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Engineering Case Method Applied in Teaching Modularization Management

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Abstract

The paper is describing the insights and experiences from developing a case method to teach undergraduate students modularization management. The well-known case method is a teaching approach that uses decision-forcing cases to put students in the role of people who were faced with difficult decisions. In sharp contrast to many other teaching methods, the case method requires that instructors refrain from providing their own opinions about the decisions in question. In this paper the purpose is to develop a variant of the case method that builds on Scandinavian mentality and tradition. The Scandinavian mentality means that the case development is done in close co-operation with the companies, which is made possible since Scandinavian companies in general are very open in sharing experiences with universities and researchers compared to companies in many other countries around the world.
The case development is an example of co-creation between different university disciplines and industrial companies. This co-creation approach is seen as a generic process that can be applied in other settings. The paper will document the co-creation development process, present the concept of the teaching case, and analyze the initial experiments with students.

Keywords: Engineering case based teaching, modularization management, co-design of teaching materials

1 Introduction

It can be noticed that there in many businesses is an increasing need for customized products, being able to offer customized products can give companies a competitive advantage (Jiao et al, 2007; Simpson, 2004). But, more customization lead to more complexity in a company. One way to deal with the increased complexity caused by more different product variants is product modularization (Simpson, 2004). Implementing a product modularization strategy means to divide a product into a number of modules, each one consisting of a number of components. It is of major importance to define and develop standardized interfaces in between these different modules.

Modularity is a general systems concept, typically defined as a continuum describing the degree to which a system's components may be separated and recombined (Schilling, 2000). The concept of modularity applies broadly to products, services, production setups, knowledge, and supply chains (Sanchez, 2000).
By adopting a modularization strategy a company can mix and match the modules in different ways according to different customer demands (Schilling, 2000; Starr, 1965). By this a company can gain a number of benefits from the product modularization strategy, such as defining a flexible product architecture that makes it easier for a company to respond to new customer demands (Simpson, 2004). Product modularization also has the potential of reducing product development lead-time and cost (Baldwin and Clark, 2000; Pasche et al, 2011). It also increases the possibilities to accomplish different development activities in parallel (Baldwin ad Clark, 2000).
The management challenges that relate to developing and implementing a modularization strategy can be seen as making and coordinating a series of complex and interdependent decisions that concern both product and production features. In that respect the modularization management task is a truly complex cross-disciplinary and cross-organizational challenge.
The nature of modularization management in terms of complexity and cross-disciplinarily makes it a difficult area to teach. However, the importance of the subject makes it a highly important teaching area. This dilemma calls for new approaches to teach the subject of modularization management, and this is the reason why we have made an attempt to adapt the case method in order to deal with the complexity.
The well-known case method is a teaching approach that uses decision-forcing cases to put students in the role of people who were faced with difficult decisions at sometime in the past (Andersen & Schiano, 2014). In sharp contrast to many other teaching methods, the case method requires that instructors refrain from providing their own opinions about the decisions in question. Furthermore, the cases will be developed to illustrate technical and organizational aspects. This is important since the traditional Harvard Business School cases are focusing more on strategic business perspectives. Also, the case will include specific theoretical concepts and models that the students should train and apply.
The aim of this paper is to describe the process of developing and testing a specific case. The initial process can be seen as an emergent normative approach to developing future cases.

2 Case based method in an engineering teaching context

Case teaching is a very effective, but underused, way of teaching (Andersen and Schiano, 2014). The case method aims to give students the possibility to test the reality of managerial decision-making. A decision making that in reality includes a lot of challenges, such as for example incomplete information, time constraints but also a number of conflicting goals to deal with. Cases can service as effective basis on which students can explore which theories are needed and can apply theories on simulated practices (Courtney et al., 2015). Since the mid-19th century case based learning has been an integral part of education in medicine, legal process and social science (Courtney et al., 2015). HBS (Harvard Business School) cases today dominate the international academic market claiming an 80% share (Courtney et al., 2015).
There are a number of potential benefits to gain by using the case based method in teaching. For example it can develop the students' critical thinking skills (Courtney et al., 2015). Case teaching is also an interactive learning strategy that shifts the emphasis from teacher-centered to more student-centered activities (Grant, 1997; Courtney et al., 2015). Case discussions transfers experience-based knowledge, the students will not only learn from the teacher but

also from each other's experiences (Andersen and Schiano, 2014). In previous literature is has also been argued that it is important to use the case teaching method in engineering education, this to expose the students to real-world issues that they might face in their future working-life (Courtney et al., 2015).
However, despite the recognized need for applying the case based teaching method also in engineering there is no well-established practice. This means that individual teachers apply fragments of case methods mainly based on their own research and experiences. The cases are rarely shared between teachers because they are so closely bound to own experiences. Therefore, we see a large potential in initiating a process that aims at defining frameworks that will support the process of generating cases and introduce the methods of case teaching methods in an engineering context.
Furthermore, we believe that there can be developed a particular Scandinavian approach that utilize the close collaboration between industrial companies and academia.

2.1 Teaching modularization management in an engineering context

Modularization management is a complex phenomenon that potentially has a significant impact on the performance of the companies that are able to apply it efficiently and effectively. Students should ideally be able to experience the complexity and be exposed to methods of how to deal with the complexity. Complexity arises both from the technical complexity associated with the products and technologies, and from the cross-disciplinary nature of taking decisions in regards to the specific modularization effort.
The traditional pedagogical approach of engineering 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 practice of industrial companies, and therefore modularization management is a typical example of such an integration discipline.
The concept of modularity in product development has traditionally been seen as an integral part of teaching product development in general. Teaching is supported by textbooks that introduce the basic concepts of modularity (Ulrich & Eppinger, 2016). These basic concepts are supported by illustrative examples and most often the teachers of the field will supplement with additional examples derived from their own research or from their industrial relations.
As already described, there are a lot of potential benefits for a company to gain by implementing a product modularization strategy. However, there are a number of challenges/issues in relation to implementing product modularization, and, therefore, modularization management is a key discipline in realizing these potential benefits.
Modularization management is also an area that is not well researched. The majority of the existing literature is focusing on the technical solutions and to much less extend on realizing the potential benefits and the complexity of understanding the multi-dimensional nature of the many parameters playing together in a timely dynamically perspective.
In order to support students in gaining insight into the complex challenge of managing modularization a very focused and delimited effort will be needed. It is also clear that all aspect cannot be covered by one case. A series of cases that rely on a consistent theory basis will be needed.

3 Case development and test

Following the intention of adopting a Scandinavian approach to case-development an involving co-design method was chosen (Prahalad & Ramswamy, 2004). The method was inspired by a Living Lab approach that is characterized by a real-life test and experimentation where users and producers co-design solutions (Eskelinen et al., 2015).

In the specific context the co-designing participant are the industrial companies, the teachers of various disciplines, and the students.
Initially, the adopted co-design approach involved only the two stakeholder groups of teachers and industrial companies. The purpose was to define the learning scope to be addressed by the case, thus identification of specific modularization cases was carried out along with clear links to the relevant theoretical disciplines of managing modularization.
At the start, the co-design activities were more explorative in nature, resulting in open-ended themes, topics and measures. However, as the themes and content of the potential case topics became more focused the workshops got more focused. As the series of workshops progressed the teachers were able to test some of the ideas and insights on their students.
The first rounds 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 the modularization area.
- There is a rich learning 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 engineering 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.

The common topic that would inspire both industrial companies and teachers turned out to be the challenges that relate to making the potential benefits and realized results of modularization efforts visible. Companies did in general express needs for approaches and methods that could support review of decision situations that involved modularization. Teachers and researchers reported a general lack of insight into the causal relationships between specific modularity features and benefits derived from these.

3.1 Finding the initial case topic

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.
A breakthrough came when it was proposed to reframe the discussion and focus on what initially seemed as being far too simple products. This led to the idea of focusing on a simple LEGO minifigure. The various disciplines provided proposals for how they could contribute to enlighten the many challenges that are associated with developing and realizing a launch of product series derived from such a simple product.
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 to more advanced challenges associated with their particular disciplines (for synchronous development of a modular production setup). The shared simple starting point became the integrating element.

The overall aim of the case was set to illustrate, and simulate/calculate, the effects of product variety in product development and manufacturing; and in particular to focus on explicit product/production modularization as means to realize a need for product variety.
The case should explicitly include the two inter-related concepts, efficiency and effectiveness. Efficiency is about speed, lead-time and productivity (Brown and Eisenhardt, 1995). In terms of modularization this means that the products, and the different product variants, are developed and manufactured to the lowest possible cost and in the shortest possible development lead-time. The effectiveness is defined as for example, in terms of fit with market needs (Brown and Eisenhardt 1995), here it means that the products and the product variants that are decided to manufacture are something that is wanted by the customers, in other words that the company's product assortment consists of products and product variants that are possible to sell.

3.2 The case elements

The initial tests with students proved that the simplest possible starting point gave the best results in respect to the defined focus, efficiency and effectiveness. Consequently, the case is started with a simple white LEGO minifigure without any decoration (see figure 1).

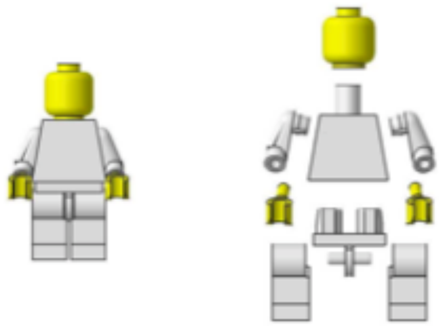

Figure 1. The start of the case is a neutral white minifigure.

The specific case applied is the continuing development of the LEGO minifigure. This product has been on the market since 1978 and is still the most important iconic product for the LEGO Company. The long life of the product and the popularity means that there is a substantial amount of materials available online. During the development a substantial part of this material has been analyzed and classified. Various ways of making the materials available for the students have been tested.
The simple initiating product structure is well documented and the simple modular features give the students a first insight into the benefits of the modular structure. Furthermore, the simple product structure allows the students to focus on the modular production setup.
The close collaboration with industrial companies during the case development secures that the specifications and prices are real prices. A substantial amount of video materials support the students in getting overview and insight into details. All of above have a significant impact on the motivation of the students.
From the simple start the case progresses by giving the students challenges. The specific challenges have changed from test to test. Also, the method of driving the case forward by challenges are chosen to give local teachers a possibility to formulate their own challenges and, thereby, create a particular focus that would fit their learning goals.
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 (Csíkszentmihályi, 1990). Pine and Gilmore (2001) 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 (Pine & Gilmore, 2011).

The co-design activities with industrial companies had generated commitment from the companies to continually 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 case setup was changed based on the feedback from the various test sessions. The current case elements will be reported in section 5 concerning the findings from the whole case development process.

3.3 The case testing

The pre-test was done with only four students. In order to develop and test the initial case ideas 21 additional tests has been executed. Presently, a total of 660 students divided in 20 different classes with different educational background have been testing various versions of the case.

The initial case test and assessment targeted different types of students and the duration of the case test varied according to their availability and the specific context where the case was introduced. Some test of the case was done in subsequent series of lectures. The tests were conducted from September 2014 until February 2016.

Each test has been evaluated by a comprehensive questionnaire. The questionnaire was to a large extent based on general questionnaires developed in similar studies (Christensen et al., 2014). This was done in order to ease comparison and ensure validity. These questionnaires measured interest, awareness, usability, enjoyment and knowledge in regards to modularization, modularization management and the case. The questionnaires also measured the student's general interest in science, technology, engineering and mathematics (STEM). After some of the test rounds a few of the students were additionally interviewed.

Each test group was given a short introduction to the modularity theory and the production processes needed to produce the LEGO minifigure. 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 case was to be integrated. The teacher had initially introduced the idea behind the case 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.

4 Findings

The initial results showed 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) experienced a neutral impact on their interest and awareness. The following interviews documented that the stronger students felt that the challenges of the case was moving too slow to retain strong interest. Therefore both the pace and the complexity were increased.

The interviews also revealed that the students liked in particular three features of the specific case setup. They pointed to the videos, the trustworthy real-life setting, and the game element that time restricted pace of the case introduced. These elements were emphasized further in the following rounds.

In particular, the game element was essential in the feedback from the students. This is in line with recommendations for improvements in teaching technical subjects (Johnson et al., 2010). Following this feedback dividing the class into two-persons teams and increasing the game-element of the case organized the next rounds. By increasing the game-element it became more important to put more emphasis on the financial aspects of modularization management. The reason for this was that the students reported that the financial aspect was the strongest driver when a more game based approach was chosen. The financial aspect simply made it easier to compare the performance of the teams.

The co-design approach did also involve the students. They were continuously invited to propose improvements and additional challenges. In one of the first rounds a LEGO enthusiast among the students proposed that the case should be based on LEGO's collectable series of minifigures (LEGO, 2016). This proposal was incorporated and it led to a huge increase in the variety of the number of different LEGO minifigures.

The LEGO collectable minifigure series product was launched in 2010. Each series contains 16 various LEGO minifigures packed in non-transparent aluminum foil bags. Since 2010 LEGO has launched three new series each year. In total the LEGO collectable series comprises 288 very different variants of the minifigure. In figure 2 the LEGO minifigure collectable series 1 is illustrated.

Each LEGO minifigure is based in a common product architecture that provides interfaces for different headgears (hairs, hats, head accessories) and different accessories to be attached to hands or legs. The LEGO minifigures come in a variety of colors and the decoration of head, upper body, lower body, arms, and accessories lead to a very high potential variety.

Figure 2. The LEGO collectable minifigure Series 1. The non-transparent bag is seen to the left and the sixteen various LEGO minifigures of Series 1 are seen to the right.

The ongoing findings have resulted in frequent adjustments in the case setup. By choosing the specific challenges to be the driver of the case the continuous adjustments have been easy to adopt. When engaging teachers that are going to use the case the adjustment of the challenges have also been used to make it possible to add their personal ideas to the case. The current formulation of the challenges will be reported in the next section.

4.1 The challenges that drive the case

Initially the students are introduced to the architecture of the LEGO minifigure. The historic development is revealed and the challenge associated with maintaining a balanced development of product and production is discussed (Abernathy & Utterback, 1978).

4.1.1 Modularization management challenge 1

The students are asked to establish a small production of only 250,000 white LEGO minifigures. The emphasis is on the manufacturing processes and in particular on the process time aspect. The challenge is to determine the time of delivery.

4.1.2 Modularization management challenge 2

Based on the former limited production of 250,000 LEGO minifigures the financial aspects of investment and product cost are introduced. The students are to estimate a cost per produced minifigure. Hereafter the production demand is raised to 10,000,000 units and introducing decoration, packing, and accessories increases complexity. The challenge is to handle the parallel requirement of delivery and cost.

4.1.3 Modularization management challenge 3

The LEGO collectables minifigure Series 1 is introduced. The historic background for the product is discussed. The students are challenged to identify which product features are the most appropriate seen from a manufacturing perspective. In order to challenge the students they are allowed only 15 minutes to make a decision of which 4 of the 16 different minifigures they would choose produce. The choices have to be motivated from a modular management perspective. Given so short time the choices can only be qualitatively supported based on the students' current insight into modularization management.

4.1.4 Modularization management challenge 4

The former challenge is now seen from a quantitative perspective. Based on insights from challenge 2 the students are to give a quantitative analysis of the financial consequences of the launch of Series 1. The analysis is not unambiguous and leaves a number of open questions in regards to the future development of the collectable series. The challenge is to formulate a modularization strategy based on the current insight.

4.1.5 Modularization management challenge 6

The launch of Series 1 does not only challenge the product strategy. The manufacturing strategy is also being challenged. The challenge of the students is to identify gaps between the simple production setup and a scaled production setup with higher capacity and higher ability to respond to demands for variety.

4.1.6 Modularization management challenge 5

The Series 2 and Series 3 collectable minifigures are planned and launched. These launches make it possible to answer some of the ambiguous questions from challenge 4. However, the launches also raise new questions. In particular the dilemmas between being efficient (producing fast and at low cost) and effectiveness (developing innovative solutions that please the customers) are raised. The challenge is to make a follow-up and eventually adjust the modularization strategy to accomplice the needs for both efficiency and effectiveness.

4.1.7 Modularization management challenge 7

The collectable minifigure product has established itself as a major success on the market. LEGO has been decided to launch three new series per year. The series 4 to 9 are now included. The challenge is to review the modularization strategy. This should include both the product and the manufacturing strategy.

4.1.8 Modularization management challenge 8

Given the established success a number of technology development possibilities are considered. These are manufacturing technologies that will allow for better efficiency as well as provide new product options that can support better effectiveness. The students are challenged to analyze the impact that these technologies potentially have, and the expected outcome is a quantitatively supported investment plan for the future development.

The current eight challenges do not need to be applied in full. When doing the next iterations and developing the next version of the case description and providing the supporting case materials it will be a priority to allow teachers to pick a single challenge or a few challenges.

5 Conclusions

Case teaching is argued to be a very effective, but underused, way of teaching (Andersen and Schiano, 2014). This paper has aimed to describe the process of developing and testing a specific case. The case method aims to give students the possibility to test the reality of managerial decision-making. Many companies today faces a constantly increasing need for customized products, which gives an increasing number of product variants. A lot of companies have therefore adopted a product modularization strategy to deal with this increasing complexity. But, to implement a successful product modularization strategy the company will face a lot of difficult decision-making. Therefore, the implementation of a product modularization strategy could be fruitful to teach to students by using cases.

In the paper we have described the development of a modularization management case, based on the LEGO minifigures. In the case the effects of the decisions regarding eight different modularization management challenges are simulated.

This paper, and the development of the LEGO minifigure case, also aims to develop some learning points that can be useful for future case developments. From the case developed, and the feedback given by students in the classes in which the case has been used, we can make the following conclusions:

- It is fruitful to co-develop cases that are to be used in engineering education together with the industry. Using evidence, which can be both qualitative and quantitative, is very important when developing a case (Ellet, 2007).
- One important issue to consider in the case is the pace, it should not be too fast, and neither too slow. It is important to find a good balance there so that all students in a class can deal with the pace.
- By including for example videos the interest among the students can increase, this because it creates a trustworthy real-life setting.
- We can also conclude that having a game, or competition, element in the case increase students' efforts. In the modularization management case simulating and measuring the financial performance of different decisions did this.
- It is also important when starting to develop a case to have a sharply focused position statement, since this will organize the entire case (Ellet, 2007). Without a clear position statement the case has no purpose or direction (Ellet, 2007). In other words, decide early in the process which learning points do you want to show with the case. Do not aim to illustrate a lot of different learning points with each single case (Andersen and Schiano, 2014).

References

Abernathy, W.J. and Utterback, J .M. (1978) Patterns of Industrial Innovation. *Technology Review*, Vol: 80 No: 7 Pages: 40-47

Andersen, E. & Schiano, B. (2014). *Teaching with Cases*. Harvard Business School Publishing

Baldwin, C.Y. and Clark, K.B. (2000). *Design Rules: The Power of Modularity*, Vol. 1, MIT Press, Cambridge MA

Brown, S. and Eisenhardt, K.M. (1995), "Product development: Past research, present findings, and future directions", *Academy of Management Review*, Vol. 20, No. 2, pp. 343-378.

Christensen, R., Knezek, G., & Tyler-Wood, T. (2014). Student perceptions of Science, Technology, Engineering and Mathematics (STEM) content and careers. Computers in Human Behavior, 34, pp. 173-186

Courtney, N., Poulsen, C. and Stylios, C. (2015). *Case Based Teaching and Learning for the 21st century.* Libri Publishing, Oxfordshire, UK.

Csíkszentmihályi, M. (1990). *Flow: The Psychology of Optimal Experience*, New York: Harper & Row

Ellet, W. (2007). *The case study handbook: How to Read, Discuss, and Write Persuasively About Cases,* Harvard Business School Press, US.

Eskelinen, J. et al. (2015). *Citizen Driven Innovation*, European Network of Living Labs

Grant, R. (1997). A Claim for the Case Method in the Teaching of Geography. *Journal of Geography in Higher Education,* Vol. 21, No. 2, pp. 171-185

Jiao, J., Simpson, T.W. and Siddique, Z. (2007). Product family design and platform-based product development: a state-of-the-art review, *Journal of Intelligent Manufacturing*, Vol. 18, No. 1, pp.5–29

Johnson, L., Smith, R., Willis, H., Levine, A., & Haywood, K. (2010). *The 2011 Horizon Report*. Austin, Texas: The New Media Consortium

LEGO (2016). http://www.lego.com/en-us/minifigures

Pasche, M., Persson, M., and Löfsten, H. (2011). Effects of platforms on new product development projects, *International Journal of Operations and Production Management*, Vol. 31, No. 11, pp. 1144-1163

Pine, B.J. & Gilmore, J.H. (2011) *The Experience Economy*, Harvard Business Review Press

Prahalad, C.K. & Ramaswamy, V. (2004) Co-creation Experiences: The Next Practice in Value Creation, *Journal of Interactive Marketing*, Vol. 18, No 3, pp 5-14

Sanchez, R. (2000). Product and process architectures in the management of knowledge. In Robertson & Foss (Eds.), *Resources, Technology and Strategy*. Routledge, London

Schilling, M.A. (2000). Towards a general modular systems theory and its application to inter-firm product modularity. *Academy of Management Review*, Vol 25, pp. 312–334

Simpson, T.W. (2004). Product platform design and customization: status and promise. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, Vol. 18, No.1, pp. 3–20

Starr, M. K. (1965). Modular production – a new concept, *Harvard Business Review*, Vol. 43, No. 6, pp. 131-142

Ulrich, K.T. & Eppinger, S.D. (2016). *Product Design and Development - Sixth Edition*. McGraw-Hill, New York