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Problem-Based E-Learning to Increase Motivation of Stem-Students: Gamification of A Startup Enterprise

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Abstract

First semester students often face major challenges in adjusting to university studies. Inexperienced students may not appreciate the practical relevance of abstract, theoretical concepts taught using traditional, instructor-centered lectures. Furthermore, the rise of generative artificial intelligence (GenAI) can mislead some to believe they no longer need to exert effort to learn academic skills.

To encourage students to engage in learning material and thus improve retention rates, two complementary teaching methods were integrated into a large, introductory course for first semester STEM students: Problem-Based Learning (PBL) and gamification. Problem-Based Learning was implemented to make the subject matter more meaningful by simulating a real-world experience: How to start up a small business. This entrepreneurship task was simulated in an online game, to increase student motivation.

Quantitative questionnaires of student motivation and experiences with e-learning were evaluated. Based on input obtained in expert interviews, a fictitious startup enterprise was designed to serve as the used case. An online e-learning game was developed, which leveraged gamification elements to try to increase motivation. Each phase of the startup process was represented as one level of the e-learning game. The e-learning game was tested by a group of first semester students. Their opinions were collected using an anonymous online survey. Aggregated results of the survey are discussed and plans for further research are presented.

Keywords: E-Learning, Gamification, STEM, Problem-Based Learning, Used-Case Learning

1. Introduction

First-semester students often have difficulty in adjusting to the transition from school to university. In STEM (Science, Technology, Education and Mathematics) subjects, the drop-out rate in the first year has consistently remained quite high (Casanova et al., 2023). Passeggia et al. (2023) found that autonomous motivational styles predicted students' engagement. This, in turn, had a direct influence on students' decisions whether to drop out. Constructivist, self-directed learning which focuses on concrete, real-world problems has been shown to increase student motivation and encourage critical, analytical thinking (Loyens et al., 2022).

The current cohort of new students faces additional motivational challenges, such as the rise of Generative Artificial Intelligence (GenAI). Some students mistakenly believe that they do not have to put any effort into their studies because they can simply copy the answers from a chatbot. This can have a negative effect on their willingness to exert effort to learn new skills.

The goal of this study is to investigate the effectiveness of student-centered teaching methods to increase the learning motivation of first-semester students in STEM subjects and thus increase their retention rate. An e-Learning system was developed which implements two pedagogical methods: PBL (Problem-Based Learning) and gamification. This work investigates three research questions:

R1: Which factors influence motivation in e-learning in first-semester STEM students?

R2: How can Problem-Based e-Learning be applied to large, introductory courses?

R3: Can creative teaching methods, such as gamification, motivate students to learn?

Section 2 examines related literature on this subject. Section 3 describes the methods used to gather information about student motivation and their experiences with e-learning and gamification. Techniques implemented to collect expert advice are explained. Section 4 presents the results of this study. Section 5 discusses conclusions and plans for future work.

2. Related Work

This section examines some of the related literature on the topics investigated in this work, such as motivation of STEM students in e-Learning, problem-based learning and gamification**.**

2.1 Motivation of students in STEM subjects in Online Learning

During the pandemic, STEM students faced a number of motivational challenges. Ofori-Boadu et al. (2022) reported that the motivational challenges experienced most often by undergraduate STEM students in the U.S.A. were:

1. Assignment overloads
2. Lack of in-person peer interactions
3. Uncaring professors
4. Lack of in-person professor interactions
5. Lack of in-person laboratory experiences.

Wester et al. (2021) examined how the shift from in-person to online learning during the pandemic impacted student engagement. They found a significant decrease in emotional engagement and a drastic decline in positive attitudes toward science. Students participated less frequently in class discussions. Previously, students' sense of belonging and self-efficacy would increase over the course of the semester. During the pandemic, however, this positive personal growth did not occur.

Sanheeta and Robinson (2024) compared motivational experiences of online STEM learning environments to face-to-face learning. When face-to-face learning was possible, they found that a higher proportion of students planned a career in STEM fields after their studies. In online learning environments, future career plans in STEM fields were lower. However, students reported that remote instruction helped to support their own autonomy. This suggests that flexibility could also increase learning motivation in traditional learning environments.

2.2 Problem-Based Learning (PBL)

Problem-Based Learning (PBL) (Barrows & Tamblyn, 1980) was originally described as “the learning that results from the process of working toward the understanding or resolution of a problem”. Although there are a number of different variations of the PBL method, most models include the following characteristics:

1. The nature of the problem: complex, ambiguous, real-world, meaningful
2. The context in which the problem is embedded in
3. Integration of different subject areas: interdisciplinary
4. Learner-centered approach
5. Instructor as a guide or facilitator of the learning process.

Smith et al. (2022) found that four principles of Problem-Based Learning proved especially effective in teaching the following skills:

1. Construct an extensive, flexible knowledge base.
2. Develop effective problem-solving skills.
3. Develop self-directed lifelong learning skills.
4. Collaborate based on intrinsic motivation.
5. Become intrinsically motivated to learn.

Although Problem-Based Learning (PBL) and Project-Based Learning (PjBL) are often used interchangeably, there are slight differences. The PBL method is driven by the search for answers to a problem and thus focuses primarily on student-centered research and inquiry. (PjBL) is often used in engineering, because it focuses on the process of producing a product. Noordin (2011) classifies PBL as a subset of PjBL.

Beier et al. (2018) investigated the effectiveness of project-based learning (PjBL) courses on student attitudes, choice of major and career aspirations. They found that participating in at least one project-based course during the first four semesters of university studies positively affected students’ perceptions of STEM skills, perceptions of utility and career aspirations. Interdisciplinary STEM Project-Based Learning (STEM IPBL) was found to have a positive impact on students’ learning motivation, self-efficacy of learning, enjoyment and recognition of the significance of STEM subjects on future career development (Kuo et al. 2018).

Wijnia et al. (2024) performed a meta-analysis to investigate the effects of student-centered, problem-driven learning methods compared to lecture-based teaching. They found positive effects on motivation, with larger effects in the domains of healthcare and STEM.

2.3 Gamification

Encouragement of certain types of behavior observed when playing games has been used advantageously in many different fields: e-commerce, human resources, data gathering, enterprise organization, innovation, sustainable consumption and also in education (Hamari et al. 2014). Detering et al. (2011) define the term “gamification” as the “use of game mechanics in non-gaming contexts”. Huotari & Hamari (2012) argued that desired behavioral patterns, such as customer engagement, can be strengthened by positive, intrinsically motivated psychological reward systems, such as those typically experienced when playing games.

The application of gamification principles to the field of education has been studied by number of researchers. An extensive literature review performed by Caponetto et al. (2014) discovered that gamification encourages productive behavior, such as team-work, creativity and self-guided study. They ascertained that gamification made learning more effective, because students found learning games attractive and captivating.

Game-based learning has been applied successfully in the field of computer science education. Wang et al. (2024) developed a serious game to teach project management. By guiding players to progress through projects of increasing complexity, they incorporate intrinsic motivation with perceived learning. Chen & Huang (2024) explored the effects of rewards and competition in game-based learning to teach computational thinking. They found that students performed best with rewards, but without competition.

Chapman & Rich (2018) carried out an empirical study of a gamified course. Students reported an increase in their levels of motivation and preferred the following game elements:

- The opportunity to earn points for assignments,
- Acquiring bonuses or flexibility for due dates,
- Indication of their current grades,
- Course map,
- Leaderboard.

The effectiveness of gaming elements specifically for asynchronous learning on e-learning platforms was addressed in a systematic literature review by Popp & Schuhbauer (2023). The following gamification elements were judged to be the most successful: badges, leaderboards, level-up systems and progress bars. The integration of two gamification elements further increased students’ motivation. The combination of badges with leaderboards or level-up systems proved advantageous.

Not all of the results reported in the literature were positive. Toda et al. (2018) conducted a systematic mapping study. They identified four negative effects associated with gamification. The most commonly reported negative effect was a loss of performance. The game itself actively hindered some students’ learning process. Students who spent the most time playing the gamified activity actually focused more on the game itself, rather than the learning material. As a result, these students scored lower than their peers on tests which measured transfer skills. The second most common negative effect identified was the encouragement of undesired behavior. Some students experienced demotivation due to excessive competition among other course members. The gamification component with the highest correlation to negative effects was the use of leaderboards. The authors conclude that this finding agrees with psychological literature, which cautions that ranking systems in learning environments can lead to demotivation. They caution that the design of learning games should carefully select which gamification components to include, in order to avoid undesired behavior.

2.4 Problem-Based Learning with Integrated Gamification

Few authors have reported on the integration of Problem-Based Learning with Gamification. Cubela et al. (2023) integrated problem-based learning with game-based learning for engineering education. They described a student-centered course to tackle real-world issues, such as burglaries of automated teller machines. The game-based aspects consisted of reward systems, points and leaderboards. This class was conducted at the master's degree level with only nine students. Due to the high level of instructor support, it is not clear whether this method would work for larger, introductory courses.

Junior et al. (2019) performed a systematic literature review of game-based learning in the context of project-based learning. Most of the studies they found utilized simulation of virtual worlds. Although some of the studies reviewed list PBL as a keyword, most of them appear to focus on the technical aspects of the simulations and less on PBL methods. Deshpande and Huang (2011) postulate that simulation games are an extension of PBL. Although simulation games are experiential and can be collaborative, the independent research and creative inquiry aspects vital to PBL are missing. The search for original solutions is limited by the extent of the features already pre-programmed into the simulation.

Huang et al. (2023) conducted a systematic literature review of gamified PBL. They classified approaches into four types: gamifying the content, gamifying both content and structure, integrating prefabricated games and defining the game as the activity in PBL. They did not, however, differentiate between applications suitable for large undergraduate courses.

A research gap can be identified in the lack of literature on the integration of PBL methods with gamification for large, introductory courses at the undergraduate level.

3. Methods

A mixed methods approach was implemented to gather the data analyzed in this study. Challenges to motivation and previous experiences with e-learning platforms were gathered via anonymous online questionnaires. Interviews were conducted with regional startup companies and with an expert on business case studies to elicit requirements for the fictitious startup problem. Anonymous online questionnaires were used to obtain user feedback about the e-learning game developed.

3.1 Anonymous Online Questionnaires

Anonymous online questionnaires were used to gather data at both the beginning and the end of the study. Van Selm & Jankowski (2006) discuss the advantages of online surveys to reach a large number of respondents with a minimal amount of effort. Statistical analysis of the data gathered in digital format is highly efficient. They caution, however, not to ignore the same methodological issues which can bias the results of analog surveys: problems with survey design, low response rates and non-representative survey samples.

The questionnaires in this study were conducted online using the web-based tool SoSci Survey (https://www.soscisurvey.de). SoSci Survey was chosen because it conforms to the General Data Protection Regulation of the European Union (GDPR, 2016). It also offers accessibility to respondents with disabilities. An anonymous format was chosen, because students have expressed a preference for anonymity. Anonymous questionnaires have also been shown to reduce student anxiety. (Kobayashi 2020).

The surveys included questions with binary answers (yes or no), multiple choice questions and answers on a 5-point Likert scale:

- 5: Agree completely
- 4: Agree somewhat
- 3: Neutral
- 2: Disagree somewhat
- 1: Disagree completely.

Open-ended questions with free text answers were also placed at the end of each survey, in order to avoid respondents quitting the survey in the middle without completing it.

Anonymous online questionnaires were used in two phases of the research study presented here. First, during the requirements elicitation phase, a questionnaire was distributed to STEM students at different levels of studies at a technical university in Germany. The purpose was to gather information about students' experiences and motivation in their previous use e-Learning. These results are presented in Subsection 4.1.

A second questionnaire was conducted at the end of this research study. First semester students were asked to test the online learning game which was developed for this project. The results of this second questionnaire are presented in Subsection 4.3

3.2 Expert Interviews

Semi-structured interviews feature both closed as well as open-ended questions. They are more resource intensive, because they require a one-on-one meeting between an interviewer and a respondent. They are especially suited when open-ended questions require follow-up questions to clarify responses. Complex questions which cannot be adequately answered in one sentence may require further inquiry to ascertain the motivation or reasoning of a respondent (Adams 2015).

During the requirements engineering phase, semi-structured interviews were conducted with local entrepreneurs. The goal was to gather real-world experiences from CEOs who had successfully started up small companies. These experiences serve as the basis for the creation of a fictional company which serves as the problem case for the course developed here. After the fictional case was developed, an additional semi-structured interview was conducted with an academic expert on business entrepreneurship. The goal of this expert interview was to validate whether the case study developed was realistic in practice.

4. Results and Discussion

Results of this study are divided into four sections. First, the motivational challenges experienced by first semester STEM students are presented. Next, the fictional startup company which was developed as the problem to be analyzed is explained. The e-learning game prototype is illustrated and the feedback from the evaluation is discussed.

4.1 Survey of Motivation in e-Learning of First Semester Students

An anonymous, online questionnaire was conducted during June and July of 2024 at the Nuremberg Institute of Technology in Germany. 172 students from STEM subjects took part in total. Students self-identified their own gender: 100 male, 50 female, 4 diverse, 18 no answer. Respondents stated that their ages were between 17 – 36, with an average of 22.18 and a mean of 21. 82% of respondents reported that they had to switch to online instruction during the pandemic. 68% reported that the availability of content on e-learning platforms helped them avoid dropping out of the university during the pandemic. These results confirm the findings of Wester et al. (2021), who found a significant decrease in emotional engagement due to the shift from in-person to online learning during the pandemic.

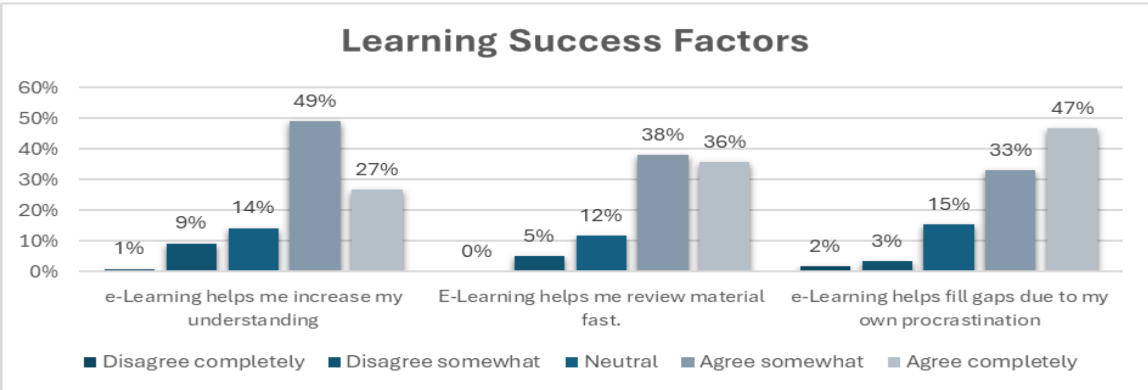
Students expressed a preference for in-person instruction once it was again possible. Even if e-Learning material was still available online, students reported that they still attended in in-person classes (Tab. 1). These quantitative results agree with the comments entered as free text. Students wrote that e-learning offers could never fully replace in-person learning. Although they appreciated the possibility to access e-learning materials at the time and place of their convenience, they missed the social contact and interaction inherent in learning together with their peers. Students also stated that they valued the possibility to get immediate feedback from instructors during in-person teaching. These results coincide with the results found by Ofori-Boadu et al. (2022), who found that students missed social contact and personal interaction with instructors and peers during the pandemic.

Table 1: Attendance at in-person lectures even if e-learning is available online (self-reported by students)

Frequency	Percentage
Never	8%
Seldom	20%
Half the time	19%
Often	39%
Always	13%

The learning success factors identified most often by the respondents are shown in Fig. 1.

Success Factors



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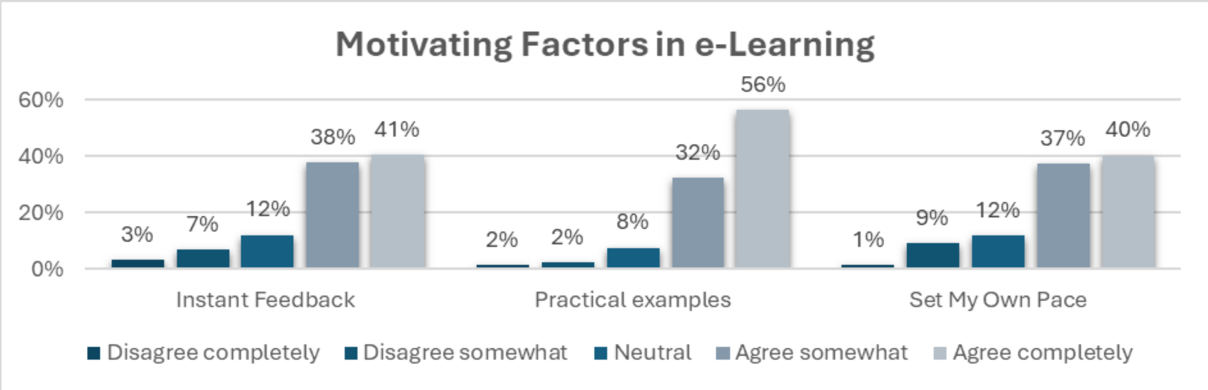
Students valued the opportunity to increase their understanding of course subjects and to review material quickly. The highest scoring positive answer was to “fill gaps due to my own procrastination” (33% agree somewhat, 47% agree completely). Although the high score on this answer was at first surprising, it could be explained by the time period when the survey was conducted: June through July of 2024. At the Nuremberg Institute of Technology, lectures end in June and exams are conducted in July. This may explain why the ability to fill in knowledge gaps caused by their own procrastination was valued so highly at the end of the semester. This result could suggest that students recognize their own poor planning and lack of organization.

Fig.2 shows the aspects of e-learning which the students found most helpful to increase their motivation levels. The possibility to get instant feedback about their learning progress was rated positively (38% agree somewhat and 41% completely) by a large majority of respondents. The ability to work at their own pace was valued by a majority (37% agree somewhat, 40% completely) of respondents. These results are in agreement with the findings of Sanheeta and Robinson (2024), who found that remote instruction helped to support students in their own autonomy.

The importance of practical examples was ranked as the most motivating factor (32% agree somewhat, 56% completely). These findings confirm the results found by Wijnia et al. (2024), who found that student-centered, problem-driven learning methods inspired higher motivation than lecture-based teaching. This demonstrated preference for practical examples serves as an argument for the use of PBL in this study.

Figure 2: Motivating Factors in e-Learning



In the free-text response to the inquiry on what other sources students consult to support their learning, the most common answers were: ChatGPT, Google and YouTube videos. The attractiveness of generative AI chatbots, such as ChatGPT, poses new challenges for educators. Threats, such as the dangers of plagiarism and of blindly believing answers without any critical reflection have been identified by King (2023). Opportunities for constructive use of generative AI in education are still being investigated (Kasneci et al., 2023).

The most common answers to the open-ended question at the end of the survey about what they would like to see in e-learning but are still missing include:

- Audio podcasts
- Recorded lecture videos
- More exercises with solutions
- More interaction with other students
- More feedback from instructors
- Interactive quizzes and games

Students' expressed wishes for more interactive quizzes and games serves as the motivation for the learning game developed in this research.

4.2 Fictitious Startup Enterprise for Problem-Based Learning

Problem-Based Learning (PBL) (Barrows & Tamblyn, 1980) was implemented for a first semester course of approximately 100 students. A real-world problem which had relevance to the lives of students was chosen: How to start up your own company. Practical information about typical problems encountered when starting up a company was needed. As described in Subsection 3.2, semi-structured interviews were conducted with the CEOs of three regional startup enterprises. Each of these startups offered environmentally sustainable solutions for an age-old problem: eradication of pests, such as rodents and insects. One of these enterprises offered an especially innovative solution: the integration of IoT (Internet of Things) technology to improve pest eradication. Instead of marketing their products to pest eradication companies, their goal was to market their products directly to small companies in the food industry, such as restaurants, bakeries, hotels, food warehouses, etc. The integration of pest traps with IoT sensors made it possible to oversee a large number of traps remotely with a mobile app. This greatly decreases the amount of effort required to manually check old-fashioned traps. To avoid potential copyright infringement problems, a fictitious version of this company, named Trap-IT, was developed to use as the real-world problem for this study.

The feasibility of this fictitious startup enterprise Trap-IT was evaluated by an academic expert for market feasibility, as described in Subsection 3.2. Based on the results of this expert evaluation, the case study was adapted to include additional aspects, such as an analysis of the market and more detailed financial planning to include risk contingency. Long-term plans for an expansion into international markets were also added to the case study.

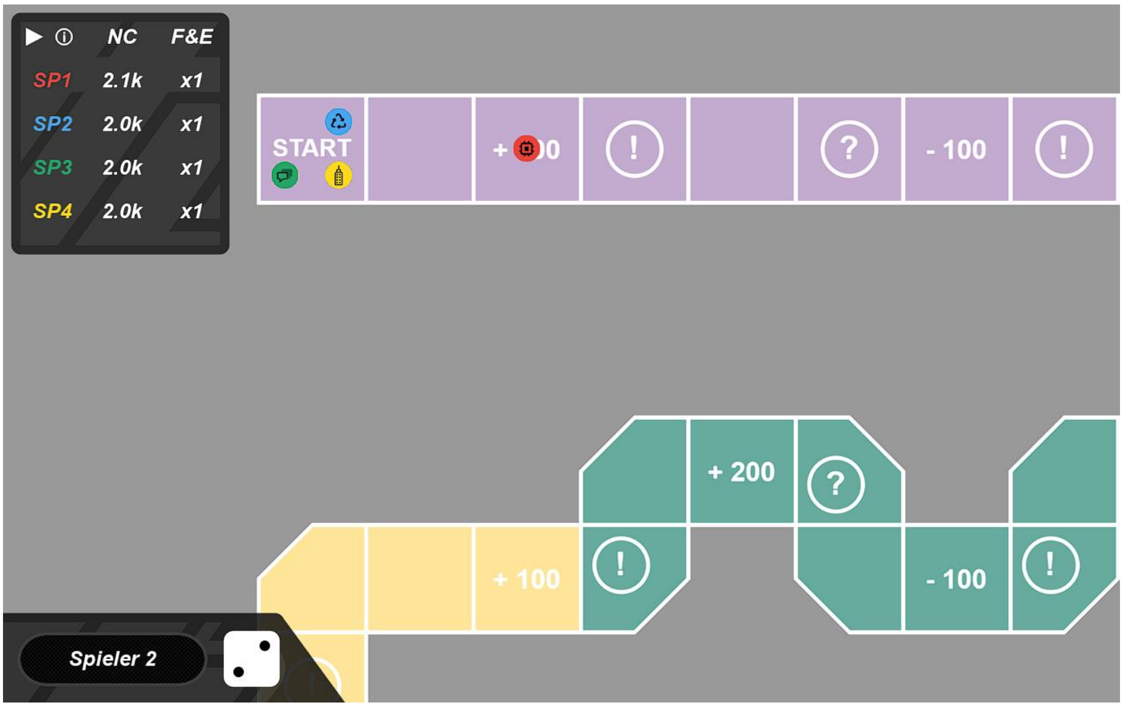
Due to the large size of introductory classes, it was not possible for one instructor to coach each student individually. Groups of four to five students were formed at the beginning of the semester. This also gave first-semester students a chance at teambuilding and forming friendships. The problem description was made available to all of the student groups in the Moodle e-learning environment. Every week, one new step in founding the startup enterprise called “Trap-IT” was revealed. For example, in the first week, student groups debated which legal form would be best for Trap-IT. Should they start the company as a private enterprise or should they establish a corporation with limited liability? Every week, a new problem was discussed in class together within each of the student groups. Just like in the real world, interdependencies between the strategic decisions made in the previous weeks could have a direct effect on the options available to construct solutions for subsequent weeks. In keeping with PBL (Smith et al., 2022), students perform their own research to gather the information they need to construct their own solutions to each weekly problem. The role of the instructor was to help the student groups to search for the information necessary to solve each problem. Some student groups required advice from the instructor on mediation techniques to address difficulties in communication and to solve conflicts between group members.

4.3 e-Learning Game

An online board game was developed to represent each of the steps necessary to found the startup company Trap-IT. As shown in Fig. 2, each color-coded level of the playing field correponds to one major problem task which needs to be solved when starting up a company: The game begins with the decision on the legal status of the company. Each level progresses on through the choice of a location for the company headquarters, developing a strategic marketing plan, acquiring materials, planning production, human resources, finance, international expansion, etc. The first prototype for this online board game has been developed using a game engine called GameMaker (https://gamemaker.io). Up to four teams can compete against each other to start up their own companies. The game makes use of typical game components, such as rolling dice to advance along the playing field path. Students solve assignments related to each color-coded level to earn fictitious money units for their startup. Wrong answers can lead to losing money units. Random events which positively or negatively affect the company can sometimes occur, just like in real life. At the end of the game, the team which earns the most money units without going bankrupt is declared the winner.

This game implements some of the gaming components identified in the literature Chapman & Rich (2018). A color-coded course map gives students a visible representation of where they currently are on their startup journey. The position of each piece on the playing field serves as a leaderboard. The opportunity to earn points give instant feedback on correct or incorrect answers. The roll of the dice adds a stochastic element to the game, which can give weaker players a chance to catch up. This may help to reduce one of the negative aspects of gamification identified by Toda et al. (2018), namely demotivation of weaker students.

Figure 2: Board Game to Startup a Company



A beta test of the first prototype version of the e-Learning game was conducted. 35 first semester students took part in October of 2024, during the first month of the fall semester. Initial feedback was obtained by using an online anonymous questionnaire. 74% of the participants self-identified as male, 26% self-identified as female. Participants were asked to rate their answers on a 5 step Likert scale as described in Subsection 3.1. Results are presented in Table 2.

Table 2: Results of initial online anonymous questionnaire on e-Learning game.

Questions	Disagree Completely 5	Mostly Disagree 4	Neutral 3	Partial Yes 2	Agree Completely 1
Do you enjoy using games to learn?	0	2	12	17	4
Do games help to increase your learning retention?	0	2	7	17	9
Do games help you to apply knowledge in practice?	0	3	8	16	8
How satisfied are you with the use of games in your studies so far?	0	2	12	16	5
Did this particular game motivate you to learn?	0	2	5	20	8

A follow-up questionnaire is planned at the end of the fall semester in February of 2025. The goal of this second questionnaire is to investigate whether students‘ opinions have changed over the course of their first semester at the university.

4.4 Limitations

The results of this study are subject to a number of limitations. First and foremost, the small number of respondents to the questionnaires (172 for the questionnaire on motivation for e-learning, 35 for the questionnaire on the evaluation of the learning game) is one of the main drawbacks. These small samples sizes are not necessarily representative of all of the students in the target group and thus not statistically significant. Quantitative studies with a larger number of participants are necessary. Because the semester at the Nuremberg Institute of Technology begins in October, this test may have been conducted too early to obtain significant results. A follow up test at the end of the semester in February 2025 is planned. Changes in student opinions by the end of the semester, shortly before exams, are expected.

Student interactions with the gamification course need to be evaluated in more detail using robust qualitative methods. The “Thinking Aloud” method was first proposed by Lewis & Mack (1982). This method implements cognitive theory of exploratory learning to the design and evaluation of intuitive user interfaces for computer systems. Test subjects are given specific tasks to perform when testing a prototype. They are instructed to verbally express every thought which crosses their minds as they attempt to complete each step of the assigned task. A test facilitator observes, records or takes notes of the comments expressed by the test subject. The test facilitator should not intervene in the task, in order to allow the test subject to complete the assigned task as naturally as possible. This “Thinking Aloud” method will be implemented to evaluate the e-learning prototype.

An eye-tracking system, such as the Tobii Eye-Tracking system (https://www.tobii.com/) will be used to evaluate the e-learning prototype. Eye-tracking systems can help to provide insight as to how users navigate a computer system and where they focus their attention. Gaze-plots record which components users focus on and measure how long users pay attention to each portion of the computer screen. This can help to identify which design elements capture users' attention and which elements are overlooked. Novák et al. (2024) found that in addition to analyzing users' interaction with a computer system to improve usability, machine learning methods can recognize different emotions linked to users' interactions.

5. Conclusions and Future Work

This study looked at motivational challenges faced by first-semester STEM students. An integration of problem-based learning (PBL) within an e-learning game was attempted. Three research questions were investigated:

R1: Which factors influence motivation in e-learning in first-semester STEM students?

- E-learning cannot replace in-person interaction with peers and instructors.
- Students use e-learning to rapidly review material and to make up for procrastination.
- Students trust internet sources, such as generative AI, without critical analysis.

R2: How can Problem-Based e-Learning be applied to large, introductory courses?

- A fictitious startup company was designed to serve as the real-world problem.
- Students together work in small groups to solve problems encountered by a startup.

R3: Can creative teaching methods, such as gamification, motivate students to learn?

- Initial feedback on using gamification to increase motivation shows positive results.
- Statistically significant sample sizes and more rigorous tests need to be conducted.

This work in progress study investigated the integration of PBL with gamification for an introductory first semester course. Concepts implemented here could be applied to wider educational settings, such as other STEM fields, business or health care.

Further work will include more extensive testing of the e-learning game. Quantitative surveys of large numbers of students will be conducted at the end of the semester to obtain feedback data which can be statistically analyzed. In addition, two qualitative methods, "Thinking Aloud" and eye-tracking, will be used to gain more detailed user feedback. Based on the user feedback obtained, the learning game will be further developed. Future plans include components to increase the amount of online interaction between players by adding chat functionality. Accessibility for users with visual impairments will also be addressed by adding audio output to guide users who cannot see the game board.

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