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Gamification in factory management education – a case study with Lego Mindstorms

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Abstract

Research oriented teaching in universities provides opportunities to support the student's desire to explore. A student's learning success can benefit from gamified project work, especially when students face self-guided learning processes in demanding educational activities. Gamification is defined as the use of game elements in a non-game context. Games offer the chance to improve the motivation of students, support group work, train communication skills and introduce the capacity for experimenting in safe environments. Therefore the learning effect of prospective engineers can be increased through the integration of Gamification into educational activities. This leads to higher student participation in university courses and encourages the development of the student's social, personal and technical competences. In this paper a game concept for teaching in universities is introduced focusing on the impartment of the state of the art on manufacturing for value creation, e.g. production planning and control. The concept covers a level based storyline with rules and goals using physical artefacts of Lego Mindstorms. Due to the modular characteristic of Lego, which supports creativity by having a high number of possible combinations, a "free playing space" for students is established. In groups, the students work in a highly problem oriented way, e.g. finding cost savings for their factory due to a changing market condition. Feedback in the sense of the success of student's strategies is given directly through the designed Lego model and its functionality.

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1. Introduction

The growth of prosperity and increase of product consumption goes along with increasing resource consumption and global ecological impact. The people in emerging countries strive towards the western life style. Without technological innovation development at this rate will exceed every responsible economic, environmental and social limit. New awareness of the importance of innovations in manufacturing technology and management is fundamental to a global economic development considering the conservation of natural resources and creation of social justice. In order to facilitate sustainable development, stakeholders in society need to understand economic, ecological and sociological connections and implications [1]. This is a tremendous mediation task, which demands increased learning and teaching productivity. New methods and tools for mediation need to be developed. A research approach taken at TU Berlin is creating "objects, both tangible and intangible, which automatically demonstrate their functionality to the learner. They consist of aspects of cognitive stimulation and emotional association with new and existing ICT [Information and Communication Technology] and design approaches for productive mediation. They allow a reproducible, widely available, language independent and qualification based approach". Such artifacts are called "Learnstruments" and are researched within the Collaborative Research Centre 1026 (CRC 1026) [2] at TU Berlin. [3] [4]

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Gamification facilitates learning due to increased attention spans and fun during the interaction and learning process. Game elements are crucial elements of "Learnstruments", as described in the social perspective of sustainability, because they provide many technical options for language independence and for adequate game challenges based on skill levels. If the technique of Gamification also addresses the economical and environmental perspective of sustainability by its application, then it is best suited to impart and build up an understanding for the reasonably demanded sustainability on our globe.

Social competence, demonstrated by the necessary collaboration of students in order to reach the game goal, technical competence, demonstrated by dealing with technical content, methodic competence, which is necessary in order to structure the work to reach to game goal and personnel competence through individual actions can be acquired through the application of Gamification.

The concept and elements of "Gamification" are presented through the example of gamified project work including physical "Lego Mindstorms" models at TU Berlin. Lego Mindstorms is a building system of Lego where robots, consisting of sensors, actuators and programmable logics can be created [5]. Within the scope of the project work, they are used to design and build an automated Lego car factory in order to experiment with different configurations of it, e.g. line vs. job shop production. Students should be enabled to acquire knowledge autonomously and apply it in group work.

2. Concept of games

Deterding, a Gamification expert, introduced in 2011 a classification where he divided different game and play concepts according to four criteria: Playing vs. Gaming, Whole vs. Parts. Playing vs. Gaming mainly differentiates concepts according to whether there is a serious purpose behind it (Gaming) or the main goal is to amuse the users without a serious intention (Playing). Whole means to consider a game as closed system in which the game or play concept itself stands in the center of users perception, whereas Parts implies that elements which create fun are used in order to be applied in another context. [6]

Because the authors are focusing on the mediation of technical content in universities, a serious background is given. So it is not focused on Playing any longer.

2.1. Serious games

Abt, a well-known games and simulation expert, defined "Serious games" as games with an "explicit and carefully thought-out educational purpose" [7]. They "are not intended to be played primarily for amusement. This does not mean that serious games are not, or should not be, entertaining". Not necessarily such a game has to be designed digitally. [8]

Serious games and simulation have a broad application through different areas of life, e.g. healthcare, public policy, education, training and simulation [9]. A classified database on existing Serious games can be found in the internet: serious.gameclassification.com [10].

Serious games can be divided according the platform where they are played on [11]: Popular applications of *Virtual Serious Games* are often represented in mobile applications (apps) and video games. One example for this is the game "Remission 2". It is designed for children with cancer in order to make them aware about their illness and the effects of the treatment. *Physical Simulators* need associated hardware. Examples of this are professional flight simulators for pilot training or train simulators with the purpose of practicing a train driver's behavior in response to unexpected events. *Alternate Reality Games* (ARGs) are designed to tap into the power of collective problem solving through powerful stories and participatory mechanisms; aspects of reality in the form of text messages, phone calls, instant messages and real world meetings are incorporated in an extended mechanism of digital gaming [12]. The concept of *augmented reality* is one sub-concept among ARGs.

2.2. Gamification

The word Gamification was first used in 2003 in order to describe the work of the computer game designer Pelling, first documented in a blog post by Terrill [13] [14]. Also the concept of using Games in relation with serious contexts is not new. Recently researchers proved that the motivation of people applying the concept are more motivated compared to people who do not. [15] [16] [17].

The most acknowledged definition of Gamification was evolved in 2011 by Deterding et.al: "Gamification is the use of game design elements in non-game contexts". [6]

2.3. Non-Linear Story Telling

Non-linear storytelling (NLS) enables players to take meaningful decisions. This is the basis to increase the motivation for users of Serious games and Gamification.

A first approach allowing gamers to make decisions in a non-playing field environment was created by the video game designer Crowther. He developed a role playing game, a Multi User Dungeon (MUD), where several people interact on a text based level. By writing, players connected by internet were enabled to make decisions in real time. In 1979 Edward Packard published the book "The Cave of Time" where he applied the concept of NLS. The reader is asked during reading to take decisions; e.g. if you want to take the left branch, turn to page 20, if you take the right one, turn to page 61. Nowadays interactive movies have been developed. E.g. cinema viewers are enabled to communicate with the protagonist while watching a film. Using automated audio recognition software, the protagonist acts according to the decision of the audience member. An example therefore can be seen in [18].

2.4. Psychology behind games

The basic principle behind games is to create motivation by fun, which leads to happiness [19]. Fun however is a feeling that every human being feels individually. Many scientific theories try to explain, why and how the motivation

of people works. Well known psychological approaches like Maslow's hierarchy of need, the ERG (Existence, Relatedness and Growth)-theory of Alderfer, the Goal-setting-theory of Locke and Latham, the Flow-theory of Csikszentmihalyi, the Balance-theory of Adams and the Self-determination theory of Deci and Ryan are examples of this [20].

Especially for game contexts, Radoff published 42 so called FUNdamentals [21]. The concept is about how fun is created; one of them is e.g. "Competition": People enjoy the sense of accomplishment that comes from winning. But, not necessarily every FUNdamental creates motivation to every character.

Reiss developed a list of 16 basic human motivators [22]. The listed motivators capture what individuals are striving for and what is really important to them. One example of his motivators is status. People, motivated by status aim to identify themselves with a high social standing; this is expressed by e.g. the clothes they wear. People with a weak basic desire for status e.g. respect other people regardless of background or status symbols [23].

In order to enhance fun during game play, Lazzaro suggested in 2004, based on a field study, four keys to more emotion [24]:

- Hard Fun: emotions from meaningful challenges, strategies and puzzles; players want to test their skills and want to feel accomplishment,
- Easy Fun: grab attention with ambiguity, incompleteness and detail; players want to fill attention with something new,
- Altered States: generate emotion with perception, thought, behavior and other people; players want to move from one mental state to another or think or feel different,
- The People Factor: create opportunities for player competition, cooperation, performance and spectacle; players want to see games as mechanisms for social interaction.

It can be distinguished between two basic kinds of motivation: intrinsic and extrinsic. Intrinsic motivation is defined as "doing of an activity for its inherent satisfactions" whereas the extrinsic one refers to an activity that is done "in order to attain some separable outcome" [25]. When designing gamified experiences it is recommended by Rodrigo to not apply external incentive like rewards or points because it will hinder the intrinsic motivation for skilling the inner energetic power of the activity [26].

As a guide to help individuals find paths to flourishing in the sense of happiness, Seligman developed the so called PERMA-Model [27]. PERMA stands for Positive emotions, Engagement, Relationships, Meaning, and Achievement. By strengthening each of PERMA's areas, it should result in helping individuals find lives of happiness, fulfillment and meaning.

2.5. Potential of Games in the context of university teaching

For the time being, it is widely appreciated that games offer the chance to improve the motivation of students, support group work, train communication skills and give opportunities for experimenting in safe environments. Through the integration of game or game elements, the learning effect of students can be increased. The high number of existing Serious Games is a good indicator for this [10].

Studies were performed where game elements were included into university courses [15] [16]. Points and levels served for displaying progress and providing feedback. Leaderboards, challenges and badges were used as game mechanics in order to create autonomy for the students. Hereby the authors indicate, that the lecture attendance (the considered course provided optional attendance), number of downloads of lecture slides and the number of posts on the course's forums increased. The students participated more, they were more proactive in the forums (students replied five times more to other posts and initiated about eight times more threads) and paid more attention to the lectures' slides which indicates a deeper engagement. Students' feedback showed a higher motivation and interest than comparable classes; the participation and performance of the students increased. Furthermore the authors stated that grade differences between students seemed to decrease.

Coller and Shernoff published in 2009 a preliminary study where they measured the student engagement after redesigning an undergraduate mechanical engineering curriculum [17]. Hereby all assignments and learning experiences were built around a video/computer game in the sense that students got in charge of programming a computer program in order to race a simulated car around a track. The author's conclusion is that students experience higher intellectual intensity. When working with the developed video game the participating students reported greater levels of challenges and concentration on the one hand, and enjoyment and interest on the other. Students felt active and interested, possibly because goals were clear and feedback about performance was immediate.

2.6. Gap

Multiple definitions for Gamification are available, Deterding established the most accepted one due to a wide literature research and logic argumentations. In order to create gamified experiences for higher education, further instantiations of such concepts are necessary for being able to estimate the success of them. Reise et al. discovered that Serious Games for the areas of factory management and resource efficiency are available. However, no Gamification applications for these fields have been developed yet [28]. In order to fill the gap of gamified experiences for factory management education and to provide further examples for the scientific community to pursue in the development of a best practice strategy, this paper provides a Gamification concept with physical Lego Mindstorms models for deepen specific aspects of a teaching course "factory management" for engineering students.

3. Factory management game design

Manrique, a Gamification assistant professor, proposes seven steps to design gamified experiences [29], which are briefly explained afterwards:

- Step 1: Love: If the creators of a game do not love it, the game will surely fail.
- Step 2: Elaborate strategy and get ready: get the game design team ready, gain some knowledge about essential documents and think of the client's main problem.
- Step 3: Visualize the Why, What and Who: The main thing in this step is to understand the target players and which way the gamified experience should affect the users.
- Step 4: Explore a new world: Creating a small draft of the theme and story of the gamification experience. It is a big mistake to define the whole story in detail before designing the game mechanics.
- Step 5: Level up the mechanics: Take the decision of which game mechanics should be used for the gamified application (e.g. levels, gifts, avatars, teams, quests and many more).
- Step 6: Upgrade the graphics: in order to create an eye-catching, experience, it is recommended to create a good looking interface for the gamified experience.
- Step 7: Repeated play tests: Considered as the most difficult part of the game design process, testing is mandatory.

3.1. Step 2: Elaborate strategy and get ready

Provided step 1 is successfully fulfilled, the game strategy can be elaborated. A game design team consisting of students and lecturers is chosen because they know best about what they like and dislike in factory management courses. Due to their different experiences by participating in different courses of study, technical competence is provided. The essential documents that have to be taken into consideration are on one hand professor's handouts of the accompanying lecture, on the other the study and examination regulations of the respective education institution; in this case of the TU Berlin.

3.2. Step 3: Visualize the Why, What and Who

The students are defined as the clients of the game as they are supposed to play the game in the end. Teachers assist as supervisors and advisors during gaming. The focus is set on undergraduate students because the failure rate in the courses for undergraduates in factory management is higher compared to the graduate ones. According to the User Types of Marczewski [30], the afterwards described characters of students are expected for participation. Students who participate in lectures because they are motivated by relatedness (so called Socializers) is possible, e.g. they want to meet their friends during class and interact about the possible tasks of the exam. They are grouped as intrinsic motivated so called "Socializers". Also the intrinsic motivated "Free Spirits" are a possible client group; e.g. students who want to explore new technical stuff where they are interested in. They are joining the lecture because they want to gain knowledge. "Achievers", also intrinsically motivated, are those who want to learn new things and improve themselves. They are motivated to learn more and more. From the extrinsic motivated point of view, "Players" who want to get a reward (e.g. grade) and feedback are expected. This is probably the most obvious reason why students participate because of the external, and from their point of view attractive, incentives. Nevertheless the game design has to also be prepared for the extrinsic motivated "Disruptors" participation. They are students who could have fun when disrupting the game or users.

The client's problem which should be solved is determined by the fact that students often are bored while learning technical stuff in engineering lectures. The time spent by the students engaging themselves with the content of lectures should be increased in order to raise the learning success of them. This goal should be solved by increasing the motivation through gamification.

3.3. Step 4: Explore a new world

Three rough story alternatives were developed. The first one is about the analysis and improvement of production processes using the improvement tool Define – Measure – Analyze – Improve - Control (DMAIC) [31]. Secondly, the product life cycle is taken into consideration beginning with the product development over the market introduction, growth, maturity, saturation to the recycling of the product. [32]. The third possible topic identified is about the history of production, regarded from handicraft in the middle ages over the industrialization, rationalization until the digitalization.

In order to make a decision of which storyline suits best for being applied in the gamified experience, the project team compared the lecture contents with the three rough ideas explained earlier. To ensure that during game play students can take meaningful decisions in the sense of which topic of the lecture they want to deepen, the ideas were compared by help of a value benefit analysis on how many topics of the lecture they are able to cover. The general topic of history of the production was selected to be the storyline of the gamified experience; hereby 44 sub-topics could individually be picked up by the students in order to deepen them.

3.4. Step 5: Level up the mechanics

The game design team decided to use a competitive form of experience for the main part of the game. The decision was taken because the design team was convinced that a competitive experience would engage them more than the cooperative one. Nevertheless, in order to give students in the beginning of the game - until they understood the game mechanics - the feeling of helping them and not being alone, the game is designed to be collaborative in the first stage. Students solve the first challenge together, after this they play in teams against each other. Main actions in game mechanics are "avoid, match, destroy, create, manage, move, random, select, shoot and write" [33]. For a storyline about the history of production, the design group assessed that the mechanisms avoid, match, create, manage, move, random and select are very suitable for a level based game, where students have to overcome new challenges during gameplay. Furthermore it was decided to integrate Lego Mindstorms into the game work due to the highly flexible pattern based on the

modularity, fast reconfigurability and the game-play character. Cognitive science proved that active participation of students in learning situations is more effective than forms of teaching which are only based on reflective learning [34]. In order to create an attractive game, rewards are essential, especially for the extrinsically motivated people. The challenge is to design the game in a way that the intrinsic motivated people participating are not getting hindered due to external incentives. So it seems to be a good decision to give students credit points for their participation because the whole study structure of Germany is justified on getting points according to the European Credit Transfer System (ECTS). The evaluation of student's performance basically depends on the quality of documentation and presentation which are created by them during gaming.

3.5. Step 6: Upgrade the graphics

Regarding the visual representation, the game design team decided on using Microsoft Power Point based slides, where the storyline is written out. An example for this can be seen in Figure 1.

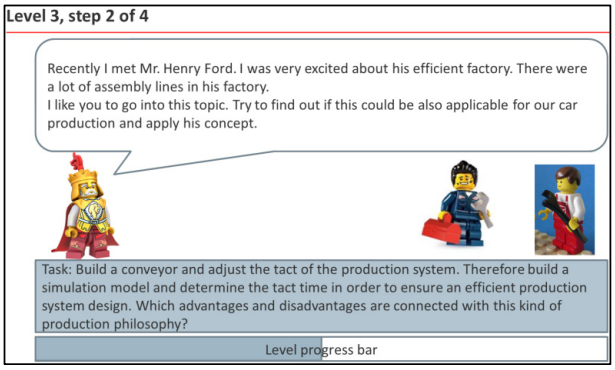

Fig 1: Example for the current graphical interface

3.6. Step 7: Playtest, playtest, playtest

Currently, the game is in the development phase. A small scaled playtest was performed up until now by the game designers. Nevertheless they reported having fun.

4. Implementation

During the semester, a standard lecture is given to the students, introducing the basics and state of the art of factory management. Additionally the game, including seminars, should be offered for interested students. The sequence of levels and seminars can be seen in Figure 2. The interval of seminars at the beginning is closer compared to the rest of the game in order to mediate technical basics about Lego Mindstorms EV3. Due to an increase in challenge throughout the semester, students then get more time to work on those challenges. The game ends with a final presentation.

During level 1 each student is supposed to manually build a car of not more than 20 single parts according to the design for assembly (DFA) principle. After agreeing in groups for one type, an assembly network plan has to be created and an investment proposal for automated assembly has to be worked on. During the seminar the topics DFA and assembly process planning are conducted.

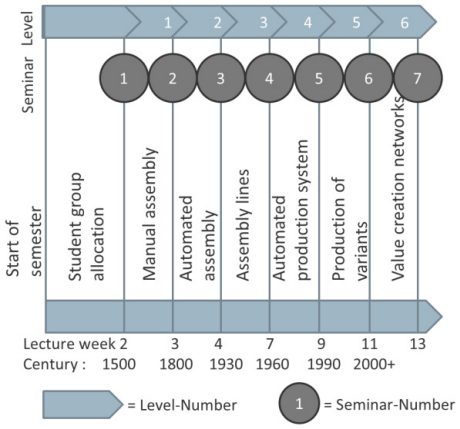

Fig 2: Project plan for seminar and game

At the beginning of level 2 students have to present their investment decision based on technical and economic considerations and build one assembly machine to replace one of the manual assembly steps. Restrictions according to the storylines decade like the non-availability of sensors have to be taken into consideration. The validation of the investment proposal and the construction of the Lego assembly machine are mediated in this level.

Level 3 is focusing on methods of management and the analysis of assembly processes according to Methods-Time Measurement. The reduction of the process times of the hybrid manual and automated assembly is the focus. Furthermore a production line should be built to raise the level of automation due to the progress of the assembly technology over time (see Figure 1). The mediation of manufacturing organization (e.g. line production, job shop production) and production planning and control (e.g. job release) are also focused on.

During level 4, students have to take occupational safety in their factory into consideration (e.g. dead man's switch). Furthermore, improvements of the efficiency of the factory are necessary due to changing market conditions.

In level 5, car variants (e.g. color of car or size) are introduced to the students. In order to be able to produce them, a rearrangement of the production is necessary (e.g. increasing numbers of parts delivered to the final assembly line leads to space limitations). Procurement strategies like Just-in-Time have to be taken into consideration by the students. Also the change of the production method from push to pull is a possible action students can take.

The last level 6 is about cooperation. The globalization requires according to the storyline that student groups collaborate in a kind of a "global classroom network". Hereby the students compare their production figures and agree based on them which group keeps the focus on which production process. The appropriate lecture content therefore is about collaboration / cooperation. Technologic and economic

leadership of each group have to be determined. Negotiations with other groups should lead to contracts about e.g. outsourcing.

4. Summary and outlook

This paper presents an approach for the implementation of Gamification in universities which focuses on the mediation of the state of the art on manufacturing for value creation. Lego Mindstorms are used to create a gamified experience. The storyline is based on the history of production. By playing the conceptual game, a "free playing space" for students is established based on a high number of possible combinations of Lego pieces, e.g. different machine tools with different functionalities. This helps to create a high degree of motivation and deepen students understanding of production engineering.

Games motivate people to learn in an environment defined by aims, rules and rewards. Interaction involves objects, which give the learner feedback and create uncertainty. Games create cognitive stimulation and emotional association. Game settings can be reproducible, widely available, language independent and qualification based. Therefore they fulfill main criteria for Learnstruments, which are defined as "objects, both tangible and intangible, which automatically demonstrate their functionality to the learner" [3], and have a major intersection with it. Gamification as a tool-set for increasing people's motivation in learning situations can be applied to Learnstruments, who will gain additional functional value by game elements. Thus Gamification has the potential to increase the learning and teaching productivity.

Further research has to be conducted towards the creation of a stabile gaming environment. Further development of the user interface from Power Point to a web interface or mobile application is necessary in order to obtain a more attractive visualization. In addition, it is intended that a development towards international gamified teaching experiences is made.

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