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# Educational Gamified Science Simulations

**Johanna Pirker and Christian Gütl**

**Abstract** Modern STEM education is mainly grounded in constructivism. It requires instructors to not only recite learning content, but also to teach the concepts and ideas behind abstract formulas. Interactive simulations are one of the most powerful tools for increasing the students' problem-solving abilities, and enhancing their understanding of conceptual models and formulas, which are hard to visualize without technology-enhanced tools. Creating simulation tools of interest to students has the potential to enhance their understanding of the phenomena and increase their interest in science. However, many simulations are not engaging and students will lose interest in interacting with them after a short time. Hence, it is important to advance in particular the motivational design aspects of such educational tools. One idea for motivating students is the use of computer games. Different studies show the positive impacts of a game-based or gamified approach in the field of STEM education and training. Several theories and frameworks were researched and developed to support the game design and gamification process of various scenarios. However, only a few cover specific design issues and implications of educational and instructional simulations. In this chapter we introduce a gamification model, which is adapted accordingly to the characteristics of constructivist STEM education approaches with focus on the usage of science simulations. Therefore we will introduce a model for the adaption of gamification techniques to design, develop, and adapt educational simulations. Based on a background and literature study, a framework for implementing a gamification approach for different kinds of simulations is introduced and applied to an application scenario of our own research. As a result, both the lessons learned and further recommendations are outlined.

Johanna Pirker

Institute for Information Systems and New Media (IICM), Graz University of Technology, Inffeldgasse 16c, 8010 Graz, Austria

e-mail: jpirker@iicm.edu

Christian Gütl

Institute for Information Systems and New Media (IICM), Graz University of Technology, Inffeldgasse 16c, 8010 Graz, Austria

School of Information Systems, Curtin University of Technology, Perth, Australia

e-mail: cguetl@iicm.edu

## 1 Introduction and Motivation

Teaching conceptual content such as is found in STEM (Science, Technology, Engineering and Mathematics) fields represents a challenge for many educators. Modern instructors use pedagogical approaches based on constructivism and interactive engagement (Sanders, 2009; Hake, 1988). It is important to not only recite formulas, but to teach how to solve problems and apply these formulas. Major issues include the level of abstraction and the invisibility of phenomena such as electromagnetism. In this context, visualization of concept can improve students' understanding.

Interactive simulations are one of the most powerful tools for teaching, learning, and understanding the behaviour and characteristics of physical laws, processes or systems. Computer-animated science simulations allow users to observe a variety of phenomena more easily while also supporting the conduction of expensive or dangerous experiments (Sanders, 2009). But even a well-designed simulation can be frustrating and does not sufficiently focus on motivational aspects. This can reduce the learning outcome and efficiency. Motivational, interactive engagement formats, such as a game-based or collaborative design, can be used to overcome or at least mitigate this issue and not only improve the students' understanding of the concepts, but also increase their enthusiasm for the field.

The introduction of gaming strategies and game elements in these simulations can help to overcome the issue of insufficient motivation and engagement. Creating a motivational simulation which reminds the students of a computer game, however, requires an elaborate design process (Schell, 2008). Many studies provide information about designing games, learning games, or simulations but say little about design principles to integrate game-design strategies into simulations which are in line with pedagogical and instructional design heuristics.

In this chapter we propose a gamification framework with a focus on educational simulations in STEM fields. The aim is to support designing, creating, and even converting an existing simulation into a gamified, motivational simulation, which considers educational implications in a cost and time-efficient way. The second part of this chapter introduces a first application of the model demonstrating the gamification process using the example of the Java-based educational visualization and simulation framework TEALsim. The last section concludes with lessons learned and further.

# 2 Background

## *2.1 Educational Simulations in Science Education*

One major challenge in STEM education is the presentation and discussion of abstract concepts, such as physical laws and phenomena, which are difficult to conceptualize and visualize. One example might be the interaction of electric fields with charges (Dori & Belcher, 2005). Neither textbooks nor the explanation of talented instructors can replace computer-based dynamic visualizations such as animations or simulations, which can conceptualize these effects. Invisible effects can be made visible, time and space can be stretched, and even dangerous or otherwise impossible experiments can be easily conducted (Lunce, 2006). Aldrich (2009) defines educational simulations as "[…] structured environments, abstracted from some specific real-life activity, with stated levels and goals."
Dori and Belcher (2005) reflect on their impressions of simulations in the field of physics as follows: "These visualizations enable students to develop intuition about various electromagnetic phenomena by making the unseen seen in game playing and experimentation." (p. 252) Animations are passive representations of principles and phenomena, and are only designed for students to watch. Instead, simulations have a more interactive character and allow the manipulation of the conditions of the principles and the parameters modeled, and therefore the behavior of the visualizations (Lunce, 2006). Exploring and experiencing principles and phenomena on their own help students to link the abstract formulas with visible behaviors. Different educational tools such as Physlets (Christian, 2005) and online platforms and collections such as Open Source Physics (OSP, 2003), or PhET (PhET, 2011) are available to support the STEM curriculum. Another important example is TEALsim, which focuses on the visualization of abstract physical concepts in the area of electromagnetism (TEALsim Website, 2004).

Research revealed that simply showing simulations to students does not enhance or prompt deeper understanding of concepts. Depending on the context of the learning content, the interactive character of simulations, however, can serve as an excellent tool to engage students and encourage them to explore difficult topics in more details. In an interview study with 89 students using different PhET simulations, Adams et al (2008) observed that "simulations can be highly engaging and educationally effective, but only if the student's interaction with the simulation is directed by the student's own questioning" (p. 1). They also suggest that if students only observe simulations and do not interact, they do not ask questions and cannot make new connections.

Different research groups have identified strategies and guidelines for enhancing the quality of educational simulations. Bell & Smetana (2008) highlight the importance of student-centered instructions, which mean that simulations supplement, but do not replace instructional modes. Windschitl & Andre (1998) found that constructivist simulations with exploratory character are “more effective in altering learners’ misconceptions” in comparison to confirmatory simulations, where students are following clear instructions. The importance of adding exploration-based activities to enhance the students’ understanding of the learning concepts was also observed by Adams et al. (2008). The authors found that factors such as interactivity, presence of little puzzles, visual aids such as labels, and fun and playful elements influence the students’ engagement.

In the light of the discussion above, the following heuristics can be applied to guide the design process of instructional simulations:

- Educational simulations should be constructivist with exploratory character.
- Educational simulations should supplement and not replace instructions
- Instructions should be student-centered
- Limitations of simulations should be pointed out
- Simulations should be designed in an engaging manner to support conceptual learning

Student engagement is a powerful tool for enhancing understanding and motivation to learn with the simulation. In the next section we will discuss this idea in more detail.

## *2.2 Motivation and Learning*

According to Graham and Weiner (1972) “motivation is the study of why people think and behave as they do. In the context of academic achievement, motivational concerns would be addressed if we were to ask, for example, why some students complete tasks despite enormous difficulty, while others give up at the slightest provocation, or why some students set such unrealistically high goals for themselves that failure is bound to occur.” An important term hereby is *intrinsic motivation (IM)*, which refers to doing activities because of their satisfying, fun, and interesting nature (Vallerand et al., 1992; Deci, 1975). IM is an important concept for instructional designers and teachers, because it results in “*high-quality learning and creativity, it is especially important to detail the factors and forces that engender versus undermine it”* (Deci & Ryan, 2000). In the context of learning, three types of IM are identified: (I.1) Intrinsic motivation to know, (I.2) intrinsic motivation toward accomplishments, and (I.3) intrinsic motivation to experience stimulating sensations such as sensory pleasure or excitement (e.g., through excitement from active class discussion). In contrast to IM, *extrinsic motivation (EM)* represents behavior which does not stem from personal interest. It is possible to differentiate between three types of EM: (E.1) External regulation (e.g., child learns because the parents force him to), (E.2.) Introjection (the individual has already internalized the reasons for the action), and (E.3.) Identification (the actions are perceived as chosen by the individual). Beside IM and EM, *amotiva-*

*tion (AM)* is used to describe the state where individuals are neither intrinsically nor extrinsically motivated and do not experience any external or internal motivators (Vallerand et al., 1992).

Vallerand et al. (1992) introduce the *Advanced Motivation Scale (AMS)* as a scale for measuring motivation in educational settings. It is based on the Echelle de Motivation en Education (EME) and helps to measure the three types of intrinsic motivation, the three types of extrinsic motivation, and amotivation.

Csikiszentmihalyi (1990) identified eight major components that cause enjoyment: (1) Tasks we have a chance of completing, (2) ability to concentrate on what we are doing, (3) tasks with clear goals, (4) tasks with immediate feedback, (5) deep and effortless concentration, (6) sense of control over actions, (7) loss of self-consciousness, (8) sense of the duration of time is altered. Csikiszentmihalyi describes experiences which are full of enjoyment as "so gratifying that people are willing to do it for its own sake, with little concern for what they will get out of it, even when it is difficult, or dangerous" (Csikiszentmihalyi, 1990, p. 71). These experiences can be described as state of flow. Csikiszentmihalyi (1975) introduced the term flow as an optimal experience characterized by full attention and maximum performance on an activity. Flow can be found in different activities such as experiencing a book, sports activities, art, or music. Plays, games, and computer games are obvious activities which are likely to promote such flow states. Many of the eight components that cause enjoyment can be found in games. Using these strategies, games and game-based teaching methods can be a powerful way to achieve higher student motivation in different learning environments, such as in classrooms, in online environments, or in blended systems.

## *2.3 Games and Gamification in Education*

The idea of using digital games in contexts other than fun, leisure, and entertainment is not a new one. The first experiments with games with a serious purpose were grounded in military training (Deterding et al., 2011). In the last year, more and more gaming strategies were also making their way into the classroom to enhance intrinsic student motivation. With key statements such as "Games are a more natural way to learn than traditional classrooms" (Aldrich, 2009), various ideas emerged how to integrate games or game elements into learning settings in classrooms and online learning environments. James Paul Gee (2003) suggests that educators might benefit from studying how game players learn through game play. Schell (2008) even compared the traditional classroom design with a game (see Figure 1).

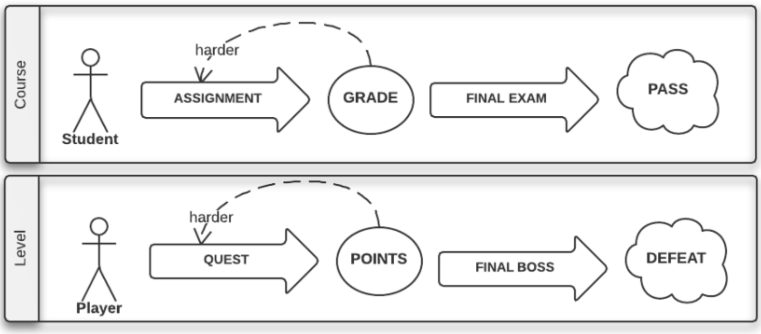


**Fig. 1.** Traditional class educational systems are arranged like games (Pirker, 2013)

Playing a game is already a powerful learning tool in itself: players have to learn new skills in a new (but safe) environment (Koster, 2004). Mayo (2007) summarizes five reasons to not only support small computer games, but also to invest into large scale parallel education in science and engineering via video games: (1) a single game can reach more people than one single lecture. (2) Video game-based education would attract students outside the classroom. (3) Video games stimulate chemical changes in the brain that promote learning. (4) Video games achieve higher effectiveness than a classic lecture. (5) Video games are designed according to effective learning paradigms such as experimental learning, inquiry-based learning, self-efficacy, goal setting, cooperation, continuous feedback, tailored instruction and cognitive modeling.

We have learned that games can be a powerful tool to support learning behavior. So, why aren't today's classrooms and learning strategies fully supported by these fun and motivation triggers? Schell (2008) summarizes the following challenges of introducing games and game-based approaches to learning settings:

1. Time constraints: Games usually require more time to impart the learning content.
2. Age constraints: Usually, games are designed to attract the gamer generation, and therefore focus on learners who have experience with this kind of multimedia.
3. Expenses: Usually, good games include a long and deliberate design process, which involves many developers, artists, and designers. This design and development process can be highly expensive.
4. Design challenges: Designing a game which is fun for players but still educational is challenging.

In the next section we analyze different aspects which can help to improve the design process and facilitate the involvement of games, game elements or game strategies in learning environments.

**Designing Instructional Environments with Game Elements**

When using game elements, strategies or fully-fledged games to support the educational strategies, various implications must be considered. When introducing games to teach content, it is important to find out which topics can and should be covered by a game, and which areas are either not suitable or would be too time- and cost-intensive for a game-based approach. Randel et al. (1992) examined different studies comparing the learning outcomes of simulations and games with those of conventional instructions and found that "subject matter areas where very specific content can be targeted are more likely to show beneficial effects for gaming." In particular, studies involving STEM fields such as math and physics showed that the instructional effectiveness of games was higher than that of conventional classroom instruction.

Early studies have already resulted in taxonomies and strategies to enhance intrinsic motivations for learning based on fun elements of games. Malone and Lepper (1987) have identified heuristics for designing intrinsically motivating instructional environments based on studies identifying fun elements of games. They range from interpersonal motivators, including motivation, to cooperative or competitive activities or the receipt of social recognition, and individual motivators. Individual motivators can be one of the following. First, students should experience challenges, which require a balanced level of difficulty. Students should have goals, encounter uncertain outcomes (such as variable difficulty levels, multiple levels of goals, hidden information, or randomness) and need frequent, clear, constructive and encouraging performance feedback, including positive feedback to enhance self-esteem. Second, the curiosity of students should be encouraged. It is important to balance the level of informational complexity according to the students' current state of knowledge. Third, students should have a sense of control and a feeling of self-determination. Fourth, inspirational, playful environments and the involvement of imagination can promote intrinsic motivation.

Another approach to make the learning experience more incentive and enhance the students' motivation is the use of gamification strategies. Instead of designing an entire game, what is expensive and requires lots of resources and specialists, gamification is the "use of game design elements in non-game context" (Deterding et al., 2011, p. 2426). Adding these elements is a comparatively cost-effective way of adapting existing processes and services to make them more fun. One famous example of gamification in classroom education is Quest to Learning (Q2L). Q2L is a school in New York City which uses gamification strategies as a basis for the curriculum design. Instead of learning for exams, students learn by solving riddles, finishing missions, or enacting role-playing scenarios. Students are rewarded for their effort by getting points, instead of getting frustrated and stressed through failing exams (McGonigal, 2011).

An example for an online educational platform grounded in gamification strategies is Khan Academy. Khan Academy is a collection of different learning resources connected to courses created with the purpose of enabling users to learn different topics, such as STEM fields, history, languages, or finance. It helps people to track their learning progress and uses gamification strategies such as points, badges, and awards to create a more fun, exciting, and motivating environment (Thompson, 2011).

In the next section we introduce different mechanics for both game design and gamification strategies.

## *2.4. Game Design and Gamification Strategies*

Different authors have proposed different sets of game design strategies and frameworks for creating games and gamified scenarios for various purposes. The purpose of this section is to outline various ideas from different authors and to pave the way for analyzing science-based games, simulations, and gamified applications on the basis of these strategies.

### Game Design Elements

Looking at the structure and elements of games, it can be seen that most are made up of the same or similar kind of principles. An early description of game elements was introduced by Avedon and Sutton-Smith (1981). They identify ten structural elements of games: purpose, procedure for action, rules governing action, number of participants, roles of participants, results, required skills for action, interaction patterns, physical settings, environmental requirements, and required equipment. Koster (2004) summarized the following game elements: preparation before a challenge (such as choosing cards for a card game), a sense of space (such as the environment or the game board), a solid core mechanic or game rule, a range of challenges, a range of abilities required to solve the encounter, and skills which are required to use the abilities.

To make a game into a learning experience, he also suggests including features such as a variable feedback system, balance between player level and game difficulty, and consequences for failures.

Schell (2008) breaks down a game into four main elements, which he describes according to their visibility to the player (see Figure 2). The most visible element is the *aesthetics* of a game. This includes aspects such as the interface, the sounds, and the game atmosphere. Less visible, but still tangible for the player are the *game mechanics*, which describe the goal and rules of the game, and the *game story*. Barely visible for the players is the *technology*, which Schell describes as the *"medium in which the aesthetics take place"*. To design a game, all four elements are important and must be designed in line with each other.

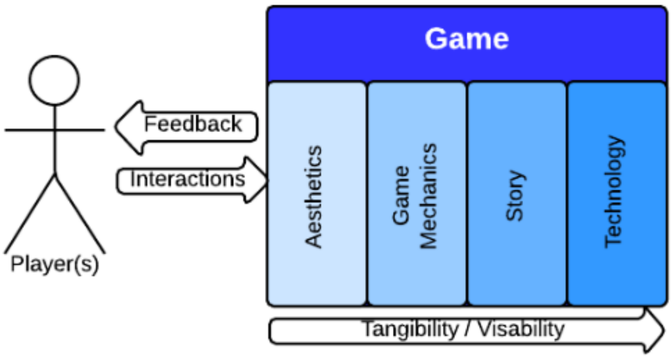


**Fig. 2.** Schell (2008) describes the four main game elements. Moving away from the player, their visibility and tangibility drops. The player communicates with these elements through interaction and system feedback.

### Gamification Strategies

Gamification uses different game design elements that are characteristic to games (Deterding et al., 2009). Gamification frameworks focus on game components which are considered as fun and ignore concepts which are based on Schell's story element (see Figure 2). Zichermann and Cunningham (2011) refer to the game design framework MDA (Mechanics, Dynamics, and Aesthetics) as a basis for gamification strategies:

1. Game Mechanics are used as single atoms. Typical elements for gamification include points, levels, leaderboards, badges, onboarding strategies, challenges and quests, social engagement, and customization (see below).
2. Dynamics represent the player interactions with the mechanics.
3. Aesthetics involve the feelings of the players towards the application.

To apply these strategies to applications, these elements can either be implemented from scratch or an existing framework can be used. Many services already provide instant gamification frameworks such as badgeville, which provides mechanics such as badges and reward programs to simplify the gamification process (Zichermann and Cunningham, 2011).

### Game Mechanics in more detail

Since game mechanics are discussed by most game design authors, and since it is also a crucial part of understanding gamification strategies, we should take a closer look at this concept. Instead of describing single atoms of game mechanics Schell (2008) introduces six main categories of game mechanics: (1) the space where the game takes place; (2) objects, attributes, and states which are in the space; (3) actions as an operative or resultant of the player; (4) rules to define the relationships between space, objects, and actions; (5) skill of the player; (6) chance to make game outcomes uncertain. It is crucial for the game experience that all mechanics are in balance. More advanced mechanics include interactive story elements or puzzles. Puzzles should be easy to use, should reward the skills of the player and should have meaningful consequences in the main game (Brathwaite and Schreibe, 2009).

Zichermann and Cunningham (2011) describe game mechanics as a "series of tools that, when used correctly, promise to yield a meaningful response" (p.36). In the context of gamification the authors especially refer to elements such as scoring elements (e.g. points), progress elements (e.g. levels, progress bar), competitive elements (e.g. leaderboards, high scores), onboarding strategies (to help users learning the games and acquiring new skills), badges (to support user pleasure such as when collecting items and signaling status, or as a surprise element), small activities with a clear goal (e.g. challenges, mission, and quests), or social engagement.

## 3. Gamification of Simulations and Simulation Games

In this section we want to enrich the educational simulations with game design elements, and therefore introduce a separation between gamified educational simulations and educational simulation games. Whereas educational simulation games describe, similar to serious games, fully-fledged games, gamified educational simulations are designed with game elements. Often the differentiation however, is not easy, and the boundaries can be blurred (Deterding et al., 2011).

### 3.1. Towards a Definition

Many educational simulation games were designed from scratch as a game to enhance the understanding and motivation of students while learning concepts such as physical laws. Supercharged, for example, is a 3D simulation game developed by game researchers together with a MIT physicist that enables players to control a ship by altering its charge (Squire et al., 2004). Designing an educational simulation game with pedagogical aims does not only require an elaborate game design process, but also needs experienced pedagogues and domain experts (Laurel, B., 2008). Educational simulations, however, can serve as an excellent basis for designing games or gamifying them without the need to rival commercial entertainment games (Squire et al., 2004). Their interactive character can make the integration of playful activities and game mechanics easier. Several simulation games are based on specific game mechanics such as puzzle elements and motivate the user to solve a problem with the simulation. While a gamified simulation mainly uses game elements such as reward systems and points to enrich the simulation, the simulation game often changes the purpose of the single task to create entire game scenarios and a game environment, and include different game-specific activities (game play). A well-designed simulation game is a valuable educational resource but has drawbacks, such as the need of an elaborate design which leads to high design and implementation costs. A gamified simulation can overcome those issues to some extend as long as it does not miss out the fun and engaging aspects, by simply adding high scores, points, and badges without taking the design into account (Koster, 2004).


**Fig. 3.** While simulation games include game activities and story elements, in gamified simulations game mechanic atoms are applied to simulations

*Gamified simulations* use the original simulation as a basis and enrich it with different game elements (such as progress bars, points, and challenges) without the need for an elaborate game design. Figure 3 illustrates the coherence of game elements and game activities (such as core mechanics, game rules, game goal, and

game type) in the simulation type. The differences between a gamified simulation and a fully-fledged simulation game can be blurry. A gamified simulation can still have some game activities, such as solving puzzles, but it mainly applies the game design elements to the simulation to make the single tasks more engaging.
*Simulation games* tend to have a more playful character and can be more engaging than gamified simulations. However, due to the modification of the purpose of the simulation, game-based implementation such as simulation games tend to privilege engagement over accuracy and completeness of content (Van Eck, 2006).

Another way to differentiate between simulation games and gamified simulations is by referring to Schell's (2008) main game design elements which include mechanics and a story. While gamified simulations use the original simulation and enrich it with game mechanics, a simulation game also needs additional design aspects such as a story with elements such as goals, obstacles, and conflicts.

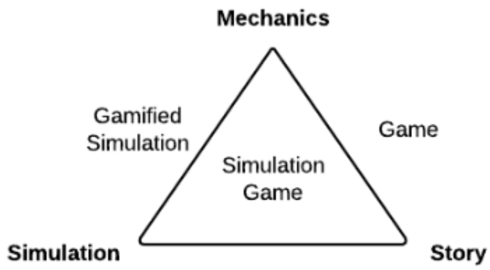


**Fig. 4.** While simulation games include the aspects of the simulation, game mechanics, and a story, in gamified simulations game mechanics are simply applied to simulations

In the next section, different game design and gamification strategies are outlined and discussed based on successful examples to find a common basis for design heuristics suitable for educational simulations.

## *3.2 Educational Simulation Games*

Several authors have described different educational simulation games. In this section we will introduce selected games and analyze their main concepts. Following this, we will discuss existing guidelines for the design of simulation games with a focus on instructional aspects.

### Analyzing Successful Examples

***Supercharged!*** is an educational simulation game developed in consultation with a MIT physicist which challenges players to use electromagnetic forces to

navigate a ship through a maze. The gameplay is structured in the two phases of planning and playing, and consists of several levels. In the planning phase, the players can place a limited set of charges to set a navigation path for the ship. In the play phase the player can change the charges to change the direction of the ship. In a study with students, Squire et al (2004) found out that playing the game "enabled some students to confront their conceptions of electrostatics, as they played through levels that contradicted their understandings" (p. 518). However, many students had problems memorizing different physical concepts and terminology which was introduced in cut scenes, which were skipped by many students (Squire et al, 2004).
***PhET*** provides several freely available online simulation games for learning physics. Most of the simulations use a similar user interface with drag and drop mechanics (Adams et al., 2008). PhET simulations remind the player of real world objects and familiar setups, thereby enhancing understanding. Instead of traditional simulations, PhET uses a comic-like representation to visualize objects and setups. Students are free to explore the environment and start the animations and interactivities. Most of the simulations involve small puzzles with clues to help students to understand the concepts (Adams, W.K., Perkins, K.K., and Wieman, C.E., 2006).

#### Educational Simulation Game Design

Several authors describe design guidelines for creating educational simulation games. PhET simulations, for example, follow design guidelines for creating new simulations that were based on a user study with over 200 students (Adams et al., 2008). In this look and feel guide, the authors describe important aspects for successfully creating educational simulations which focus on imparting conceptual knowledge. These guidelines focus on applying an attractive layout, encouraging exploration, and including intuitive controls, representational aspects and help items (Adams, W.K., Perkins, K.K., and Wieman, C.E., 2006). The simulation design process is based on a cyclic principle, which starts by setting learning goals. In the next steps the design gets iteratively enhanced after student interviews. After achieving the final desired design, the simulation can be used and evaluated in classroom scenarios (PhET Simulation Design Process, 2013).

### *3.3 Educational Gamified Simulations*

Recently developed "citizen-science" games such as Foldit became famous for their ability to not only educate people about scientific phenomena, but also to help researchers to develop new scientifically valid theories or models. Even though the main purpose of these gamified simulations is not to educate, but rather to encourage involvement in the scientific process, it is still necessary to apply educational strategies to impart basic knowledge to the players, so that they are able to play and advance. In the next sections we will introduce some of these gamified science simulations and analyze their design according to the mechanics and strategies discussed in the previous section.

## Analyzing Successful Examples

***Foldit*** is a multiplayer application, which has successfully gamified a real-world problem in the form of a simulation game. It uses the power of "human intuition and three-dimensional pattern-matching skills to solve challenging scientific problems" (Khatib et al., 2011). The main mission is the creation of complex buildings. Foldit is designed as a puzzle game with points and ranks. It uses typical game elements, such as rankings, scores and progress bars. To learn the game mechanics, Foldit uses a typical onboarding strategy, where users learn about the gameplay and the single elements via small missions. It uses ranking information, points, and progress bars as integrated game mechanics.
***EteRNA*** is a project developed by Stanford and Carnegie Mellon that enables the playful design of RNAs. With the slogan "played by humans, scored by nature" EteRNA tries to highlight its realism. It is an online game, where users manipulate nucleotides to decipher real RNA problems (Wired, 2012).
Similar to Foldit, EteRNA uses a puzzle-based game strategy to attract players. The users learn about RNA during the first tutorials which are used as onboarding and which introduce new game elements. The game uses social engagement strategies such as a live chat. The gamification mechanics can be summarized as onboarding, missions, points, leaderboard information, social engagement and progress feedback.
***Phylio*** is a science game which allows the comparison of genomes of different species. It is designed to solve the Multiple Sequence Alignment problem (Kawrykow et al, 2012). Similar to the previous science games, Phylio is based on a puzzle game design. It uses tutorials to teach both the initial content and constant instructional content during the first missions. Leaderboard information and points provide the player with constant feedback about their status, and players receive new "talents" when solving new puzzles.

## Educational Gamified Simulation Design

While many authors have described how to design educational simulations, educational games, or educational simulation games, only a few have provided guidelines on how to gamify an existing simulation or educational simulation (Ibrahim & Jaafar, 2009; Teed, 2012). An exception is the gamified simulation design process described by Becker and Parker (2011). The authors suggest six steps. First, the needs are analyzed. The second phase is the research and preparation phase, to identify observable elements, and gather data. In the third phase, elements such as the interface, gameplay, game mechanics, or the structure are designed and evaluated. Step four and five involve the production of the conceptual model, and the programming phase to create the operational model. Finally, the process ends with the testing phase. A model showing how to use existing simulations to create gamified educational simulations, however, is still missing.

## *3.4 Analyzing Design Characteristics of Gamified Simulations*

Educational gamified simulations and educational simulation games share one important common issue: They require not only players and game developers, but also scientific and pedagogical experts for the design process (Cooper et al., 2010). In the previous section we introduced some gamified simulations with a scientific background. Most of these exemplary games applied gamification and game design strategies based on genres with problem-solving characteristics such as puzzle game elements to challenge individuals with a scientific background to accomplish higher goals. To teach the required learning content they usually use small tutorials followed by a small quest which forces the player to apply the new knowledge. After that, the users earn points, achievements, and/or badges as feedback on their learning and mastery progress. An important feature of gamified science applications such as Foldit is the meaningful context. Players do not only have fun, they also learn, and in some of the examples they can even solve real world problems. Another important element found in these science games is the freedom to explore and experiment. These games support both collaborative plays, where players can exchange tips via an online chat, and competitive plays, triggered through leaderboard information.

Based on the observations stated above, game design, and gamification mechanics, the following selection of important and frequently used game elements found in educational science games (either simulation games or gamified simulation) can be summarized as follows:

- Instructional Missions (Onboarding): Players should be strongly encouraged to do instructional missions with an onboarding and explanatory character. Players are likely to skip or ignore cut scenes, so important learning content shouldn't be placed there, and players should instead learn the content during small missions.
- Interactive Challenges: Constant missions and challenges with an interactive character should engage users to ensure that they continue to play. Missions can get harder, but they have a clear objective and the rules do not change.
- Puzzle Character: Challenges and missions can be designed as a puzzle mechanism, which challenges players to solve different small activities with a clear goal.

- Collaborative Challenges: Working together on problems and solving riddles together can help players to understand the phenomena in more detail.
- Competitive Challenges: Leaderboard information, rankings, points, and versus games support competitive play.
- Feedback: Feedback types such as points, achievements, and badges give players valuable feedback on their current skill level. Also, players are more likely to repeat levels with a lower score and can recap and reinforce what they have learned.

## 4 Design Principles for Educational Gamified Simulations

When designing a simulation with game elements it is important to integrate the game design elements and scenarios without losing sight of the pedagogical goal. There are three different strategies that can be used to create a simulation with game mechanics. (1) Design the gamification simulation from scratch, (2) build a separate gamification framework around the existing simulation, and (3) integrate game elements into the existing simulation. In each of these situations it is crucial that the gameplay strategy supports the learning objectives to make the game an interesting and fun experience for the player (Kelly et al., 2007).

### *4.1 Design Elements*

We can identify three major design elements for educational gamified simulations based on the observations in the previous section.

- Interactivity: This includes elements and activities which challenge players to actively interact with the simulation. This includes instructional missions, interactive challenges, and puzzle missions.
- Feedback: Feedback elements are triggered by user behavior and interactions with the simulations. They should help the user to find the correct solution or to get information about their performance.
- Game Participants: This indicates how many players are involved in the game activities. The gamified simulations can be designed either for single player, competitive, or collaborative activities.

Figure 5 demonstrates the relationship between the interactive behavior and feedback possibilities of simulations and gamification mechanics (which are demonstrated as a selection of game design elements). The number of potential players can influence the gamification strategy by allowing for advanced feedback information in the form of leaderboards and high scores, and by allowing missions to be designed that involve group assignments, either in a collaborative or a competitive way.

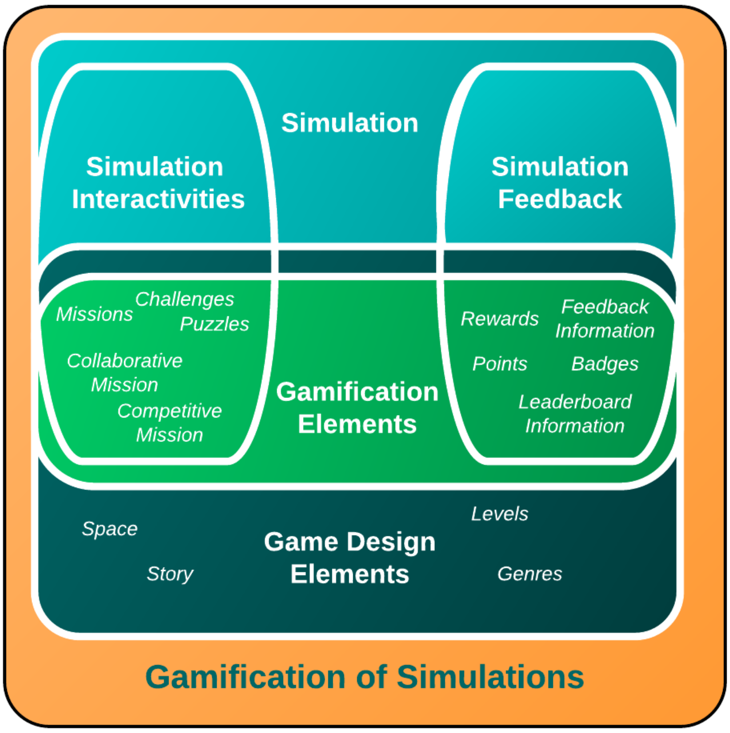


**Fig. 5.** Overview of the interactive and feedback elements used to gamify simulations

### *4.2 Design Process*

Based on these assumptions, we can define five major steps for the design process (see Figure 6). First, the pedagogical goal is outlined and defined. Second, the interaction possibilities within the simulation are defined. Third, potential cooperative and collaborative strategies are specified. Fourth, feedback possibilities of the simulation and missions are identified and linked to feedback types such as points, badges, or similar. In the last step the challenges are designed and linked to the feedback systems.

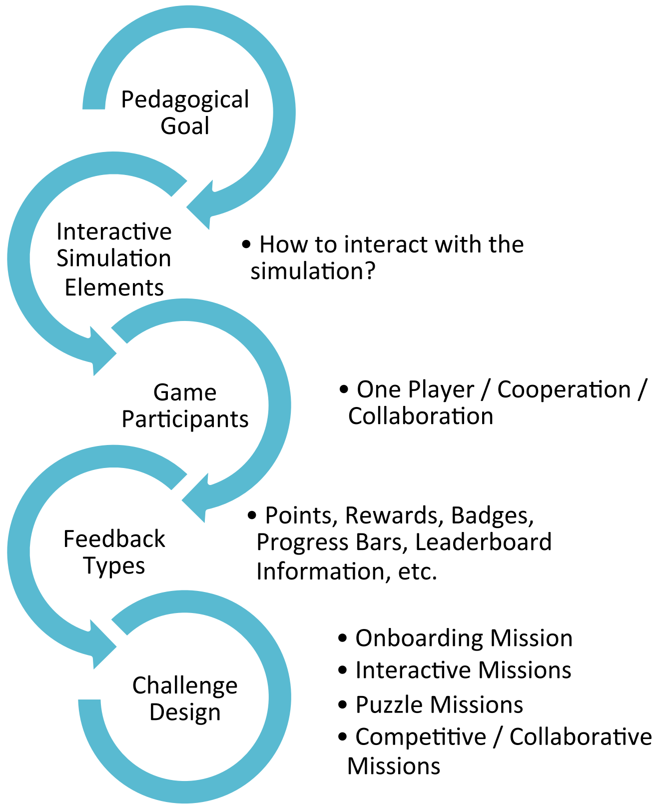


**Fig. 6.** Major steps used to gamify an educational simulation

In the next section we will discuss how to apply the gamification elements and the gamification process in the three different strategies of gamification.

## *4.3 Gamification Strategies*

We already defined the three possible strategies for gamifying educational simulations. It is possible to either start from scratch with the simulation design and apply gamification strategies to it at this stage, or to gamify an existing simulation. Here we can also differentiate between two strategies: In the first case, gamification mechanics and elements are directly integrated into the simulations. The second possibility is to integrate the simulation into an existing gamification framework or other tools or applications which support gamification strategies. In this paper we are especially interested in the process of adapting existing simulations and will describe the last two strategies in more detail. However, many of the processes and elements described above can still be applied to simulations which should be already designed in a gameful way. A simulation can be redesigned more gamefully without changing, redeveloping and redesigning it by adding more (i) interactive challenges, and (ii) a feedback system.

**Integrate game elements into the existing simulation**

Interactivities and feedback elements are directly connected to the simulation framework and can communicate with each other. This enables direct and immediate feedback which is an important aspect of learning success. To use this method, the simulation must feature an interface to directly communicate with the gamification framework, or must be adaptable to be directly capable of being integrated.

***Interactive Challenges.*** Interactivities and according events can be directly linked to the simulation behavior. Missions or challenges, but also advanced interactivities with the simulation can be added directly to the simulation.

***Feedback System.*** Feedback information and behavior corrections can be automatically triggered by simulation events. This enables direct and immediate feedback for an improved learning experience.

Usually this integration requires programming knowledge, which reduces the ability of instructors to easily adapt the single elements, add additional content, or gamify a simulation without support.

**Build a gamification framework around the existing simulation**

Issues such as adding missing simulation interactivities or missing interfaces to the simulation, or additional requirements, such as simple extensibility and adaptability require the designers to use other tools to support gamification mechanics. This requires a separate stand-alone tool for the gamification ideas. These tools should be manageable by the instructor.

***Interactive Challenges.*** Even though a simulation does not provide the possibility of arranging playful interactivities with players, the instructor can still prepare different interactivities such as word problems, which force the students to interact with or observe the simulation.

***Feedback System.*** Interactive challenges can be linked to an external pointing system. Based on this information, different gamification elements, such as rewards, leaderboard information, or badges can be applied.

These arrangements can be applied to different learning environments and are not limited to instant gamification platforms, online, or e-learning tools. The challenges and feedback information can be calculated automatically by tools such an e-learning system but can also be provided personally in-class by the instructors.
An advantage is the adaptability that is also possible for instructors without programming knowledge. However, the system does not provide immediate feedback on simulation activities. The user behavior within the simulation cannot be observed and assessed or corrected using feedback. This strategy is suitable for simulations which offer limited interaction possibilities with the user.

## 5 Case Study – Gamified TEALsim

One example of our own research is based on the simulation framework TEALsim. It is a java-based open-source framework for creating physical simulations in the area of electromagnetism and was developed at the Center for Educational Computing Initiatives at the Massachusetts Institute of Technology (TEALsim Website, 2014). TEALsim allows users to create new simulations (Figure 7, left shows a simulation of Faraday's Law) or simulations games (Figure 8 shows a pin ball based game with charges)

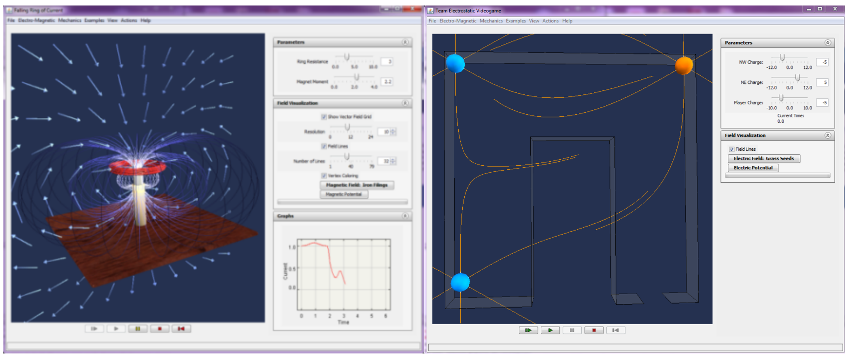

**Fig. 7.** Left: a simulation of Faraday's law. Right: A simulation game based on pin ball

In the next section we discuss the application of the gamification strategies with the related elements and the process on one selected simulation of the TEALsim framework.

### Integrate game elements into the existing simulation

To add interactivities and related feedback methods, a TEALsim simulation demonstrating Faraday's Law was used, which allows user input in the form of moving the magnet. Figure 8 shows the original simulation.

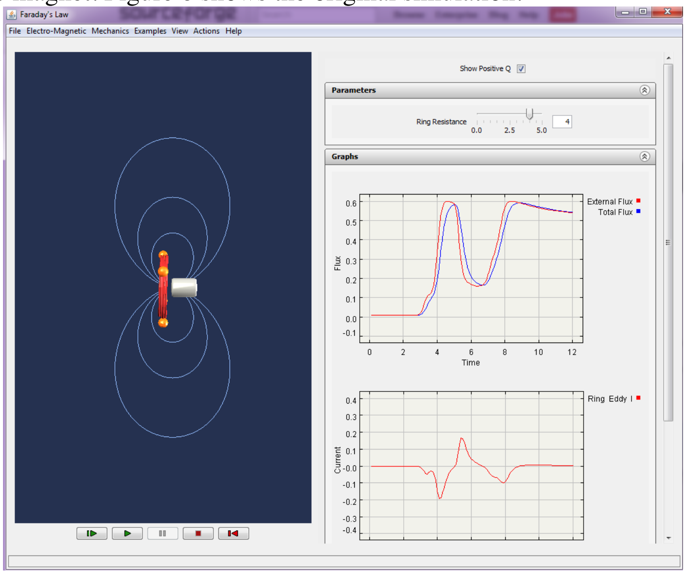


**Fig. 8.** Original TEALsim simulation of Faraday's Law

Based on the gamification process model the single steps of the gamification process (see Figure 6) are outlined:

1. Defining a pedagogical goal: The student should learn the first principles of Faraday's Law and should learn about current and flux in this context.
2. Identifying interactive simulation elements: The user can move the magnet or the coil and change the resistance of the ring. Over time the simulation delivers information about flux and current as output on the graphs.
3. Game participants: The gamified simulation will be designed for one person challenges. However, the interactions and possible missions would support both collaborative and competitive challenges.
4. Feedback types: The simulation is a rather small one, and its pedagogical goals are also accomplished in a short time. Only progress information and notification about finished challenges are integrated.
5. Challenge design: One small onboarding mission to familiarize the user with the possibilities of interaction. Other missions include small quizzes which require the user to work with the graphs and the ring resistance settings.

Figure 9 shows the advanced Faraday's Law simulations which integrated a player progress module on the upper right, which informs the user about his progress and communicates new challenges and missions.

This small simulation could be one of many in a series of simulations demonstrating and teaching Faraday's Law. Further feedback types such as badges could be used to reward the user after they have successfully completed the task.

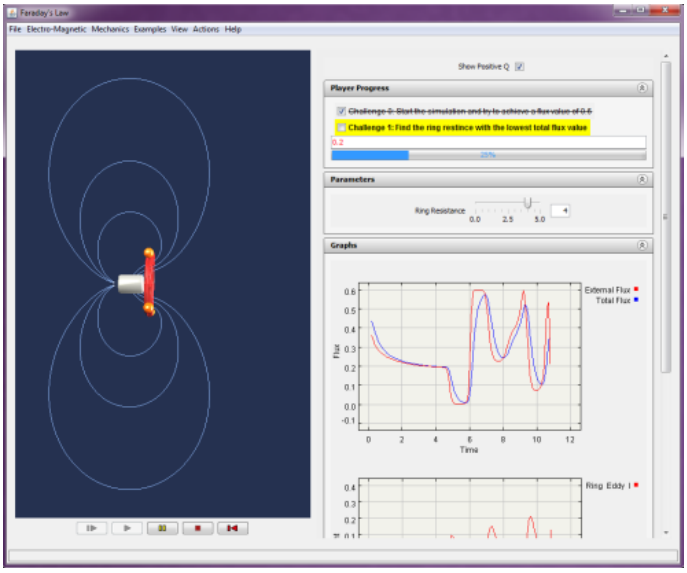


**Fig. 9.** TEALsim simulation with integrated player interaction behavior

### Build a gamification framework around the existing simulation

The concepts stated above can also be used to gamify simulations without adapting the original code, or using an interface for the simulation. Direct interactions are not possible but the missions can be integrated into an online system such as the learning management system Moodle, which supports progress representations, points, and also reward systems such as badges.

## 6 Conclusions

Most pedagogical experts and game designers agree with the statement that games have high potential for teaching new concepts and can make learning fun. Koster (2004) even states that *"with games, learning is the drug"*. Based on the example of very successful gamified scientific simulations such as FoldIt, we have learned that gamification strategies can be a good way to adapt scientific simulations and processes to make them more motivating and engaging, and to attract larger user groups.

When developing a gamified simulation it is important to focus on the interactive aspects in order to attract the user's attention. In contrast to traditional simulations, it is not only the user who should interact with the simulation. Instead it is equally crucial that the simulation motivates the user through constant interaction and feedback possibilities.

Many frameworks support the embellishment of different applications with gamification strategies. However, especially in educational scenarios it is important to avoid losing the focus on the main educational objectives and to create game mechanics such as missions, which are both fun and educational.

In this chapter we have discussed the single elements that are important when creating educational simulations which are both fun and of pedagogical value. Furthermore, we have described a step-by-step process for combining these elements to create simulations without losing sight of the pedagogical goal. This model was particularly designed for science simulations and is strongly dependent on the interactive elements of the simulation. However, the model can also be applied to other areas if a clear pedagogical goal exists and if there is the possibility of interacting with the application.

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