AN EXPERIENCE-BASED APPROACH TO TEACHING PRODUCT DESIGN

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ABSTRACT
This paper presents a new experienced-based approach to teaching product design. The goal is to address specific issues that are difficult to teach to students effectively in a purely theoretical setting, as students need to have experienced in some way the behaviours involved in managing a product design process. The backbone of the approach is a design game that allows students to experience themselves some of the most important challenges in product design. Later during the course, the concepts of product design are taught by always referring to the specific part of the game in which that aspect was relevant.

Keywords: Experienced-based learning, Product design process, Product development process

1 INTRODUCTION

Product Design has become a standard Operations Management (OM) course in engineering, industrial design and business master programs all over the world. The course is often based on formal and well-accepted design literature (e.g. Ulrich & Eppinger [1], Pahl & Beitz [2]). Its main goal is to teach students how the design process is structured in different phases, which design tools can best be used during each phase and, finally, how human, material and time resources are organized such that the entire design process is accomplished successfully. Although the contents of such courses are neither difficult nor complex, it remains a challenge to have students understanding the concepts taught and its importance for their professional future.

In our specific case, we have provided this course for the Mechanical Engineering master program at the University of Twente for the past 5 years using as teaching method regular lectures with several case study descriptions. However, the course evaluations done by students have repeatedly shown a common problem: students perceive the course as vague and do not think its contents will be of much added value as professionals. By further analyzing this issue in panel discussions with students, it was determined that the most likely cause of this is the fact that students' experience in product design is limited to designing simple products in groups not larger than 8 people, which is one of the learning goals of our bachelor program. Therefore, as the nature of the course is rather organizational than technical, students have difficulty in empathizing with the challenges this course addresses.

With this background, in this paper we present a new experienced-based approach to teaching product design. Such an approach has been a common practice for around half a century in OM education. In fact, OM education literature reports a variety of games [3] that range from the simple 'tabletop' game [4], to the more complex system simulation Beer game [5], up to the more interactive environments such as a 'training factory' [6]. Several reasons lie behind such a massive utilization of games in OM. One is that games address specific issues that are difficult to teach to students effectively in a purely theoretical setting as students need to have experienced in some way the behaviours involved in managing a production system. This is particularly important when the course represents one student's first exposure to OM practice. For students with more experience in OM practice, games serve as confrontation mechanisms that can make them aware of their limitations by allowing them to experience the challenges a given course deals with. Doing so also aids the instructors in having students understand the mapping between challenges, learning objectives and the themes covered in the course.

This paper is largely motivated by the practical experience the authors have in teaching design subjects to students with technical backgrounds. The rationale of the approach is that students need to experience the challenges of product design in real organizations in order to be able to learn approaches for solving them. The backbone of the approach is a design game that allows students to experience themselves some of the most important challenges in product development. Later during the course, the concepts of product development are taught by always referring to the specific part of the game in which that aspect was dealt with by them. The paper is further organized in 3 more sections. Section 2 presents the characteristics of the course, the results of a panel discussion of previous course evaluations, and proposes a new teaching method based on a Product Design simulation game. Section 3 describes the details of the game as it was applied for the first time in our course. Finally, Section 4 presents the conclusions and recommendations.

2 THE PRODUCT DESIGN COURSE

The course Product Design supports the students in becoming a design engineer or design engineering manager. The course teaches design theory and methodology, covering amongst others the design process by Ulrich & Eppinger [1] and Pahl & Beitz [2], the FBS method [7], the usage of Design Process Units [8], specific design tools (e.g. Quality Function Deployment, Product Data Management, and Failure Mode and Effect Analysis), and it observes of the complete design process from customer needs to production planning and ramp-up. Functions central to product development projects, such as marketing, design and manufacturing, are studied. Several models of integral design are treated and compared. Furthermore, different aspects of the product life cycle are involved, for instance functional performances and makeability.

2.1 Former course structure

The course has been taught in former years using a combination of lectures based on several chapters of the book of Ulrich & Eppinger [1] and asking students to make small exercises based on most of the treated chapters. As a consequence, the structure of the lectures followed the structure of the book discussing the design process from planning to production ramp-up. The course taught a total of 18 themes, over a total of 28 lectures of 45 min. each.

2.2 Students evaluation and analysis

The course was evaluated using a qualitative research method combined with open questions, to allow students to indicate their personal and anonymous perception of the course. A fragment of summary presented by the student's evaluation board –the official body in charge of organizing student's course evaluations– reads as follows [9]:

> *"During the course a lot of different models and tools are presented, but the tools are not all applied within the course. Therefore students experience little depth which is expected based on other own experiences with other master courses. A side effect of this is that student's experience that they learned a lot of stuff they still know nothing about. They know of the existence of the models and tools, but not when to use them or how to use them. To gain this insight more experience with the models and tools is needed. The goal of exercises was not really clear to a large group of students. A number of students mentioned that they would prefer fewer exercises with more depth. Students also mention they would like to apply tools more on the design of a real product instead of analyzing existing products. The name of the course indicated the focus would be more on the design of a new product.…"*

After analyzing this summary and the results of the qualitative research study [9], the main conclusion that was drawn was that students do clearly not perceive the goal of the subject. Rather than designing one product, the subject's goal is to teach how to organize the process of designing any product and determining which tools and organizational forms are available for doing so.

2.3 New course structure

Given the previously described issues, the teaching method of this subject was reformulated. The goal was to develop new didactics that would enhance how the contents are conveyed to the students. Therefore, only the teaching methods were modified, and not the contents. The new subject structure makes use of two types of teaching methods:

1. An experience game: a new Product Development Process (PDP) game was designed to reinforce learning of the organizational aspects of the PDP. The goal of the designed game is to have students experience a chaotic PDP.
2. Instruction lectures: lectures that combine teaching theory with practical workshops in which

students have to apply the newly learned contents to solve a given problem. The instruction lectures refer to those parts of the game the learning material is aimed at and the exercises are about organizing the design process of one same product.

This paper aims at describing the experience game.

3 THE PRODUCT DESIGN GAME

The game was developed following the education design game framework proposed in [10]. This model, shown in Figure 1, addresses that educational games should include:

1. An input set consisting of a description of the role of the players, the role of the game's umpire, and the eventual devices and hardware required to do the game.
2. A process description describing the initial conditions, the phases and the rules of the game.
3. An output set describing the expected results of the problem solving task regarded in the game and the expected insights to be learned by the game players.

The following subsections refer to the most important parts of this structure to describe the game. Some issues are omitted because of space constrains.

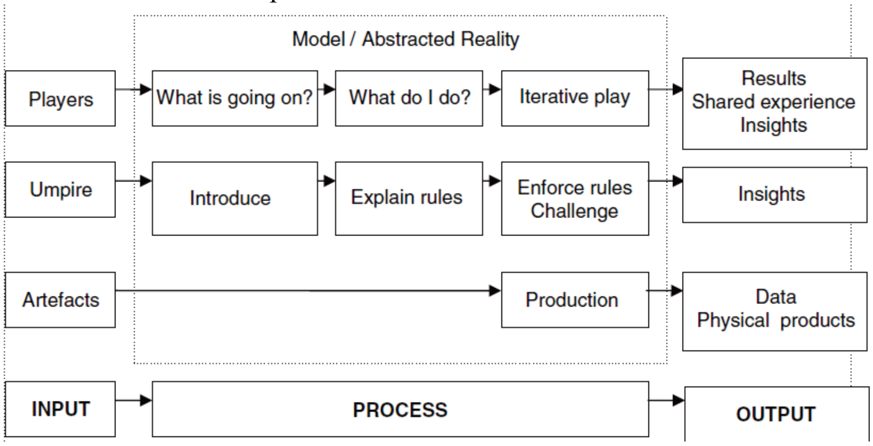

Figure 1. Framework for development learning games in Operations Management [10]

3.1 Learning Objectives

The learning objectives of this game are twofold. On the one hand, it seeks to enable students in undergoing a complex ideation process, experiencing the differences in exploring a problem space and a solution space, and understand the differences of undergoing a convergence and a divergence process in a large team. On the other hand, it strives for having students experience the chaos and stress of a real-life complex product design process by confronting them with issues as fixed decision gates and working in light and heavy weight organization structures.

3.2 General description

The new product design game we have developed consists of simulating different aspects of a complex PDP. For its first implementation, and considering the students have a background on mechanical engineering and mechatronics, the game simulates the PDP of a mechatronic anti-earth quake system for skyscrapers in seismic areas. The game assumes that there is one company developing such systems and that the company has 4 projects that have to be developed concurrently. Each project deals with one anti-earthquake system for a given building in one of four cities in different places around the world, namely, Delhi, Manila, San Francisco and Tokyo. During the game, students have to work in teams to produce one concept design for each city. As the game progresses, students experience how is it like to work with different types of team configurations (as heavy-weight, light-weight and functional teams), to do convergent and divergent design, and to undergo synthesis and analysis processes.

3.3 Initial condition

The initial condition of this game is given to each student team in the form of a design brief. The design brief provides a small technical description of one building, its geographic location and the expected earthquake damping ratio the system should achieve. The four buildings provided for this game are existing building in Delhi (Civic Center), Manila (Roxas Boulevard), San Francisco

(Transamerica Pyramid) and Tokyo (Sunshine 60). Therefore, students can use internet to search for relevant information about those building if they deem required. Another initial condition of the game is the level of awareness students have on its learning objectives as they are not told that one of the goals is to have them experience a chaotic situation with tight deadlines.

Students were also provided with a document template indicating the information they had to submit by the end of the game. The template required students to have the follow information:

- Short summary of proposed system, indicating the main characteristics of the system.
- Sketch of the solution indicating the configuration of the solution principle in relation to the building.
- Description of the main Key Performance Indicators (KPIs) of their solution proposal: installation cost, operations costs, detail design time, installation and manufacturing time of system, reliability measure.

3.4 Team configuration

The game was designed for 40 students. Four teams of 10 students each were defined. Each member of each team got two types of roles assigned. The first type of role varied between being in charge of *setting up requirements* or being in charge of *proposing concept solutions*. The second type of role made distinctions between departments the players belonged to. Table 1 describes the 5 departments considered in the game and the specifications of the roles attributed to them. In conclusion, each team dealing with one city had two students assigned to each department, initially one being in charge of setting up requirements and the other one in charge of proposing concept solutions.

Table 1. Roles of the game

Automation department	Determine the configuration of the mechatronic system. Determine sensors (#, types and positions), actuators and control.
Mechanics department	Design the mechanisms in charge of damping the building movements. Determine the dynamics and kinematics characteristics of the designed system.
Construction department	Determine the dynamics and kinematics characteristics of the building. Determine the technical characteristics of the installation of the system in the building.
Manufacturing logistics department	Determine the logistics for making the systems and installing in on location.
Project management department	In charge of project milestone evaluation. Steer the PDP process. Enable communication between departments. Document partial solutions. Calculate KPIs: installation cost, operational cost, detailed design time, building time, reliability.

3.5 Rounds and rules

The game is structured in four rounds, each one corresponding to one phase of the product design process. Each round deals with a different sub-problem solving task and uses different gaming rules. Furthermore, time schedules were kept tight within their limits. In fact, the game time count down was projected on the white board. The phases have been organized such that the divergence and convergence design activities occurred cyclically.

3.5.1 Round 1, planning

For this round the students were divided into two groups of twenty each. One group gathered all students with the role type *setting-up requirements*, and the other gathered all students with the role type *proposing concept solutions*. Therefore, each group had students belonging to all departments and to all four cities. The requirements group was assigned the task of determining requirements of such a mechatronic system (the problem space exploration), while the concept proposal group was assigned the task of exploring possible working principles (the solution space exploration). Each individual member was expected to provide requirements or concept solution proposals from the perspective of the department she/he belonged to. Students were allowed to use internet resources to investigate both problem descriptions and solution principles. Communication between both groups was not allowed during this round. The total time for completing this round was 25 minutes. The activity had a divergent nature in both the search of important requirements and the search of possible concept solutions.

3.5.2 Round 2, conceptual design
For this round, the students were organized in 4 project teams. Each project team gathered people working on the same city. The aim of this round was to force the quick convergence towards one conceptual solution by clashing the half of the project team that investigated requirements with the other half that investigated concept solutions. After doing so, each team had to decompose the designed concept into 4 subsystems for each department to further detail in the next round. The total time for completing the task of this round was 20 minutes.

3.5.3 Round 3, layout design
This round had the goal of further detailing the already chosen conceptual solution. The playing room was organized as shown in Figure 3. Here, each department's location gathered students from all four project teams. The goal of doing so was to enhance interdepartmental communication. Furthermore, students of each department were allowed to discuss their progress with the managers for 5 minutes every 10 minutes at their city project table. As an additional challenge, through the project management team updated customer requirements (e.g. building height, earthquake damping ratio) were brought into the game. The managers were free to distribute this information as they saw fit. This round of the game lasted 40 minutes in total.

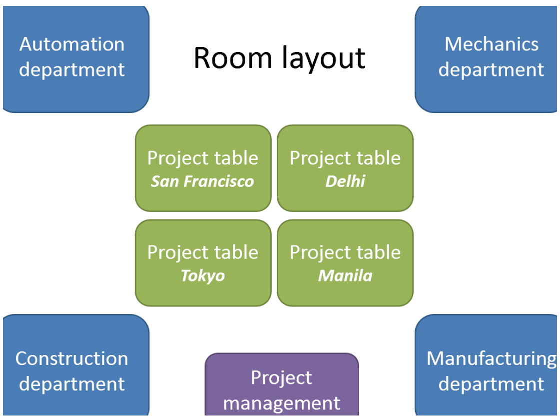

Figure 2. Departmental layout for round 3 of game

3.5.4 Round 4, documentation
In this round the resulting sub systems had to be integrated into one final solution. Also, each team had to fill-in a template describing the characteristics of their proposed solution. The game ended by submitting this template.

3.6 Reflection
After finishing the game, students were asked to reflect upon their experiences in terms of what went well and what went wrong. Interestingly not all students were aware of the updated customer requirements. Once this was done, a group discussion was initiated. After gathering most of the students' perceptions, it was revealed to them that the goal of this game was to have them experience in a short time span some of the major organizational challenges of the PDP. Next, a traditional lecture on project management was provided in which constant references to the game experiences were made.

3.7 Evaluation process
As a final evaluation of the subject, students were required to design a PDP for the fictional company developing anti-earthquake systems. Firstly, they were asked to detail the different decision-making

processes and determine which tools can be used best for dealing with them. The results had to be presented in a structured network. Furthermore, they had to include which information is input and which information is output for each design tool. Secondly, they had to describe how they would organize their PDP. More specifically, to discuss the organization in terms of teams and personnel, types of team structures, types of project management approach (e.g. agile, lean) and finally to elaborate on how they would manage decision gates such that uncertainty is minimized, documentation is assured and interdepartmental communication works properly.

4 CONCLUSIONS

This paper presented a new experience-based approach to teach a Product Design course. After analyzing the implemented approach in panel discussions with students three main conclusions can be drawn. Firstly, students were now able to comprehend the challenges of product development from an organizational point of view. More specifically, the role of communication among interdisciplinary team members distributed over several departments, the importance of documentation to both support communicating technical issues and fix current status of the design process, and finally, the need to manage design uncertainty during the different phases of the PDP and among interdisciplinary teams. Secondly, students showed comprehension on why different products require different combinations of tools arranged in specific ways through the PDP. More specifically, making the distinction that different combinations of toolsets are required for different types of products, as for example a one-off product, a new platform technology and a new product version. Thirdly, gained insights in the implications that implementing certain design tools have on the product development process, further than the principal functionality the tool has. For example, students recognize that the added value of a House of Quality (QFD) for an organization goes far beyond just having it. In reality, it is the process of making it where companies get aware of their capabilities and its relation to their market needs.

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