# Co-design of a Game to Support Increased Manufacturing Insight and Interest among Teenagers and Young Adults

Poul Kyvsgaard Hansen[1], Manuel Oliveira[2], Joao Costa[3]

[1] Department of Mechanical and Manufacturing Design, Aalborg University
Fibigerstraede 16, 9220 Aalborg, Denmark
kyvs@production.aau.dk
[2] SINTEF, Strindvegen 4, 7034 Trondheim, Norway
manuel.oliviera@sintef.no
[3] HighSkillz, Lisbon, Portugal
joao.costa@highskillz.com

**Abstract.** This paper is focusing on the specific development of a serious game to support manufacturing insight and interest among teenagers and young adults. To achieve the necessary motivation and engagement, a co-design approach has been chosen, involving students, teachers, and industrial companies. This dynamic design process involved the different stakeholders from inception of the idea to actual use and evaluation. The first versions of the game were developed as a board game to allow for the most flexible adoption of new ideas or even re-orientation of the original ideas. However, the goal is to develop an online digital version that can be played simultaneously but flexible among a number of educational institutions.

## 1 Introduction

In recent years, despite the global economic crisis, manufacturing is facing serious difficulties in the recruitment of the brightest high-skilled human resources. National and international institutions have provided important guidelines to combat these skills mismatch and several innovations have been made both in STEM and manufacturing education. However, there is still a lack of concrete strategies harmonizing delivery mechanisms and pedagogical frameworks throughout the whole student lifecycle, from primary to tertiary education. Today's students are raised in an online environment where games and videos are essential parts of their communication culture. The traditional textbook approach of organizing and communicating knowledge is highly challenged by these distinctive cultural changes.

An ongoing EU Project – ManuSkills [1] – is addressing these challenges with the aim of studying the use of enhanced ICT-based technologies and training methodologies to facilitate an increase of young talent interest in manufacturing and to support their training of new manufacturing skills. The project is experimenting with a wide range of innovative delivery mechanisms such as serious games, simulation, mixed reality and teaching factories, supported by the use of social media augmented by gamification. ManuSkills is addressing all three stages of the young talent pipeline (i.e. children, teenagers, young adults), where in the early stages the focus is on raising the awareness of manufacturing education thus making it more attractive to young talent. In the later stages of the young talent pipeline, the focus is on facilitating transformative deep learning of individuals, with reduced time-to-competence.

The ManuSkills project has incorporated six specific experiments. One of these experiments, Lego Exploratorium, has been focusing on co-designing approaches that involve the three most important stakeholders in the process of designing and launching new ICT-based educational resources to support awareness, interest and application of manufacturing knowledge in teaching institutions. The most important stakeholders are: the students, the teachers, and the industrial companies. All of these stakeholders have to be involved and motivated, and to sustain motivated to continue their engagement.

The cognitive domain of manufacturing can be seen as a number of resources (machines, processes, people, materials, information, and finances) that are brought together in order to produce some kind of physical product. If combined right the collection of resources can produce in the right quality, the right amount, and at the right price. The combination of the resources is a combined technical and organizational task. Essentially, the output is determined by the decisions taken by the people involved in the specific manufacturing setup. These decisions should take into consideration both what is the immediate task and what might be the task of the future. Also the general technical development will impact the decisions. New machines or changes in the portfolio of resources might change the competitive setup. The customers might also behave different than anticipated. This can be due to new and better product from competitors or a general change in the preferences of the customers.

The traditional pedagogical approach of manufacturing education has been to teach the various disciplines individually. However, the individual disciplines have specialized deeper and deeper, and this has led to challenges in teaching the integration of the disciplines. Integration of disciplines is essentially what happens in the real life of industrial companies. In order to bring these experiences more explicitly into teaching, a co-design approach involving industrial companies was chosen. The ManuSkills approach taken is based on living labs where the co-design is embedded in a process that lasts from idea inception to deployment.

The current version of the specific game supported educational framework was initiated September 2013 and the focus of this paper has been on the first 18 months of development and application.

## 2 Methodology

The adopted methodology has been inspired by the “Living Lab” approach, which according to the European Network of Living Labs (Enroll) “is a real-life test and experimentation environment where users and producers co-create innovations” [2].

The four main activities that characterize the Living Lab approach are:

1. Co-Creation: co-design by users and producers
2. Exploration: discovering emerging usages, behaviors and market opportunities
3. Experimentation: implementing live scenarios within communities of users
4. Evaluation: assessment of concepts, products and services according to socio-ergonomic, socio-cognitive and socio-economic criteria

Initially, the adopted co-design approach involved the two stakeholder groups of teachers and industrial companies. The purpose was to define the learning scope to be addressed by the Lego Exploratorium, thus identification of specific manufacturing cases was carried out along with clear links to the relevant theoretical disciplines of manufacturing engineering.

After the overall scope being defined, the subsequent workshops, involving mainly teachers and students, focused modernizing education through the adoption of game-based learning in the form of a serious game (Lego Exploratorium). At the start, the co-design activities were more exploratory in nature, resulting in open-ended themes, topics and measures. However, as the themes and content of the serious game became more focused the workshop topics got more focused.

Each round of workshops has led to an updated version of a serious game supplemented by various ICT based materials. The workshop activities were documented as written summaries, which were complemented by interviews with some of the participants (both teachers and students).

Interleaved with the co-design workshops has been formative assessment of the use of the serious game within different educational settings. The students exposed to the Lego Exploratorium have been high school students, vocational students, and university students. These assessment activities have been documented by observations, interviews, and followed up by questionnaires to the students. In particular, the questionnaires were designed to capture interest, awareness, usability, enjoyment and knowledge. All the questionnaires that we used were pre-manufactured and their validity and reliability was tested in previous projects by their designers [3].

## 3 Co-design in an Educational Context

The traditional conception of value creation assumes that value is created inside the firm and that consumers are separated from the value creating process [3]. The critical interaction with the consumer is the moment of exchange. In today's markets the consumers are informed, connected, empowered, and they are increasingly learning that they can extract value beyond the traditional point of exchange [5]. Consumers are now subjecting the industry's value creation process to scrutiny, analysis, and evaluation [6]. In comparison, the value creation process in an educational setting has been seen as the teacher being the instrument by which knowledge is communicated. Students played a passive role as recipients and the traditional approach also insisted that students were taught the same materials at the same time.

The traditional approach to teaching has been surprisingly persistent though it has for a long time been questioned and considered an extremely inefficient use of students' and teachers' time [7]. An important aspect is that most of the existing teaching materials are still in the form of textbooks.

Teachers within the manufacturing field have traditionally had a mechanical engineering background. Many of the teachers have had some practical experiences from working in industry. Today the teachers need to qualify to tenure positions largely based on their research qualifications. Consequently, the teachers develop a higher degree of specialization, and fewer teachers have practical industrial experience.

The relevant topics in manufacturing have changed and expanded. Besides the traditional mechanical engineering topics the new areas are automation, digitalization, logistics, ecology, supply chain management, and many others. The higher degree of specialization among teachers has led to challenges in regards to the integration of the disciplines. This is further reinforced by the general lack of practical industrial experiences among the teachers.

The rapid technological development makes it difficult to keep the textbooks updated with the most recent technologies

## 4 Co-designing the LEGO Exploratorium

Initially three types of workshops were defined: 1) Workshops with teachers of different manufacturing disciplines, 2) Workshops with teachers and industrial companies, and, 3) Workshops with students from various studies.

The first workshops were guided by the two open-ended questions:

- What characterizes good teaching within the broad discipline of manufacturing?
- What are the barriers and enablers in providing good teaching within the broad discipline of manufacturing?

The first round of workshops led to the following main findings:

- Both students and teachers are highly motivated by real life, realistic, and updated cases (that they can relate to). Current textbooks rarely support this.
- Both teachers and students experience a lack of cross-disciplinary and integrative understanding of manufacturing.
- Currently there are substantial investments in e-learning platforms at educational institutions. The platforms are improving rapidly in terms of performance.
- There is a rich potential in video material and informative web pages publicly available. Both students and teachers valuate good video material. However, it is difficult and time consuming to get an overview and to verify good quality.
- There is only limited experience sharing between various manufacturing disciplines and between different educational institutions. Therefore, each individual teacher often has to develop his or her own real-life cases.

- Companies are willing to deliver updated content but find the requests from the educational institutions unfocused and uncoordinated.
- Students are highly motivated by elements of gamification in teaching

### 4.1 Initial Game Preparation

Initially, the workshops with teachers from various disciplines (mechanical process technology, logistics, automation, IT, supply chain management and production economics) led to little progress. Participants found the workshops interesting but felt difficulties in collaborating in the integration areas. Teachers brought cases that would highlight the focus of their particular discipline. These cases were illustrative when applied within one particular discipline, but were generally not suitable to illustrate examples of integration.

A breakthrough came when it was proposed to reframe the discussion and focus on very simple products. This led to the idea of focusing on a simple LEGO minifigure (see figure 1). The various disciplines provided proposals for how they could contribute to enlighten the many challenges that are associated with planning and developing a production of such a simple product.

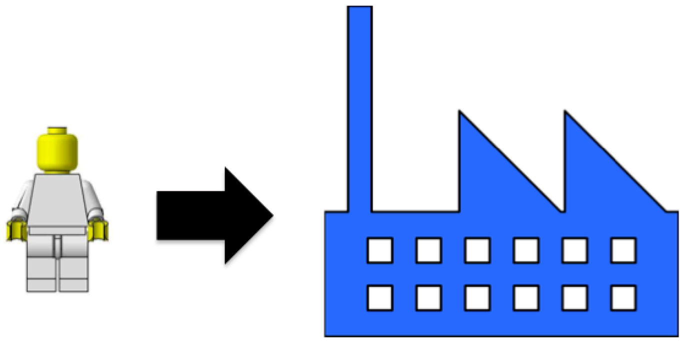

**Fig. 1.** Illustration of the simple problem that led to the basic idea behind the game "LEGO Exploratorium".

The formative assessment with students proved that the simple initiating problems developed into complex problems after a few rounds of increasingly more advanced challenges, and, furthermore, that teachers from the various disciplines felt it easy to scale from the simple challenges (for example simple moulding technology) to more advanced challenges associated with their particular disciplines (for example advanced simulation of moulding processes). The shared simple starting point became the integrating element.

The fast scaling from simple to complex challenges is often defined as "flow". This is the case when improved skills among participants are carefully synchronized with increasingly challenging tasks [8]. Pine and Gilmore refer to the task of engaging the participants as “staging” a user involvement. They emphasize that staging experiences is not a question about entertaining users; it is primarily about engaging them [9].

The co-design activities with industrial companies had generated commitment from the companies to deliver updated technical information about materials, machines, and supporting equipment. In parallel, a group of teachers with different background had identified and reviewed publicly available web-based video materials. The information from the industrial companies and the video materials were integrated in an application that was made available to the students via the specific e-learning platform of the particular educational institution.

The pre-test was done with only four students. In order to develop and test the initial game ideas four additional tests were planned. A total of 206 students with different educational background was schedule to test various versions of game setups derived from the pre-test activities.

### 4.2 Initial Game Assessment

The initial game assessment targeted different types of students and the duration of the game test varied according to their availability and the specific context where the game was introduced. Table 1 highlights the characteristics of both the students and the duration of the gaming period. The tests were conducted during September and October 2014.

**Table 1.** The four groups of students participating in the game test.

| Group No. | Level of Students | Educational Focus | Duration |
|---|---|---|---|
| 1 | 130 Undergraduate Students | Innovation and Logistics Engineering | 5 x 2 hours |
| 2 | 30 Undergraduate Students | Manufacturing Engineering | 3 x 2 hours |
| 3 | 30 Vocational School Students | Technical Integration | 4 hours |
| 4 | 16 High School Students | Technical High School | 4 hours |

Each test group was given a short introduction to the plastic injection moulding process. This was supported by the reviewed video material and made available on e-learning platforms at the different institutions. In each case the person in charge was the teacher of the course where the game was to be integrated. The teacher had in each case introduced the idea behind the experiment to their classes and assigned preparation tasks to the groups. This would typically involve studying the video materials in order to understand the manufacturing processes associated with producing the LEGO minifigures. The clarification of the role of the teacher was essential since this led to new co-designed options, further development, and most importantly, a foundation for a strong local ownership.

In order to apply the newly gained plastic injection moulding knowledge the groups were given the same challenges. The following describes the test with group 3 and group 4. These tests were limited to 4 hours.

The larger groups were divided in smaller teams of 2-3 persons and asked to establish a production of 250,000 white LEGO minifigures (the minifigures were not supposed to be assembled). Their first assignment to the teams was to report when they would be able to deliver the order. In the assignment they were limited by having only one plastic injection-moulding machine, one mold per part of the minifigure (head, upper body, arm, hand, hip, leg), and a 64 $m^2$ production facility (8 by 8 meter).

After half an hour the students reported that they could deliver at a given date. During the assignment they had clarified practical problems related to change of molds, change of colors, safety rules of the production, working hours per week, etc.

With the newly gained knowledge they were presented with the next challenge: Scale the production to a yearly capacity of 10,000,000 minifigures. In this task they were supported by LEGO bricks in order to prototype their factory layout (see figure 2). The production task was also expanded to include decoration of both heads and upper bodies of the minifigures. During this task the students faced a number of critical choices in regards to deciding on the number of machines and the number of molds. This led some of the teams to formulate an initial manufacturing strategy for their production.

The last 90 minutes of the 4 hours were devoted to simple game sessions based on the factory layout developed by each of the small teams of 2-3 persons. Their production plans were challenged by "customer" requests for different orders. In response to each "customer" request they needed to re-schedule their production in order to comply with the delivery dates requested by the "customer". The planning and scheduling process were supported by a simple Excel Spreadsheet program that had been developed by one of the teachers as a part of the co-design activities. Most of the teams came up with proposals of how to improve the program and some of the teams did implement some of the improvements as a part of the continuing class activities after the game test.

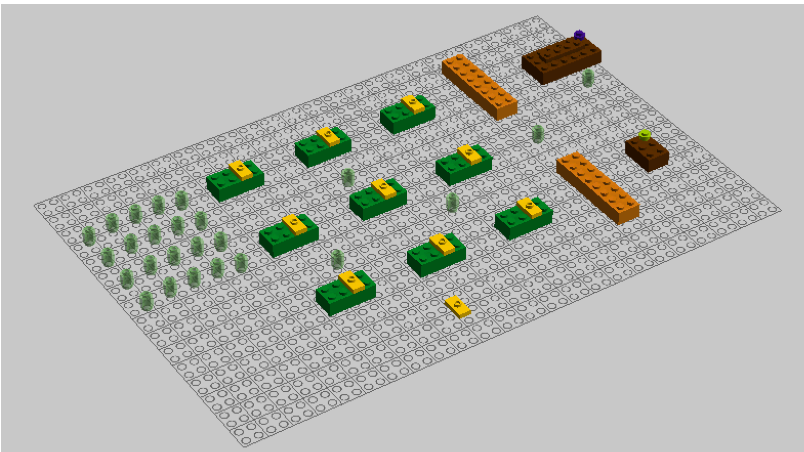

**Fig. 2.** A LEGO model of a production layout with a capacity of 10,000,000 minifigures per year.

The feedback from the groups 3 and 4 (cf. Table 1) was focusing on three aspects. First, the impact on the students' insight and potential interest in manufacturing.

Second, the students' experience of utilizing video and gamification more intensively. Third, ideas from the students in regard to potential improvements of current the game setup.

The feedback was generally very positive. Group 4 (High School Students) had only limited insight and interest in manufacturing before the test. They experienced the integration of the videos and the game setup to be the most important benefit. Regarding the game setup they had a large number of potential improvements and provided examples from existing commercial games that could inspire for the further development.

Group 3 (Vocational Students) were positive in line with group 4. They specifically pointed out that they got a new insight into how technical improvements (process specifications, technical setup, technological developments, etc.) influenced the flexibility and efficiency of the manufacturing setups.

Both groups emphasized that a financial dimension of the game setup would improve both the game aspect and the insight aspect. This feedback was brought forward to the ongoing tests in Group 1 and Group 2.

### 4.3 Further testing with Group 1 and Group 2

The test of Group 1 and Group 2 (both Undergraduate Students) had begun in parallel with Group 3 and Group 4. However, the two first groups had assigned more time with the game, and, more importantly, they were schedule to have two-hour sessions with the game on a weekly basis respectively for five and three weeks.

Group 1 and 2 had the same introductory challenges as Group 3 and 4. However, due to the feedback from Group 3 and 4 a financial dimension of the game was added. This was done in a co-design activity between the involved teachers, the industrial companies, and a production economy specialist. The companies provided updated cost information and the production economy specialist co-designed a financial dimension with focus on two perspectives: 1) the investments in the manufacturing setup, and, 2) the estimated cost price of the produced minifigures.

The fact that Group 1 and 2 had a full week between the game rounds meant that the challenges given to them could be rather extensive. The larger groups were divided in smaller teams of 5-6 persons and the competition between the smaller teams were made much more explicit. A LEGO enthusiast among the students proposed that the production orders should be based on LEGO's collectable series of minifigures [10]. This proposal was incorporated between round 2 and round 3 and it led to a huge variety of the potential production orders. In total the LEGO collectable series comprises 256 very different variants of the minifigure.

The feedback from Group 1 and 2 was very positive. One of the teams made this comment: "It has been nothing less than fantastic. Teaching is varied with the switch between teaching and gaming. But especially the videos help to gain an insight into what it really is about. Then the game side comes in and do things exiting, because you can only understand things by trying them".

## 5 Reflections

The evidence in literature demonstrate that game-based learning will gain widespread use within the near future [11]. However, the development of the games to support the game-based learning approach is not yet delivering according to the needs and expectations of the educational institutions [12]. One important explanation is the fact that the development of commercial games for leisure purposes and serious games for educational purposes need different development processes and different business models [12].

As a response to the need for new and different development processes this paper has been focusing on applying a co-design approach that actively involve students, teachers, and industrial companies in a dynamic development of a serious game.

The co-design activity is defined as a continuous involvement from users (students) and producers (teachers and industrial companies). The involvement results in an intermediate setup that is tested with students and subsequently the reaction and active proposals is fed back to the producers. The process is then repeated [2].

The experiences have shown that the co-design approach has facilitated the creation of strong local ownerships. Initially, 206 students in various institutions tested the game setup. In the late fall 2014 and the spring 2015 additionally 5 groups of students (in total 154 students) have tested and co-design the game setup. The local ownership has led to very different game setups that have supported the specific local learning objectives. The evaluations of the game tests have been followed by questionnaires that are focusing on interest, awareness, usability, enjoyment and knowledge [3]. In every case there have been made a pre-test and a post-test.

The initial results show that the weaker students (based on the knowledge component in the questionnaire) raise the level of interest and awareness. The stronger students (based on the knowledge component in the questionnaire) lower their interest and awareness. The following interviews have documented that the stronger students feel that the game is moving too slow to retain interest. However, due to the co-design approach they also have specific suggestions on how to improve the pace and the challenges of the game. These suggestions are continuously implemented in the game.

The focus in the first period of the game development has been solely on the game content and the challenges in relation hereto. Less focus has been devoted to the learning analytics. However, in the fall 2015 a digital version of the game will be launched. The digital version will improve dramatically the gamification element since the backend server can keep track of timing and performance of the participating student teams. Through the co-design effort by the students the crucial gamification element has been identified as the financial element of the game. Every follow up interview of the students has emphasized the importance of the financial aspect. In short, the students report that without the financial aspect there is no game. The critical feedback is though that the financial aspect has to be tied closely to the technical aspects (cost of machines, degree of automation, dynamics of the market) and that the financial and technical aspects have to mirror real life conditions. This is seen as the most important benefit of the synchronized co-design involvement of industrial companies, teachers and students. The game is seen as the mediator of this complicated dialogue.

The digital version will also support the integration of the needed learning analytics and thereby provide a better research setup.

The online version will be developed in a new co-design process that will involved 400+ students and 10+ teachers from various educational institutions. The first online version will launched September 2015 but it is expected that this version will still be co-design to include new options and new supporting tools.

# 6 Conclusion

The paper describes a co-design approach to game development. The co-design has proven to be suitable because it invites for participation and local ownership. Though the initial results have been positive there are still a number of challenges in order realize a full-scale serious game. Among the most important challenges are the inclusion of learning analytics and the final decisions on the business model that can support a continuing development of the game.

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