Enhancing Online and Mobile Experimentations using Gamification Strategies

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***Abstract*—In teaching theoretical topics, modern STEM education uses interactive hands-on approaches, which support students in understanding the topic instead of teaching them simply how to memorize theoretical concepts. Pedagogical strategies in fields with an abundance of abstract concepts, such as physics or electrical engineering, additionally recommend experiential experience, such as laboratory experiments, as essential learning tools. To fulfill increased demand for engineers, additional educational opportunities have been created, which include online, remote and blended learning environments. Unfortunately, providing hands-on experience in these environments, which is as effective as in-class experiments in STEM fields, is extremely challenging. Different departments have developed online and remote solutions, from single remote introductory courses with online experiments to entire off-campus programs supported by remotely conducted experiments with mobile studios. However, in online situations, students often feel lost, have issues with the technology, and experience lack of engagement. All these factors can result in increased dropout rates or lack of understanding and commitment. Current trends in online education incline towards engaging students using gamification strategies to reduce dropout rates and to increase students' motivation in a playful way. Additionally, creating playful experiences for students can be used to attract novice students to this field. In this paper, we introduce a theoretical framework, which can be used to enhance online and mobile experiments with game design strategies to raise students' engagement and commitment and reduce initial onboarding obstacles.**

***Keywords*—gamification, game-based learning, mobile experimentation, mobile labs, online learning, remote learning**

I. Introduction

The increasing demand for engineers is making new and innovative forms of teaching large user groups necessary. Online, mobile, and virtual experimental environments allow new and more flexible forms of teaching. Many of these forms support remote, blended, and virtual learning scenarios to help more students with learning almost anywhere and at any time. However, learning and understanding concepts of STEM (science, technology, engineering, and mathematics) fields is a challenging task and requires educators not only to teach solutions to problems, but also to explain them them [1]. Different interactive engagement strategies and active learning environments are especially designed for in-class setups and include hands-on experience, such as laboratory experiments [2]. In recent years, more and more setups were introduced to include laboratory experiments in online environments. Many authors have described different online experiments and also ways to integrate them into traditional learning management systems, such as Moodle [3]. In particular, the interactive and experimental character of online laboratories makes them a powerful learning tool. New trends also offer low-cost mobile laboratories, which allow students to remotely conduct experiments with a more realistic setup compared to online-only solutions. Such hands-on mobile and online strategies have the power not only to support students who are already interested in the topic, but also to attract students without any experience in this field.

One successful example of an online and mobile experiment setup is the introduction of an off-campus program for electrical engineering in an endeavor provided by the Department of Electrical and Computer Engineering at Morgan State University. The Mobile Studio IOBoard^{TM} [4], [5] is used to provide virtual experimentations. It was found that students using this mobile laboratory were able to use regular equipment as well. However, even though the results were both promising and encouraging, students still experienced various problems. The main issue students faced regarding online experiments was how complete their laboratory and design experiments on their own. Figure 1 illustrates such a mobile laboratory setup. Many online learning environments are also facing different issues based on the lack of social interactions, technical onboarding difficulties, procrastination, or missing self-motivation, which leads to motivational throwbacks, feelings of isolation, frustration, and finally dropout [6], [7]. Motivation is one of the key factors to successful learning. In isolated online and remote settings, where the distance between students, teachers, and other students is strongly present and the activities often lack a high degree of social interaction, the implementation of additional engagement strategies is necessary to prevent people from dropping out, procrastinating, or losing interest in the course content [8].

One innovative and promising way to raise student engagement is the introduction of gamification strategies as a pedagogical tool. Gamification is defined as the use of game design elements in the non-gaming context [9]. The main aspects of game-design elements include elements to engage user interaction with small challenges or tasks and to give feedback in the form of points, ranking information, badges, progress bars, or similar rewards. Game design mechanics,

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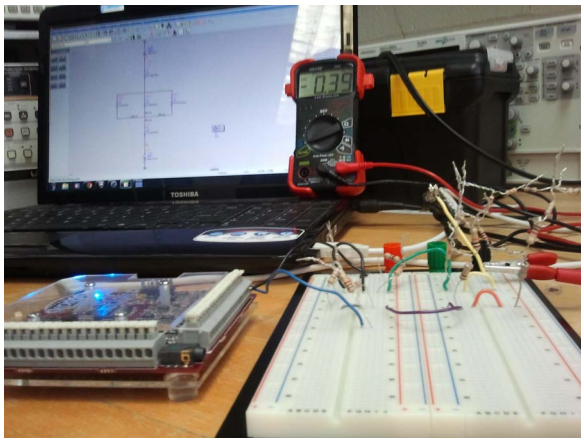

Fig. 1: Mobile labs for remote learning scenarios [5].

such as onboarding ? a game mechanism often used in games to teach people how to play and interact with the game, can be used to overcome technical challenges, teach students how to interact with the online or mobile experiments, and get them interested and excited about using the system.

Gamification strategies can be either integrated directly into the experiment setup or software or used as a framework interacting with the setup or the learning management system, such as Moodle or a MOOC platform. Also, initial studies with MOOCS on industrial electronics circuits indicate high drop-out rates and show a frequent lack of student engagement and commitment [10]. Implementing gamification strategies into MOOCs can achieve enhanced student participation and engagement in MOOCs.

In this paper, we introduce a theoretical model that describes how to (1) integrate game elements into existing course setups, and how to (2) build a gamification framework around an existing setup. This model is based on existing pedagogical gamification frameworks to create gamified educational science simulations [11] and is introduced in an abstract way for online and mobile experiments, and is then narrowed down to fit the framework of the electrical engineering course, introduced by the Department of Electrical and Computer Engineering at Morgan State University. We try to describe the solutions on a high level so that they can also be applied to other similar problems. The aim of this paper is to introduce a theoretical gamification model on an abstract level, which can then be used in different online, mobile, and remote experiment setups. We also discuss the benefits, problems, and prospect of such strategies.

II. Background

A. Virtual Labs and Experiments

Different authors have described tools and methods to enhance e-learning scenarios with online and remote laboratory experiences [12]. Evaluations with students have shown positive outcomes with online laboratories. In particular, flexible, inexpensive, safe, and interactive learning characteristics have been outlined [3]. However, many online experiment setups also have different limitations. Similar to e-learning environments, they face issues such as a lack of social interaction and collaboration, procrastination, and missing self-motivation [13]. Another problem online laboratories are facing are steep learning curves. This affects in particular the first assignments, when users have to learn how to interact with the setup and the virtual instruments [4]. Thus, badly designed first assignments often lead to early user frustration, which in turn can lead to dropout. Also, online and remote setups, where users are meant to solve the assignments on their own often face high dropout rates. New pedagogical methods designed for online experience can help overcome these issues. Online experiments and frameworks that show high potentials in adapting and integrating toolsets [12] are particularly good candidates for further pedagogical improvements. They can be used to include well-designed pedagogical scenarios and technologies which are better suited to explain abstract and difficult concepts [14]. This also includes the integration of engaging strategies, such as collaboration tools or game-based approaches. Remote laboratories with an interface to learning management systems, such as Moodle or MOOCs, also have high potential to attract a larger number of users and to integrate further pedagogical strategies.

B. Gamification in Education

Many authors describe positive learning outcomes in using games and gameful experiences for teaching conceptual understanding in STEM fields [15]. A positive relationship between games and science career motivation has also been detected [16]. Pairing instructional content with a game cycle of user judgments, behavior, and feedback can be used to engage users and to achieve the instructional goals. However, it is a challenging task to design an instructional experience that does not become repetitive, does not lose appeal over time, and does not violate the principles of gaming, such as its voluntary character and fun elements [17].

Schell describes several reasons why a lot of educational video games are not found in classrooms in spite of their positive effect on student motivation and learning gains. Playing and experiencing a game and learning content through a game is often more time consuming than learning the content in a traditional classroom setting. Another important reason that highlights the difficulty of integrating games into each concept of the learning content is the factor of good game design. Designing an interesting, fun, and also educational experience is challenging. For this reason, creating such games is often also very expensive [18].

Gamification is a method that is easier and capable of being integrated into task-based settings at a lower price. Gamification is defined as ”the use of game design elements in non-gaming contexts” [9] or ”using the aesthetics of game-based mechanics and game thinking to engage people, motivate action, promote learning, and solve problems” [19]. The current state of research examines gamification as a successful tool to enrich business, lifestyle, and educational effort with motivational aspects [20].

1) Gamification Elements: Gamification uses a variety of elements that are usually found in games. The MDA (mechanics, dynamics, and aesthetics) framework is a famous game design framework, which is used to understand and describe the single elements of games, based on their visibility to the

user. Interface elements are the most visible to the user, and these are used to communicate and interact with the player, and are also referred to as aesthetics. Components of game mechanics include elements, such as achievements, badges, collections, gifting, leaderboards, levels, points, and social aspects, such as competitive or collaborative tasks. Dynamics describes the interface between mechanics and aesthetics and can be characterized as the run-time behavior of mechanics, which react to player input and output [21]. [19] introduce game thinking as an additional important component of gamification and define it as the process of converting an everyday experience (such as jogging) into an activity with elements of competition, cooperation, exploration, and/or storytelling.

Based on the MDA framework, Werbach [22] illustrates a three-level-pyramid to describe the elements of gamification. In the top level we find game dynamics, which refer to a hidden structure including constraints, emotions, narrative, progression, and relationships. The second level consists of mechanics and elements which are used to interact with the player, such as challenges, chance, competition, cooperation, feedback, resource acquisition, rewards, transactions, turns, and win states. The ground level comprises elements which are directly visible to the player and includes achievements, avatars, badges, boss fights, collections, combat, content unblocking, gifting, leader-boards, levels, points, quests, social graphics, teams, and virtual goods. Zichermann and Cunnigham enumerate gamification strategies such as scoring elements, competitive elements, onboarding strategies (to help to user to get the skills to interact with the system), badges, small activities with clear goal, and social engagement [23].

2) Gamification in STEM Education: Many educational platforms use gamification strategies to engage their users. One famous example is Khan Academy[1]. Khan Academy is an online platform, which allows users to take lectures on several subjects, including mathematics, history, physics, and coding. The platform uses small lectures in the form of videos to teach the concepts and integrated short exercises combined with an interactive reward system - namely badges, points, and progress bars to offer assessment and interactive experiences [24].

Codeacademy[2] is another online platform that is dedicated to teaching how to program. Similar to Khan Academy, it uses traditional gamification strategies based on interactivity, social affordances, and progress feedback strategies and statistics to get users interested in the topics and keep them engaged to learn more and more. Not only can online educational efforts be supported by gamification, in-class scenarios can also be enhanced. Figure 2 illustrates an example of how gamification strategies were included in the learning management system Moodle. This approach was used for a computer science course on information retrieval, which teaches mathematical and algorithmic basics. To make the course more engaging, a pedagogical model based on gamification was introduced. Interactions with students and feedback in the form of points, rankings, and badges were integrated into Moodle [25]. A similar study, introducing gaming elements in an engineering course, describes positive effects in lecture attendance, number of social interactions such as forums, and an increasing number of post-course activities [26]. Gamification can be a powerful tool to support STEM education affordances and can be used to make online and mobile learning experiences more engaging [27]. How well these strategies can enhance the student engagement in interacting with online and mobile experiments and laboratories is an open question. As we have noted earlier, there is not a lot of research on gamification strategies in this context. Online and mobile experiments often face different issues and challenges for pedagogical interaction design. This includes for example affordances to acquaint students with the setup and the virtual or mobile laboratory [5].

In the following section, we adapt a pedagogical gamification model, which was first applied in the context of gamifying educational science simulations [11], to build a theoretical framework about how to integrate game design elements into online and mobile experiment settings.

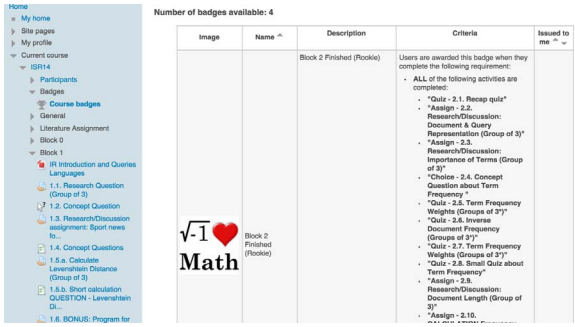

Fig. 2: Gamification Interface integrated into Moodle.

III. Gamification Model for Online and Mobile Experiments

As we have discussed in the previous section, the introduction of gamification strategies in online learning environments can be a successful way of engaging students not only to learn better, but also to increase their motivation regarding a career in science. Online and mobile environments often have additional issues and challenges of student engagement and support that can be solved or counteracted by gamification strategies. In the following section, different issues are listed and suitable gamification strategies to solve them are discussed.

A. Solving Common Problems with Gamification

1) Learning how to interact with the online or mobile setup: Learning how to interact with the online or mobile experiment is an often very challenging task and students frequently have difficulties completing the first assignments because they are not sure how to interact with the online experiments, the virtual or mobile laboratory, or the online environment [4]. However, the first encounters with such systems should engender a positive experience to prevent frustration and early dropouts and raise students' fervor for science at an early stage. Onboarding strategies in game design make the user aware of the input and interaction with the system by explaining how to play the game by means of small tutorial tasks where the player learns the single commands and mechanics step by step. The same strategy can be used to make the student aware of how to interact with the mobile or

[1] http://www.khancademy.org/
[2] http://www.codecademy.com/

online experiment. Small tasks that are easy to solve should be designed, and these should provide positive reinforcement as well as explaining the rules and input step by step.

2) Keep the student engaged: Student engagement is a challenging task. Students easily lose interest in assignments and tools if tasks become too boring, too hard, too easy, or too repetitive. Also, if assignments are too large and users encounter problems at an early stage, they will easily get frustrated. Interactive challenges and assignment breakdowns into smaller tasks with early feedback can overcome such issues and help the pedagogical designer of the experimental assignments to keep the level of difficulty balanced. Since different learner and player types require different strategies to become engaged, gamification allows the pedagogical designer to attract different learner types by means of similar strategies. Constant interactivities keep users attracted. Competitive elements, such as rankings, engage users with a competitive attitude to gain more points and achieve better results than others. Collaborative challenges and tasks attract users who are engaged by social motivators.

3) Raising social engagement: Many online platforms that integrate online experiments enable students to discuss problems and assignments with social tools, such as forums. However, only a small number of students participate in discussions actively. Being rewarded for helping other users can stimulate students to interact more with other students in the forum, give them advice, and try to help them. Special badges, point systems, or other awards can be used to trigger the feeling of being rewarded.

B. Gamification Model

Based on the observations of the previous chapters and the model described in more detail in [11] two major design elements can be identified: (1) interactivity (such as missions, tasks, or challenges) and (2) feedback (such as points, awards, and ranking). In order to design constant interactive experience, it is important to obtain a continuous and balanced cycle of user interaction and system feedback. Figure 3 illustrates the relationship between interactions, feedback and the single mechanics that can be used in this context. The interactions should be designed based on the pedagogical content (e.g. the single assignments of the experiments) and include elements such as activities, challenges, quizzes, or small tasks. Interactions are sent to the user by the system, but the input is given by the user. The feedback is designed on the basis of engagement strategies to attract different learner types (e.g. collaboration, competition, or reward), and includes small elements such as achievements, badges, points, gifts, leveling, rewards, or ranking. It is triggered by the system as an answer to the user input.

Interaction and feedback are connected via a shared interface, which can be either a separate platform or the experiment itself.

C. Gamification Strategies

As one can see on the model introduced in Figure 3, different strategies to gamify experiments can be defined. The following process to gamify online and mobile experiments can be outlined based on the gamification process introduced in [11]. First, the pedagogical goal and the pedagogical content are defined. Second, different interaction possibilities in the experiment are identified. Third, the engagement types of the students are determined. Fourth, based on the engagement types the feedback types are designed. In the last step, the different interactivities and challenges (such as small assignments and onboarding missions are designed).

Gamification strategies can either be integrated directly into online or mobile experiments, which require user input integrations and feedback possibilities, or built as separate frameworks around the experiment. Figure 4 illustrates the different ways to interact with the gamification framework. The gamification strategies can either communicate through a separate platform e.g. a learning management platform, or directly to the experiment framework.

D. Assessment Strategies

Although experiment settings vary widely (form physically presence to remote to virtual experiences), the key objective is to support an understanding between theoretical model, concepts and the reality. Required skills include planning and building an experiment as well as running the experiment and understanding the results [28]. Assessment is required to capture the skills and understanding as well as to provide feedback to scaffold and guide the students. Different assessment strategies can be integrated as interface between user input and gamification platform. Specific assessment strategies for different learning types can influence the gamified feedback. They can also be used to adapt the form of gamified user interactions to attract the different learner styles.

IV. Conclusion

More designers of pedagogical teaching models integrate games and game design elements into learning environments to make learning more engaging, especially self-directed learning. Working with online and mobile laboratories facilitates a wide range of different interactions with the learning concepts, which is a perfect starting point to integrate gamification strategies and models. Also, interfaces to integrate other online platforms, such as Moodle or MOOC systems, make the integration of gamification strategies easy.

Gamification for educational purpose can be categorized into two major components: (1) interactions and (2) feedback. Interactions refer to small assignments and tasks that should be solved by means of the laboratory or experiment and should be balanced (not too hard, not too easy, and not too repetitive) and interactive (broken down into small tasks with constant cycle of user interaction and feedback). Users should get constant feedback from the system in the form of points, rewards, achievements, ranking information, or similar. These types of feedback should be designed to attract different student motivators (e.g. collaboration, competition, or reward).

Additionally, gamification strategies allow new forms of teaching on how to interact with the system. Instead of learning how to interact with the online or mobile laboratory only on basis of documentation and manuals, an interactive gamification framework and challenges, designed in the form of onboarding missions, allows students to learn how to interact with the laboratory in a playful way.

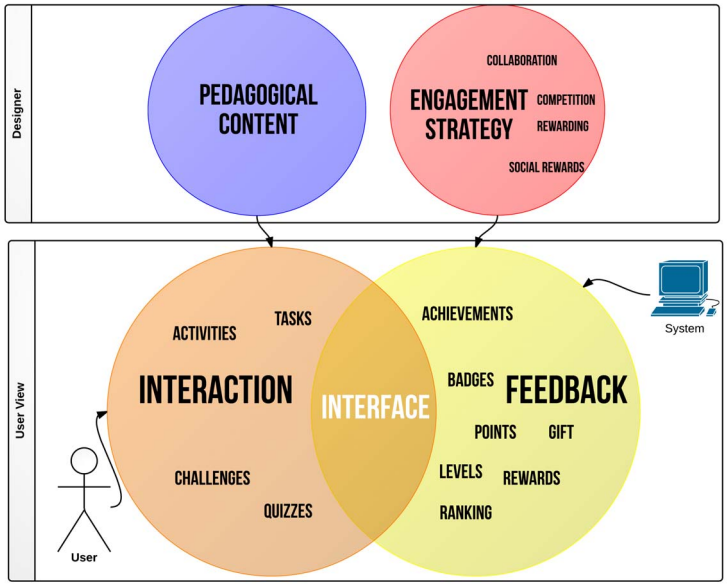

Fig. 3: Gamification Interaction/Feedback Model.

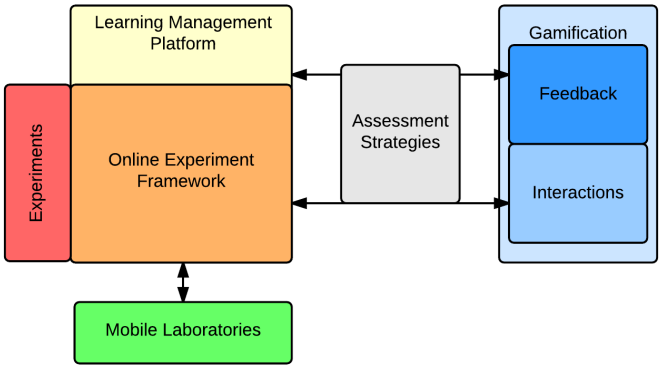

Fig. 4: Gamification Strategies to integrate Online Experiments.

Generally speaking, gamification strategies have great potential to support virtual, online, and mobile experiments to engage users, raise science-career motivation, help to overcome starting barriers, and reduce dropout-rates. Different elements of gamification can be used to engage and help students through typical obstacles found in online experiment.

Summarizing, we suggest a balanced mixture of the following elements:

- Onboarding strategies to teach students how to interact with the system and the experiments
- Constant interactions with the online experiment to keep students' engaged and interested
- Constant feedback to engage the user in their activities and giving hints on how to improve performance
- Rewards to stimulate social commitment to increase the number of social interactions (e.g. active forum discussions

Current experiments using educational science simulations indicate positive learning and motivation outcomes [11]. In conclusion, we believe that the introduction of gamification strategies in online, remote, and mobile experimental setups can help overcome different barriers and issues. In our future work, we will introduce this theoretical model in a real online experimental setup and compare outcomes with the traditional setup.

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