutureING aligns with current research discussions on game-based learning and online laboratories, which are essential components of engineering education. Laboratories serve as platforms for students to apply theoretical knowledge in practical settings and acquire hands-on experience (Bernhard, 2010).

These laboratory experiences encompass both theoretical and conceptual knowledge and provide opportunities to develop procedural and technical skills. Additionally, laboratories are well-suited for fostering employability skills, which are highly valued in the engineering field (VDI 2019). Practical experience also holds a crucial place in engineering education and is integrated into the curricula of many study programs. With the advancement of digital technologies, students now have the opportunity to engage in laboratory activities remotely, offering increased availability and flexibility in terms of time and space. This digital transformation enables students to access laboratory situations through virtual environments, thereby enhancing their learning experiences.

By embracing the potential of digital technologies and integrating them into the FutureING concept, students can engage in laboratory-like experiences from anywhere, at any time. Remote access to laboratory settings not only expands the reach of practical education but also provides students with the flexibility to engage with the content according to their own schedules. This accessibility opens up new possibilities for learning and empowers students to explore engineering concepts beyond the confines of traditional physical laboratories. Serious Games, which simulate engineering scenarios and involve collaborative gameplay among multiple students, can be regarded as a form of laboratory experience. Research has consistently demonstrated the numerous beneficial outcomes associated with game-based learning. Petko (2008) outlines several didactic potentials of digital games in education, including teaching strategic problem solving, facilitating situated learning, promoting social learning, motivating learning processes, illustrating complex interrelationships, and enhancing comprehension and dexterity skills. Among these educational possibilities, two key aspects are particularly significant for online labs, especially in the context of FutureING: the facilitation of social learning and the enhancement of motivation in the learning process through situated learning. In general, games that replicate authentic work environments can act as virtual laboratories for students to apply and assess their abilities and knowledge. By utilizing a gaming system, students are provided with a safe space for making mistakes, thus encouraging experimentation. Consequently, students can explore various approaches and assume different team roles while working on the same task.

Furthermore, games, with their diverse reward and control systems, are particularly suitable for project-oriented, problem-based, and experiential learning. They provide opportunities to train application knowledge in new situations. Virtual worlds, in particular, offer spaces that allow for the development of "digital" competencies, such as creativity. These worlds create varied and challenging work scenarios for students, engage them in real and exciting tasks, and foster a climate that promotes reflection and personal growth. Research indicates that game-based learning contributes to the development of competencies due to its motivational conditions, appealing to the instinct for play, recognition, competitive thinking, and ambition (Young et al. 2012). These approaches align well with a constructivist learning culture, where learners are active participants in the learning process and learning is seen as a social, emotional, and situated experience (Siebert et al. 2005). Consequently, game-based learning is gaining increasing importance in university teaching, imposing requirements on digital didactics in engineering education. The goal is to design "magic circles" (Huizinga 2017) where a safe environment for experimentation is created, failures are positively perceived, and motivation is encouraged. Simultaneously, these approaches should accommodate the heterogeneity of students in terms of their prior knowledge and experiences and address the diverse levels of knowledge through reflection.

3. Current Status

FutureING aims to create a collaborative mixed-reality learning environment within which a serious game is developed. This game transforms the "work techniques and project organization" module (ATPO) into an immersive and competency-based learning experience, effectively connecting interdisciplinary and specialized content. By employing action-oriented teaching methods from the realm of game-based learning, abstract knowledge is linked to practical personal experiences. The existing successful approach of combining traditional courses with elements of business games is further enhanced in FutureING. This digital, game-based concept integrates various components, including classic e-learning, immersive augmented and virtual reality elements, as well as face-to-face interactions (presence elements), resulting in a comprehensive learning experience. The concept of virtual studios (Broadfoot und Bennett 2003), adapted from the field of engineering disciplines, allows for the simultaneous development of technical and methodological skills. From the very first semester of their engineering studies, students engage in the digital transformation within a production company through the FutureING program. Acting as an engineering office, they are tasked with designing and optimizing production processes for a robotics manufacturer. Within the game's framework, students collaborate within fictitious engineering offices. In the following sections, the different FutureING elements are described.

3.1 FutureING AR-Game

The initial game in the FutureING series, known as the FutureING AR Game, has been fully developed and is now available on both iOS and Android platforms. The AR app has reached a stable release status, encompassing all the planned features. Designed as an online multiplayer game, the AR app allows every student to participate from the comfort of their homes using their smart devices. Distribution of the app was facilitated through the respective app marketplaces for Apple and Android devices. To ensure a seamless multiplayer experience, students were connected to the same game session using unique group codes. As the name suggests, the FutureING AR App incorporates augmented reality (AR) technology, creating an immersive environment by projecting a virtual factory hall onto a table and providing players with an overhead view. Within the app, students are tasked with strategically planning multiple assembly halls across a series of levels, aiming to achieve predetermined production goals. Once students believe they have found a solution that meets the requirements of a level in the game, they have the opportunity to purchase assembly cells and autonomous transportation systems. Careful selection of the assembly cells is crucial, as machines with similar qualities may perform differently based on the quantity of products that need to be produced. The same applies to the autonomous transportation systems, with some excelling in long-range transportation and others in short-range transportation. In the game, students must select two out of three optimization options: budget efficiency, time efficiency, and production reliability. The game aims to present solutions with individual strengths and weaknesses that are all valid, as there are multiple paths to achieve the goal. This variety of solution spaces encourages students to engage in discussions about which solution to pursue. Once students have placed all the necessary components within the production hall within their budget, they can start simulating the production process. During the simulation, they receive immediate feedback on whether their solution is able to meet the production goal. After the simulation, students are awarded star ratings and can choose to replay the level or progress to the next one. Beginning with a tutorial and gradually progressing to more challenging levels, students will have the opportunity to test and refine their planning skills throughout the game. The final level will present the most complex challenge.

3.2 FutureING Desktop-Game

In the subsequent game component, the FutureING desktop game, students immerse themselves in the operation of their planned production hall through the FutureING Desktop game. They assume responsibility for the initial production operations, facing various challenges and malfunctions that occur randomly. For example, they may encounter an installation within the production facility that has malfunctioned and needs to be examined for errors and restarted. The entire team is present on the production floor, with one group taking charge of the control room. This group has access to statistics and problem areas displayed on dashboards and can consult operating manuals. The other group remains on the shop floor, equipped with virtual tools and sensors. Their task is to collaboratively address technical problems by conducting research, analysis, and teamwork in a dynamic and turbulent production environment.

The FutureING Desktop Game consists of two phases, which can be played by the students in any amount of sessions. The game starts with a tutorial, in which the players learn the basics of the game in a failure-safe space. It is followed by Phase 1: In it, the players need to set-up the assembly hall using the knowledge they had gained in the tutorial. Here, the focal point lies on cooperation and communication, as many set-up tasks require inputs from several players to be solved or are puzzles that are implemented on the principle of asymmetric distribution of information. The students need to set-up the production hall in a tight, pre-defined time-frame.

In Phase 2 the assembly hall starts its production. However, errors in the machinery need to be fixed by the players to secure the group outcome. As a result, Phase 2, while having tasks of a similar manner like Phase 1, it creates a higher challenge for the students, as it also requires stress-resilience and flexibility and more communication and short-term planning.

3.3 FutureING TrainING Center

The current TrainING Center (1.0) serves as a knowledge resource and contains video lectures (such as classic and agile project management, scientific work, teamwork and team development, etc.). In addition, it contains the download links to both games. In its current state, it is used infrequently by the students. The aim of the developments described in this paper is to raise engagement of the students with the platform and thereby improving the learning outcomes and the amount of research data gathered through the competencies self-assessments and evaluations. In a next step, it is planned to assess student’s performance based on data collected throughout the games and platform. The planned concept is described in section 3.

3.4 Effectiveness of FutureING

The module itself as well as the gaming components have been positively evaluated by students throughout the semesters. In addition to that, self-assessment of employability skills competencies was carried out three times throughout the semester. The first time (CSA1) before the games are played, the second time (CSA2) after the first game has been played and the third assessment when both games have been played. Figure 1 illustrates a consistent improvement in all skills assessed.

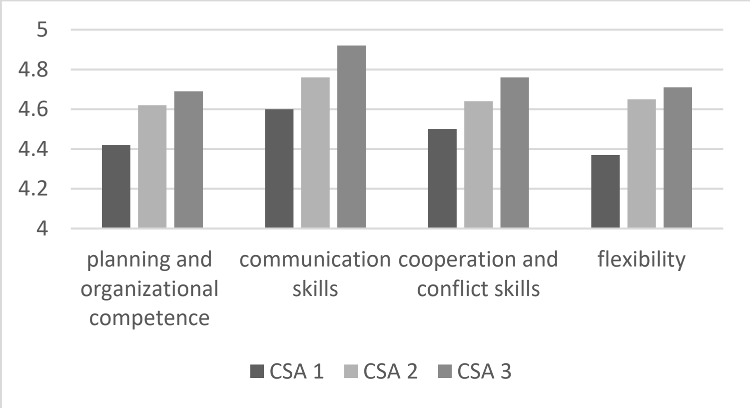

Figure 1: Results of the Competencies Self-assessment (CSA) throughout the Semester (N= 267)

The findings indicate a notable improvement in the assessed competencies throughout the semester. Students rate their competencies higher in all four areas after participating in both the AR game and the Desktop game. The observed growth suggests that students are effectively developing and acquiring the necessary competencies through the FutureING game. The data further suggests that the design of the two game components aligns with the targeted competencies outlined in the learning outcome. Based on the integration of the various teaching components, it can be concluded that the interconnected mixed-reality elements have a positive impact on the development of "future skills" competencies. Traditional soft skills, including planning and organizational abilities, communication skills, collaboration and conflict management, as well as adaptability, serve as valuable assets for handling complexity. These skills are effectively trained through the presented mixed-reality approach that combines them. As a result, we can confidently affirm that the overall FutureING concept, along with its components, proves to be highly effective in achieving the desired learning outcomes, successfully addressing our initial research question.

4. Improved TrainING Center

The TrainING Center 2.0 serves as a gamified platform for self-assessment and learning within the FutureING learning system. It operates both as an independent channel for students to engage in learning and self-assessment and as a subsidiary channel for the FutureING AR Game and the FutureING Desktop Game. In its subsidiary role, the TrainING Center connects the FutureING Games by establishing a shared account for data transfer between the TrainING Center and the FutureING games. Through their TrainING account, students can personalize an avatar. Inspired by role-playing games, the avatar possesses a set of skills that players can allocate their experience points to enhance. At the beginning of the TrainING experience, players receive a starting set of skill points based on a self-evaluation questionnaire. As they progress and perform in the FutureING games, they earn experience points that can be utilized to improve their avatar's skills. These enhanced skills grant players bonuses that prove beneficial in the FutureING games, motivating them to assume specific roles. For example, the "Purchasing Expert" skill reduces purchase prices in the games by 0.5% at level 1. Players can invest experience points to increase the skill level, with each level providing an additional 0.5% reduction in prices. Additionally, players can position their characters within the game worlds to oversee an Assembly Cell and enhance its capabilities. For instance, the "Quality Assurance Overseer" skill reduces the error rate of the assigned Assembly Cell by 5%. These example skills enable players to engage in roles during the games' planning process. For instance, a player with the "Purchasing Expert" skill might be responsible for acquiring equipment for the team, while a player with the "Quality Assurance Overseer" skill closely manages the Assembly Cells, further decreasing the error rate. However, players are encouraged to explore different roles within the team by reallocating their skills and reinvesting experience points within the TrainING Center.

The TrainING Center is designed as a website accessible either independently or from within the FutureING Games. It serves as an intermediary space between the levels of the AR Game and the phases of the Desktop Game. This creates a dynamic interplay between the intrinsic motivation derived from the engaging game mechanics of the games and the extrinsic motivation provided by the TrainING Center. The TrainING Center offers external motivation through a team-based leaderboard that tracks players' earnings in both games. To succeed in the games and improve their leaderboard position, players need to enhance their avatar skills. This incentivizes players to revisit earlier levels in the AR Game after levelling up their skills to achieve better results. Additionally, the games incorporate elements from free-to-play (f2p) games to encourage players to invest additional effort. Instead of real currency or advertisements, players can enhance their in-game performance by participating in quizzes available in the TrainING Center. These quizzes offer rewards ranging from cosmetic items and additional experience points to powerful one-time use abilities. The incorporation of f2p elements includes escalating difficulty curves that make it challenging to achieve perfect results without utilizing quizzes, as well as avatar customization options and the overall competitive nature of the TrainING Center.

In addition to that, player actions are logged and accumulated. The logs are then planned to be used to assess the players performance in the aforementioned future skills the game is trying to foster. As of now, using the logfiles from the previous semesters in combination with the exam results, the process of identifying key performance indicators for the given learning goals is underway. In the coming semester, using the TrainING center will become mandatory, and therefore much more data will be collected to enhance the logging.

5. Conclusion/Outlook

The TrainING Center as a gamified web platform aimed at motivating students to engage with lecture contents and the two serious games, seems to hold significant potential. To ensure its effectiveness and ongoing development, a comprehensive evaluation framework coupled with future developments is essential. This section outlines a scientific outlook on evaluating the TrainING Center and presents strategies for further development.

A multifaceted evaluation approach is crucial to assess the TrainING Center's impact and determine its efficacy in motivating students. Quantitative measures, such as surveys and questionnaires, can gather data on students' perceptions of motivation, engagement, and satisfaction with the platform. Additionally, analytics tools integrated into the TrainING Center can provide valuable insights into usage patterns, performance metrics, and learning behaviours, enabling a data-driven evaluation. The TrainING Center's ability to facilitate effective learning outcomes is a key aspect to evaluate. Pre- and post-intervention assessments can gauge knowledge acquisition, retention, and skill development. Traditional measures such as quizzes and exams can assess content mastery, while project-based assignments and real-world simulations can evaluate the application of knowledge and problem-solving abilities. Rubrics and scoring criteria specific to the TrainING Center's activities can be developed to provide a comprehensive assessment. To further enhance the TrainING Center's efficacy, student feedback is invaluable. Conducting user surveys, focus groups, and interviews can gather insights into students' experiences, preferences, and suggestions for improvement. This feedback should inform an iterative design process, allowing for continuous enhancements to the platform's features, user interface, and gamification elements. Regular updates and refinements should be implemented based on user feedback, ensuring the TrainING Center remains relevant and engaging. Gamification techniques such as leaderboards, badges, challenges, and rewards should be strategically implemented to foster motivation, engagement, and healthy competition among students. Exploring the integration of additional motivational elements, such as personalized avatars, interactive narratives, and social interaction features, can further enhance the TrainING Center's appeal and effectiveness.

Through a robust evaluation framework, iterative design, and ongoing development, the TrainING Center can fulfil its purpose of motivating students to engage with lecture contents and the two serious games. By employing diverse evaluation methods, incorporating students' feedback, enhancing gamification elements the TrainING Center aims to evolve into an effective and engaging platform that optimizes students' learning experiences and outcomes. The iterative nature of the development process will ensure that the TrainING Center remains adaptable and responsive to the ever-changing needs of students and the evolving landscape of educational technology.

This work was supported by the Stiftung "Innovation in der Hochschullehre" as part of the project REDiEE.

References

Broadfoot, Ouita; Bennett, Rick (2003): Design studios: online? In: Apple University consortium academic and developers conference proceedings 2003, S. 9–21.

Huizinga, Johan (2017): Homo Ludens. Vom Ursprung der Kultur im Spiel. Unter Mitarbeit von Andreas Flitner. 25. Auflage. Hamburg: Rowohlt Taschenbuch Verlag (rororo Rowohlts Enzyklopädie, 55435).

Petko, Dominik (2008): Unterrichten mit Computerspielen. Didaktische Potenziale und Ansätze für den gezielten Einsatz in Schule und Ausbildung. In: *MedienPädagogik* 15, S. 1–15. DOI: 10.21240/mpaed/15_16/2008.11.07.X.

Richert, Anja; Mai, Vanessa; Mengen, Hanna; Wolf, Susanne (2019): Mixed Reality Games in Engineering Education. In: 2019 5th Experiment International Conference (exp.at'19). 2019 5th Experiment Conference (exp.at'19). Funchal (Madeira Island), Portugal, 12.06.2019 - 14.06.2019: IEEE, S. 365–370.

Siebert, Horst; Reich, Kersten; Voß, Reinhard (2005): Pädagogischer Konstruktivismus. Lernzentrierte Pädagogik in Schule und Erwachsenenbildung. s.l.: Beltz Verlagsgruppe. Online verfügbar unter http://www.content-select.com/index.php?id=bib_view&ean=9783407291486.

Stifterverband (2018): FUTURE SKILLS: Welche Kompetenzen in Deutschland fehlen. Future Skills - Diskussionspapier 1. Unter Mitarbeit von Julian Kirchherr, Julia Klier, Cornels Lehmann-Brauns und Matthias Winde. Hg. v. Stifterverband für die Deutsche Wissenschaft e.V.

Stifterverband (2021): FUTURE SKILLS 2021: 21 Kompetenzen für eine Welt im Wandel. Future Skills - Diskussionspapier 3. Unter Mitarbeit von Julian Kirchherr, Julia Klier, Cornels Lehmann-Brauns und Matthias Winde. Hg. v. Stifterverband für die Deutsche Wissenschaft e.V.

VDI (2019): Ingenieurausbildung für die Digitale Transformation. Zukunft durch Veränderung. Unter Mitarbeit von Anja Gottburgsen, Klaus Wannemacher, Jonas Wernz und Janka Willige. Hg. v. Verein Deutscher Ingenieure (VDI). Frankfurt.

VDMA (2019): Ingenieurinnen und Ingenieure für Industrie 4.0. Unter Mitarbeit von Eckhard Heidling, Pamela Meil, Judith Neumer, Stephanie Porschen-Hueck, Klaus Schmierl, Peter Sopp und Alexandra Wagner. Hg. v. Verband Deutscher Maschinen- und Anlagenbau e.V. (VDMA). Instituts für Sozialwissenschaftliche Forschung e.V. – ISF München; Forschungsteam Internationaler Arbeitsmarkt (FIA) GmbH. München.

Young, Michael F.; Slota, Stephen; Cutter, Andrew B.; Jalette, Gerard; Mullin, Greg; Lai, Benedict et al. (2012): Our Princess Is in Another Castle. In: *Review of Educational Research* 82 (1), S. 61–89. DOI: 10.3102/0034654312436980.