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Competence Needs and a Model for the Teaching Strategy Development of Mechanical Designers in Product Development

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“The aim of teaching is simple: It is to make student learning possible.”

Paul Ramsden

Abstract

Engineers' product development (PD) skills are the key success factors for companies in countries like Finland. Universities need to regularly update their learning outcome targets to match them with the needs of the industrial sector under consideration. These targets form the basis for the development of the curriculum and the relevant courses of engineering education.

The main research problem is **"What are the contentual and pedagogical demands to optimise learning results in the field of mechanical engineering for the higher education of PD at Universities of Applied Sciences (UAS) in Finland?"** so that graduating engineers are competent to meet the PD challenges of the Finland-based companies in the Technology Industries. The word "optimise" here means that the aim is to reach the best possible learning results with the resources available at the university.

A case study research has been made to find the most important competence needs of mechanical designers working in PD in Finnish mechanical workshops. The results of this case study establish the customer needs for the curriculum and course development process in the field of PD.

A comprehensive and systematic method to develop the whole teaching and learning process of a course has been introduced. The teaching strategy of a course has been defined as a modular service product which includes five modules from the targets for learning outcomes to learning and teaching assessment. A model based on the stage-gate type PD process, widely and successfully used in the industry, has been applied to the course teaching strategy development. The detailed guidelines together with the phase tasks and the main outcomes for the phases give the information needed to use the model; including those teachers who are not familiar with the PD process.

The author's twenty year's PD work experience in Finnish companies has created a solid base for the study. The important PD tools, such as the stage-gate type PD process and the product modularization, have become well known to the author during those years. This PD work experience also helped a lot when organizing and carrying out the case study research.

The research has utilized the industrial development methodologies in the university environment. The illustrative application of the model to a PD course for mechanical designers at the Finnish Universities of Applied Sciences as well as the comparison of the model with existing models show that it is an effective tool for the comprehensive and transparent development of courses in the field of engineering.

Preface

This thesis has its foundation in the twenty years from 1986-2006, when I was working in Finnish industry. During these years I worked as a research scientist, chief engineer, engineering manager and for most of that time as the PD director at an international company in Finland. In 2006 I started work as a principal lecturer in mechanical engineering at a university of applied sciences in Finland and one year later as the dean at the school of technology at the same university. PD tools, such as modular product architecture and the stage-gate type PD process, were and still are today the key success factors in the company where I worked. In my current work as dean the development of curriculums and individual courses is very important. Based on my industrial experiences I decided to apply the same industrial PD tools to this development work.

The identification of customer needs establishes an important basis for every PD project. In the identification of the competence needs of mechanical designers working in PD I had an excellent possibility to interview PD professionals in many successful Finnish companies. I want to thank the following persons: Global Tech Platforms Manager Pasi Julkunen at Sandvik Mining and Construction, New Product Applications Director Heikki Leppänen at Kone Corporation, PD Manager Jarno Hauhtonen at Finn-Power, PD Manager Kari Holopainen at Metso Paper, Engineering Director Arto Hietanen at Valtra, R&D Director Mauno Yli-Vakeri at Agco Sisu Power, R&D Director Hannu Santahuhta at Cargotec, R&D Director Marko Paakkunainen at John Deere Forestry, Development Manager Mika Korhonen at Hollming, PD Manager (nowadays Managing Director) Timo Lehtioja at MSK Cabins, PD Director Jouko Tenhunen at Normet, R&D Manager Matti Lehto at Konecranes, Technology Director (nowadays Managing Director) Juha Murtomäki at Plantool. I also want to thank Vehicle Design Manager Seppo Anttila and Transmission Design Manager Ville Viitasalo at Valtra for the pilot case study interviews.

I want to express my sincere thanks to Dr. Tapio Varmola, President of Seinäjoki University of Applied Sciences for his highly professional comments in the field of education in my research. Tapio also encouraged me to work hard by frequently asking the status of the research. I also want to thank Kati Katajisto, R&D Director at the School of Technology at Seinäjoki University of Applied Sciences, for the creative discussions and I wish her good luck with her own research.

I have been privileged to have Professor Asko Riitahuhta as my study supervisor. I want to deeply thank Asko for his motivating support and guidance. I also give my thanks to Asko's research group, especially Dr. Timo

Lehtonen and Dr. Tero Juuti for their comments on my study. I am very grateful to my external evaluators, Professor Christopher McMahon from the University of Bristol, UK and Professor Johan Malmqvist from Chalmers University of Technology, Gothenburg, Sweden for their highly valuable comments and suggestions, which have helped me a lot to improve the quality of this work. I want to express my warm thanks to lecturer John Pearce for correcting my English.

Finally, I thank my family Tuomas, Elina, Jari, Isla and Aatos for the fresh enthusiasm they have continuously shown me and thank you my dear wife Anne-Mari for your loving support and patience.

Seinäjoki, August 2014

Jorma Nevaranta

Abbreviations

ABET	ABET Inc. is the recognized US accreditor of postsecondary degree-granting programmes in engineering
BOM	Bill of Materials
CAD	Computer Aided Design
CDIO	Conceiving – Designing – Implementing – Operating. The aim of the CDIO approach is to reform engineering education to meet the following need: “to educate students to understand how to Conceive-Design-Implement-Operate complex value added engineering products, processes and systems in a modern, team-based environment.” (Crawley et al. 2007).
CNC	Computerized Numerical Control
CRM	Customer Relationship Management
DFM	Design for Manufacturing
DFMA	Design for Manufacturing and Assembly
DFMEA	Design Failure Mode and Effects Analysis
ECTS	“European Credit Transfer and Accumulation System. ECTS is the credit system Process for higher education used in the European Higher Education Area, involving all countries engaged in the Bologna Process.” (European Communities 2009).
EC2000	Engineering Criteria 2000
E&D	Engineering and Design
ERP	Enterprise Resource Planning
FMEA	Failure Mode and Effects Analysis
HEI	Higher Education Institute
IT	Information Technology
LCP	Learner-Centred Practise

MIT	Massachusetts Institute of Technology
NPD	New Product Development
PBL	Problem-Based Learning
PD	Product Development
PDM	Product Data Management
PLM	Product Lifecycle Management
QFD	Quality Function Deployment
R&D	Research and Development
RG	Research Goal
RH	Research Hypothesis
RIT	Rochester Institute of Technology
RQ	Research Question
SME	Small and Medium Size Enterprise
UAS	University of Applied Sciences
VR	Virtual Reality

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1 Introduction

The importance of research and development (R&D) in manufacturing companies has increased lately in industrialized countries like Finland. There are several reasons for this, such as: shortened product life cycles and global competition. This means that the competence of the product development (PD) organizations and thus that of the PD engineers is more and more important in the successful development of these countries. Working methods and competence demands have changed in many modern companies; because of distributed and networked PD for example. All this means new challenges for the Higher Educational Institutes (HEIs) such as the universities of applied sciences and the science universities in the field of technology.

1.1 Background and Motivation

The author of the thesis taught for six years students who were taking a Master of Science degree in engineering at a university in Finland in the 80´s. After this time and the attainment of a licentiate in technology he has been working for 20 years in PD and for 11 of those years as the PD director for an international tractor manufacturer until 2006. Since that the author has worked for one year as the principal lecturer in mechanical engineering and after that as the dean of a school of technology at a university of applied sciences. Still as the dean he has taught bachelor and master degree students in mechanical engineering; mainly the PD courses. These experiences suggested to the author that the PD methods widely used in industry could also be successfully applied in modern universities; even though the traditional way of thinking is that universities teach the methods that are to be used in industry and not vice versa.

Technology Industries in Finland include the following branches:

- Electronics and the Electrotechnical Industry;
- Mechanical Engineering;
- Metals Industry;
- Information Technology Industries;
- Consulting Engineering.

Technology Industries is the most important industrial sector in Finland. Its turnover in 2010 was 64 Billion euros with 287,400 personnel in Finland. Among the five branches mechanical engineering had the largest turnover at 24.4 Billion euros as well as the largest number of employees at 124,600. R&D investments were 3,846 Million euros with 461 Million euros in mechanical engineering. (The Federation of Finnish Technology Industry Year Book 2012.)

The products in the technology industries sector include the features and components from many different fields of technology. A modern vehicle has tens of electronic control units (ECUs, embedded in mechanical components) with millions of software code lines.   Mobile phones which should really be referred to as mobile devices (Perttula 2007), may have: a digital camera, radio, MP3 player, navigator, office compatible e-mail and calendar, and so on.

It is clear that, for example, a car manufacturer must have a high level of competence in the field of electronics and computer science. Whilst these new competence assets may come, to a large extent, from their suppliers or from other kinds of company partners, the company itself must have the final responsibility for their products; including these “outsourced” competencies. This means that the car manufacturer itself must have, in their own organization, such people who understand these technologies and who can also lead their partners’ expert teams in PD projects.

To reduce production costs many big Finnish companies in the technology industries sector have moved at least part of their production to countries which have lower labour costs or at least their suppliers are often from these countries. The other reason for moving production, in addition to the lower labour costs, may be that production is closer to their products’ fastest growing markets (for example mobile devices). Sometimes also a part of the PD resources is located in those countries. Typically however in such cases the main PD responsibility is still in Finland. It should be noted that funding for R&D in Finnish companies in the manufacturing industry has nowadays almost the same volume abroad as it has in Finland (Figure 1).

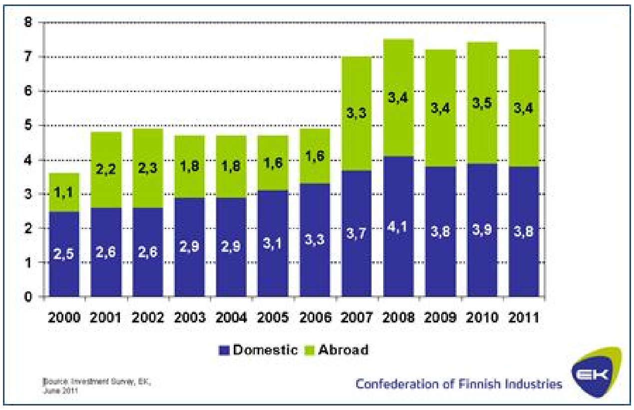

Figure 1. *Funding for R&D by Finnish companies in the manufacturing industry in Finland and abroad during 2000-2011, billion euros (Confederation of Finnish Industries 2012).*

The change has been rapid during the first 10 years of the millennium. A major growth in R&D funding abroad took place in 2007, when it doubled compared with the previous year’s funding.

1.2 Overall Problem

Many mechanical engineering workshops have come to the position that they also need electronic engineers and even software coding resources; either in their own organization or these resources are outsourced from a partner company (as was mentioned before in the case of the car manufacturers). It is very unusual that a product from a Finnish engineering workshop does not have at least one electronic control unit. Nowadays the usability of any product has become more and more important. Thus there is a need for mechanical designers to understand and to be able to communicate with user interface designers (Oswald 2010). This means that nowadays the technical competence demands on mechanical designers are broader and also include slightly the above mentioned fields of technology. This is especially important in the case of embedded systems, because the mechanical behaviour and the electronic control of the product have to be tailored to work together.

The situation in this matter is very different in small and medium sized enterprises (SMEs) compared with the situation in large companies. SMEs are often component suppliers and thus the competence demands are not normally as broad as those of the larger companies. On the other hand SMEs also usually have suppliers which are perhaps electronic component manufacturers.

The new tools for PD work are all the time under development; such as virtual reality (VR) techniques, see Figure 2. Today VR is used mainly as a communication medium, for example: for design reviews, for customer presentations and when showing new ideas. It is very seldom used in the design engineer´s daily work. Ilmenau University of Technology in Germany has the vision “To simulate and optimise the acoustic behaviour of technical systems before they physically exist, utilising extended Virtual Reality techniques.” They call this technique “Virtual Machine Acoustics” or “Virtual Sound-Design” which tells more about the application possibilities of bringing acoustic behaviour into the VR model (Weber 2010). The VR techniques still need a lot of development, such as dynamic simulation, to be used more in PD projects. Also the movability of the VR equipment should be more flexible. Anyway VR has an interesting future and new features are under development. There is a high demand for information technology (IT) skills in general, but a modern PD engineer also needs to know the possibilities of VR as well as the other new tools available in the PD environment.

The above mentioned subjects and tools are only some examples about the new competence skills for mechanical designers working in PD. The general trend is that the spectrum of competence skills needed in future is wider than ever before and new tools to help and hasten PD work will be introduced.

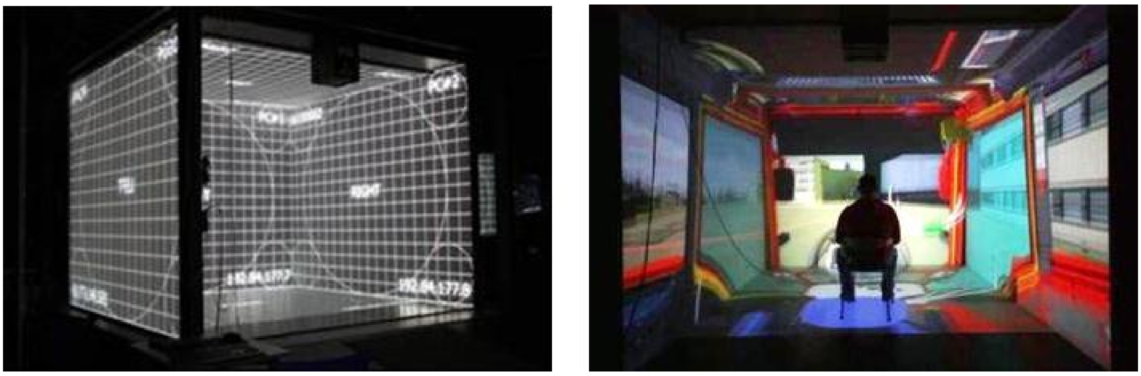

Figure 2. *Cave Automatic Virtual Environment (Cave) at Seinäjoki University of Applied Sciences in Finland.*

Because manufacturing companies nowadays make more and more national and international PD cooperation with their suppliers, customers and other kinds of partners, many kinds of non-technical competences are also needed (Perttula 2007, p. 116) such as:

- Partnership management;
- Supplier auditing;
- Business understanding;
- Negotiation skills and dealing with customers;
- Commercial contracts and laws;
- Project management practice;
- Industry intelligence;
- Technology management;
- Leadership;
- Foreign cultures.

This list could be even longer including:

- Language skills, including languages other than English;
- Computer skills (office software);
- Meeting practices;
- Presentation skills.

The PD engineer's skills are generally divided into the three areas: technical substance, technical tools and non-technical. The competence demands in all of these areas are now very different compared with the demands of 10 years ago; as explained above.

HEIs in the field of technology need to follow the changes in the competence needs of PD engineers. The contents of the courses as well as the teaching and learning methods used need to support these competences in the new situations that arise. It is evident that the technical as well as the non-technical competences mentioned above are covered in many different courses at the universities; not only in specific PD courses.

The main research problem is **"What are the contentual and pedagogical demands to optimise learning results in the field of mechanical engineering for the higher education of PD at Universities of Applied Sciences (UAS) in Finland?"** so that graduating engineers are competent to meet the PD challenges of the Finland-based companies in the Technology Industries. The word "optimise" here means that the aim is to reach the best possible learning results with the resources available at the university.

1.3 Goal of the Research

PD is normally taught in HEIs as a course or courses in different degree programmes. The contents of the courses differ a little depending on the specific degree programme. Thus teaching PD has a somewhat different emphasis in mechanical engineering from the emphasis, for example, in information technology or in biotechnology. However there are also a lot of commonalities in PD in the above mentioned fields of technology. A company must have a way to develop new products; that is to say a new product development (NPD) process. Identifying the customer needs is vitally important for the success of any NPD project in any field of engineering. A systematic way to make the NPD process step by step and by using concurrent engineering ideas forms a solid base to develop new products. This kind of NPD process is usually called the stage-gate type PD process. Every stage has its specific tasks to do before the project team may continue to the next stage. Nowadays the NPD process must include the whole sustainable life cycle design of the product.

The teaching and learning methods and assessments as well as the learning results are among the other things dependent on the contents of a course. The general motivation of a student is of course very important and there are also a lot of other influences, not only those mentioned above, which have an effect on learning results. However this research will not deal with those other influences.

When thinking of the contents of the PD courses in HEIs (and the courses which support PD skills) the essential question is: how well do they fit the PD competence needs of the industry where the graduated students will be working. Efficient teaching and learning methods are important tools to guarantee that the contents of the course get across to the students as effectively as possible.

Teaching development is innovative work in nature. When making innovation work Drucker (2011), p. 124 states: “Finally, don’t try to innovate for the future. Innovate for the present.” There will be changes in tools and the working environment during the working life of a PD engineer and thus learning is a lifelong process. The UASs need to concentrate on the present skill needs and give the graduated students the ability to learn new skills by themselves.

The goal of this research is to specify **“The systematics to develop a teaching strategy for the education of PD engineers in mechanical engineering at UASs in Finland”.** Typically the development of courses in engineering deals with either the contents, the learning methods or the assessment methods but not with the whole teaching and learning process. In this research the teaching strategy includes the whole teaching and learning process from the learning outcome targets to the learning and teaching assessments. The results of the research can also be used, to an appropriate extent, at science universities.

1.4 Research Questions and Research Hypothesis

To be able to find solutions or proposals to the research goal there are a lot of questions to answer. Such questions could include for example “are the competence needs of PD engineers changing continuously or are there some key competences which are always important” or “are the competence needs very different in large companies compared with small and medium size companies”. Also one can ask “what impact does the field of engineering have on the work of the PD engineers” or “what impact does the culture of a specific country have on the work of the PD engineers” and so on.

These are only some examples of the many possible questions which the goal of the research may raise. It is evident that there are a lot of variables which have an influence on the goal of this research. However it is necessary on the one hand to limit and focus the research itself and on the other hand to try to find the most essential questions, and answers to these questions, so as to achieve the research goal as fittingly as possible.

The research questions (RQs) needed to be answered to obtain the input information needed for the systematics of the research goal (RG) and the research hypothesis (RH), as a tentative model to reach the RG, are:

RQ1: What are the most important competence needs of PD engineers in mechanical engineering in Finland?

RQ2: What is the current level of young mechanical engineers in the different PD competence areas in Finland?

RQ3: What is the impact of RQ1 and RQ2 on the teaching of competences to PD engineers in mechanical engineering so they are able to achieve the best professional ability?

RH: The stage-gate type PD process, together with a modular service product concept, is an effective tool for the course teaching strategy development.

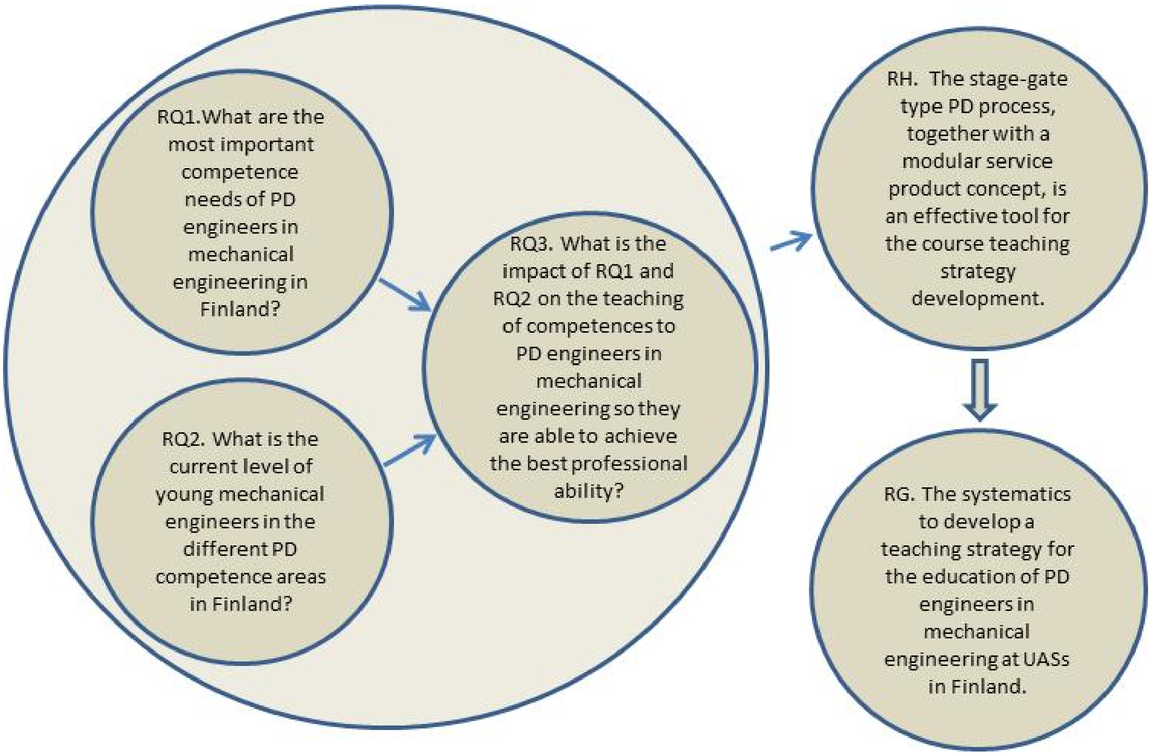

Figure 3. *Research questions (RQs), research hypothesis (RH) and the research goal (RG).*

RQ1 and RQ2 are descriptive in nature whereas RQ3 is relational (Blessing and Chakrabarti 2008, p. 91). Figure 3 illustrates the logic used to obtain the RG using the answers to the RQs and the method required by the RH. The RH needs the answers to RQs as input information.

1.5 Research Methods

Empirical and constructive research methodologies are used in this study. The results of the empirical research are used as input information for the constructive part of the research.

To find the answers to the RQs and to reach the target of the RG several kinds of information, as well as methods to use this information, are needed. A case study approach is used as the empirical research method to find evidence and answers to the three RQs. In this thesis a multiple-type case study method is used, which means that there are many participating companies in the case study. A lot of questions concerning the RQ1 and RQ2 are settled for the PD managers or directors of these companies to be answered. There are also questions which give relevant background information about the PD organisation and the other PD related items in those companies. The answers to the relational RQ3 are derived from the case study results for the RQ1 and RQ2. A comparison of the case study results with some other national and international studies is made.

The teaching strategy concept is defined as a modular service product, later defined more in details. In the constructive part of the research a special model for the simultaneous development of the teaching strategy modules is developed. This simultaneous development is important because of the interrelationships between the different modules. The model is used as the tool for finding the targets for the RG and it needs the evidence and answers from the case study. The implementation of the process of this model also needs other input information which is mainly internal UAS information, such as its strategic targets, teaching facilities and so on.

1.6 Contribution

This study has both practical and theoretical contribution types. Both of them can be used separately in other relevant studies outside the scope of this thesis.

The empirical research using the case study method gives practical information about the competence needs of mechanical designers in PD work. The results of this case study can also be used in, for example, training programme planning as well as recruitment planning in companies, especially in mechanical workshops. Other UAS fields of technology, outside mechanical engineering, can also utilize the results in the development of their courses. Outside of the substance skills there are many other competence needs, which are also relevant in these other fields of technology, as explained in section 1.2.

The theoretical contribution of this study comes from the industrial working methods and processes being used in the environment of the UASs. This includes the following items for the product (which is the teaching strategy of a course or more briefly course teaching strategy):

- The definition as a modular service product;
- Bill of materials (BOM) of the product;
- Component descriptions of the product;
- Use of the stage-gate type PD process in the development of the service product.

The comprehensive development of a course utilizing the well-proven industrial PD process and a modular service product architecture are new approaches in the UAS environment. The general development of the UASs in Finland during the last few years has been such that the working methods and processes of business life are now more suited to them than ever before. This means for example that the UAS has a higher need to define clearly its: values, mission and vision as the basis for its strategy (Kaplan and Norton 2001). It also needs to define, among other things: customers, markets, products, partners, key processes, key success factors, key performance indicators and measures together with their short and long term targets. This kind of development at US universities was anticipated by Peter F. Drucker as early as 1985 (Drucker 2011, p. 161-169).

1.7 Scope of the Thesis

This study has its focus on the field of mechanical engineering to define the systematics needed to develop the teaching strategy of PD engineers so as to reach optimum learning results. The word optimum here means primarily that the results are the best possible in the available time and with the other available resources for the courses including PD competences. Even though the main focus is on the individual courses, it also includes the more general curriculum development. The target educational institutes are UASs in Finland. One may ask why the science universities of technology are not included in the scope of the research. There are several reasons for this focus and the most important ones are:

- Engineers from the two types of universities have very often somewhat different job descriptions in companies; on the one hand the work of an engineer from a UAS is normally more practical in nature and on the other hand the work of an engineer from a science university may have a more research oriented emphasis.
- The teaching methods in these two types of universities are also a little different because of the above mentioned differences in typical job descriptions.

Figure 4 describes these differences from the point of view of: student orientation, the teaching method used and the level of engagement. To achieve good learning outcomes in the UAS environment it is better to use active learning methods, like problem-based learning (PBL), rather than standard lectures. Learning methods will be discussed in more detail in chapter 2.

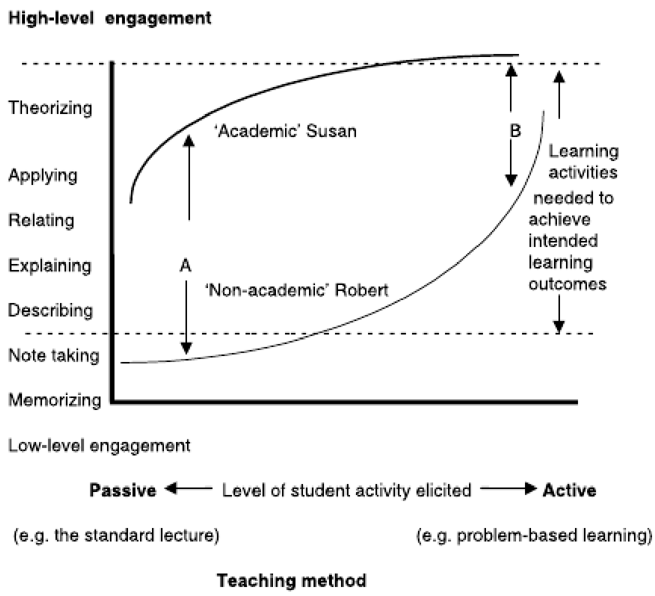

Figure 4. *Student orientation, teaching method and level of engagement (Biggs and Tang 2011, p. 6).*

When thinking of the competences of PD engineers the scope of the thesis covers the engineers who are working in manufacturing companies not, for example, those in the research institutes. For this reason the emphasis of the study is more on practical and application oriented PD than on PD which supports scientific research. This also means that Finnish engineering workshops are the main employers of the engineers who are focused on in this thesis.

The author wishes that the results of the thesis can be used as one information input for Finnish text books or other kinds of literature for PD at UASs. There are still today very few Finnish language text books for PD with a Finnish industry background. The author hopes that this thesis motivates researchers and teachers in Finland to create more discussion, research and cooperation around this important subject.

1.8 Structure of the Thesis

The study has eight main chapters and four appendices. The main chapters are:

1 Introduction;
2 Literature Review (State-of-the-Art);
3 Competence Needs of PD Engineers in Mechanical Engineering – Empirical Study using a Case Study Approach;
4 Model of Teaching Strategy Development;
5 Teaching Strategy for the PD Education of Mechanical Designers;
6 Review of Course and Curriculum Development Models;
7 Discussion;
8 Conclusions.

The first chapter introduces the background and motivation, RG, RQs and RH of the thesis. Also the scope of the thesis has been discussed in this chapter.

Chapter 2 includes the literature reviews on the two subjects: Competence needs of PD engineers in mechanical engineering and the educational methods of PD engineers in mechanical engineering. At the beginning of the chapter there is also some background information about the internationalization of the Finnish technology industry and especially about the branch of mechanical engineering.

Chapter 3 covers the case study about the competence needs of the PD engineers in mechanical engineering. The purpose of this chapter is to find reliable evidence to answer the three RQs.

In chapter 4 the teaching strategy of a course is defined as a modular service product and a model for its development is introduced to find evidence for RH. The definitions of the product, the customer and the other relevant items in the PD project of this service product are also introduced in this chapter.

In chapter 5 the development tool of chapter 4 is applied to the service product, which is a teaching strategy for a course. This is to illustrate the use of this development tool and thus the systematics targeted by the RG of the thesis.

In chapter 6 course and curriculum development models are reviewed. Existing models are analysed and compared with the model presented in this thesis as defined and illustrated in the two previous chapters.

Chapter 7 covers the discussion about the whole of the thesis and its results.

Finally, chapter 8 concludes this research.

The four appendices are:

Appendix 1: The List of Skills Questions in the Case Study Questionnaire
Appendix 2: Pilot Case Study Report
Appendix 3: Case Study Results
Appendix 4: The List of Questions on the Student Feedback Questionnaire

2 Literature Review (State-of-the-Art)

In this chapter literature on the competence needs as well as the educational methods in engineering design are reviewed. Both are very essential elements in teaching strategy development and thus in the RG of this thesis. As background information there is a brief overview of the internationalization process of Finnish mechanical engineering.

The main goal of this chapter is to highlight the national and international research of the above mentioned fields. Even though the international research results on the competence needs are not directly applicable to the Finnish industrial environment, it is interesting and valuable to compare them with the corresponding results of this thesis. Also the structures and the educational responsibilities of HEIs abroad are often different from those in Finland. This, as well as for example the differences in cultures (Lewis 2006), means that the educational methods may also have special national features.

Major journals in the field of engineering design and education are: Journal of Engineering Education, International Journal of Engineering Education, European Journal of Engineering Education, Journal of Technology Education, The Journal of Technology Studies and Global Journal of Engineering Education. Important international conferences in the field are: International Conference on Engineering and Product Design Education (E&PDE), International Conference on Engineering Education (ICEE), European Society for Engineering Education (SEFI) Conference, International Conference on Engineering Design (ICED), American Society for Engineering Education (ASEE) Conference and IEEE Frontiers in Education Conference (FIE).

After the definition and illustration of the teaching strategy development model in chapters 4 and 5, a literature review of existing course and curriculum development models is made in chapter 6. These existing models are analysed and compared with the model presented in this thesis.

2.1 Research on Competence Needs of PD Engineers in Mechanical Engineering

In many industrialized countries the working environments of engineers have changed a lot lately. There are many reasons for these changes, but one of the most important reasons is the globalization of markets. This globalization has also influenced the locations of production facilities and component suppliers. Even PD activities have been moved closer to a product’s growing markets.

All this means changes in the needed competences of engineers. Because the domestic market in Finland is relatively small for the Finnish mechanical engineering companies' products, this globalization process has been going on already for several years in Finland and it will continue further.

2.1.1 Internationalization Process of Finnish Mechanical Engineering

The Federation of Finnish Technology Industries regularly carries out several kinds of surveys among its member companies. Figure 5 shows that the number of persons employed in Finland in mechanical engineering has been stable or even decreased a little during the last decade whilst at the same time it has increased in subsidiaries abroad.

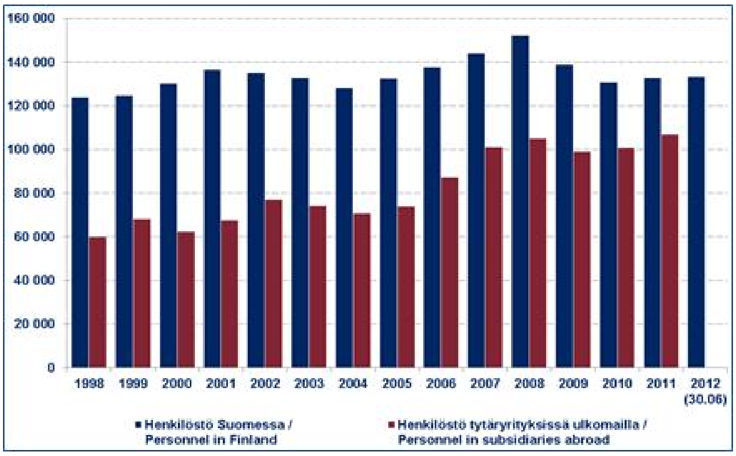

Figure 5. *Personnel in Finland-based mechanical engineering companies in Finland and in international subsidiaries (The Federation of Finnish Technology Industries Statistics 2012).*

Figure 6 shows that when thinking of the personnel in subsidiaries abroad Western Europe is the most important region for Finnish companies, although its relative importance is decreasing. It also shows that the most rapid growth is taking place in the region of Asia and Oceania.

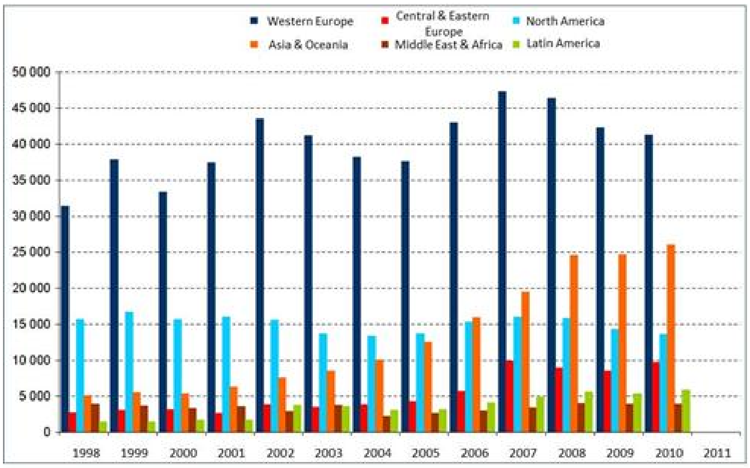

Figure 6. *Mechanical engineering personnel of Finland-based companies in subsidiaries abroad (The Federation of Finnish Technology Industries Year Book 2012).*

According to Figures 5 and 6 the Finland-based mechanical engineering companies have become more and more international and Asia (and Oceania) is very important in this process; especially China and India. This also means a new kind of competence is needed for the engineers in this sector compared with that needed at the beginning of the millennium.

2.1.2 Competence Needs in Finnish Mechanical Engineering

The skill needs of the Finnish technology industry companies were examined in the project commissioned by The Federation of Finnish Technology Industries in 2005-2007. The first part of this project was a survey among the mechanical engineering sector in 2006 which was reported by Leppimäki and Meristö (2007). In total 223 companies replied to the survey. The main purpose of the survey was to identify the most essential changes in the operational environment of the mechanical engineering sector until the year 2020 and also to identify what kind of skill and development needs these changes will cause in the sector.

The six most important competence fields, according to this survey, are: sales skills, customer interface, leadership, production methods and technologies, language skills and automation including mechatronics and robotics. In the technology and PD related skills the most important ones are: material technology, energy and environment technology, utilization of user information in PD, management of PD in the global environment, product modularization and variation and environmental viewpoints.

One can derive some competence needs for mechanical designers in PD from the results of this survey. However this survey was made of the whole of the mechanical engineering sector and thus the number of PD focused questions had to be relatively limited. Also the PD related results refer to the whole PD function, not only to the designers.

2.1.3 Competence Needs in Australian Mechanical Engineering

Research into the field of competence needs and educational contents and methods has been widely carried out in Australia. One such study of Australian mechanical engineers was made by Clive Ferguson (Ferguson 2010).

The key questions in the book by Clive Ferguson are (p. 7):

1. "What is the relative significance of each of the broad range of potential attributes that enable mechanical engineering graduates to most effectively perform the most prevalent mechanical engineering roles in those industries that engage the greatest numbers of mechanical engineers in Australia?"
2. "What are the most suitable teaching and assessment strategies to develop these attributes through both proximal and distance based delivery without further erosion of the mechanical engineering knowledge base?"
3. "How can distance education technologies facilitate and enhance these teaching methods?"

In this section only the study as related to question 1 and the results of that study are discussed (Ferguson 2010, p. 141-161). There were six different fields of mechanical engineering in the companies which participated in the study: consulting engineering, transport manufacturing, electricity and gas supply, mining and quarrying, construction contract and maintenance and defence excluding those in the armed services.

The case study approach used was by face-to-face or telephone interviews. Three different significance ratings for each of 84 attributes in 12 groups were given by the interviewees: new graduate ability, stage 1 engineer and stage 2 engineer. Stage 1 engineer is a bachelor of engineering with less than three years professional experience and stage 2 with more than three years professional experience. The interviewees were engineering managers in the companies. (Ferguson 2010, p. 141-142.)

A five point scale was used and the corresponding numeric values (0…4) were used to calculate the averages and variances. There were only 3 attributes to have an average significance value higher than 3.5 for stage 1 engineer: team skills (in the group on management), e-mail skills (in the group on written communication) and applications of office software (in the group on computer skills). On the other hand there were as many as 22 attributes with a significance value higher than the 3.5 average for stage 2 engineers. The 22 attributes are listed in Table 1.

Table 1. *Significant attributes for stage 2 engineer (Ferguson 2010, Table 6.3, p. 154-155 simplified).*

Groups / Attributes	**Av. significance**
Personal attributes	
Conscientiousness (disciplined approach to work)	3.69
Reliability	3.74
Interpersonal social skills	3.84
Time management	3.87
Management	
Team skills	3.82
Occupational health and safety awareness	3.84
Planning and organisational skills	4.00
Leadership	3.69
Project management skills	3.51
Written communication	
E-mail	3.86
Reports	3.85
Oral communication	
One-to-one technical	3.78
Committees / group meetings	3.65
Problem solving	
Application of science and engineering fundamentals	3.67
Recognition and formulation of a problem	4.00
Broad-based engineering knowledge base	3.69
Recognise when to use engineering analysis	3.67
Design	
Documentation	3.56
Application of standards and statutory regulations	3.92
An ability to sense the design looks sound	3.62
The ability to know when to call in a specialist	3.56
Computer skills	
Applications (of office software)	3.73

Another older and much smaller Australian survey study proposes that in the dynamic world of engineers the non-technical skills and attributes such as communication, problem-solving and management skills, must have a higher focus in the education of engineers. “On the other hand although the shift involves a movement to soft-engineering, the technical aspect of engineering is not less relevant and technical skills formation remains at the core of engineering” (Nguyen 1998, p. 66).

In this Australian survey study the returns from the industrial companies as a percentage was only 11%. The number of industry returns was however as high as 81, because 707 surveys were sent out. (Nguyen 1998, p. 67.) One can ask how well this 11% of the companies represent the total target group. This kind of low response rate is a typical problem in surveys when compared with case studies for example.

2.1.4 US Research on Competence Needs of Engineers

In the 80’s and 90’s the US industry lost global market share in many fields of technology, not least in the car industry. The Japanese and European competition was very aggressive. The quality of the American products was not at the same level as that of the competition.

There are a lot of reasons for this kind of development in the world market. In this case engineering design education at the US universities was criticized as being too theoretical and thus producing scientists rather than design engineers (Nicolai 1998).

Nicolai (1998) compares US engineering schools with the Japanese and European ones. He points out that the American industry needs engineers who can solve open-ended problems and produce quality design work (Figure 7). Based on this comparison he lists the following skills which are important to meet this target (adapted from the article, p. 11-12):

- Solid grasp of the fundamentals in mathematics, basic sciences and engineering sciences;
- Understand and experience of the design process;
- CAD/CAM and also drawing and sketching by hand;
- Communication skills;
- Kinematics;
- Statistics;
- Materials and processes of manufacturing;
- Economics in the sense of product cost;
- Experience with real design problems.

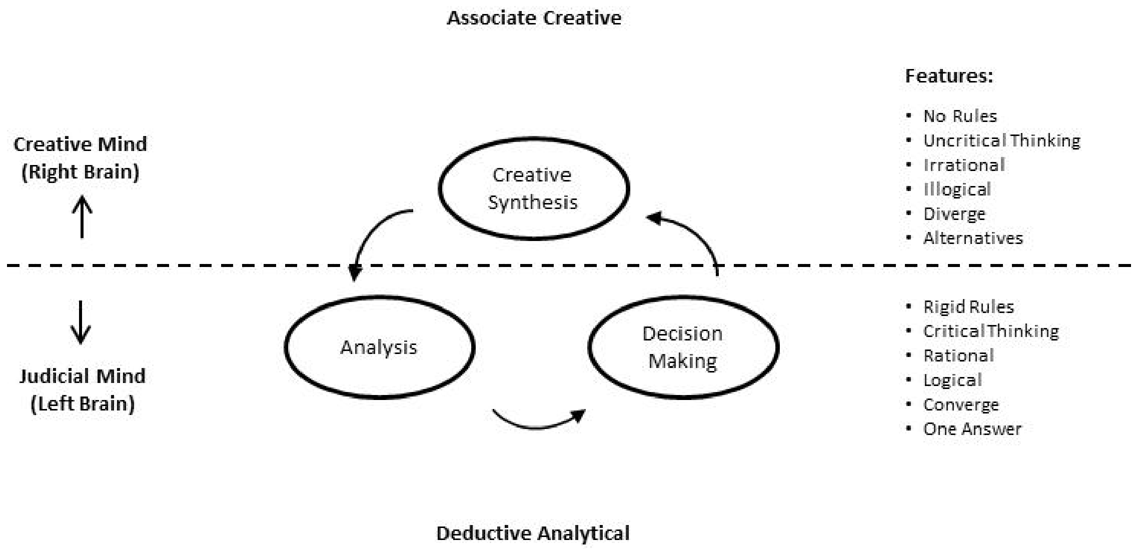

Figure 7. *Features of the design process as an open-ended problem (Nicolai 1998, p. 10).*

Another US research by Sheppard and Jenison (1997) concentrates more on design education; especially during the first study year. The article discusses many innovative design experiments going on in US engineering schools and lists 16 qualities expected in a design engineer (Sheppard and Jenison 1997, p. 249):

1. “Communicate, negotiate and persuade.
2. Work effectively in a team.
3. Engage in self-evaluation and reflection.
4. Utilize graphical and visual representations and thinking.
5. Exercise creative and intuitive instincts.
6. Find information and use a variety of resources (i.e., resourcefulness).
7. Identify critical technology and approaches, stay abreast of change in professional practice.
8. Use analysis in support of synthesis.
9. Appropriately model the physical world with mathematics.
10. Consider economic, social and environmental aspects of a problem.
11. Think with a systems orientation considering the integration and needs of various facets of the problem.
12. Define and formulate an open-ended and/or under-defined problem, including specifications.
13. Generate and evaluate alternative solutions.
14. Use a systematic, modern, step-by-step problem solving approach. Recognize the need for and implement iteration.
15. Build up real hardware to prototype ideas.
16. Trouble-shoot and test hardware”.

Even though this list is a little longer than that of Nicolai (1998) there are, not surprisingly, a lot of commonalities. Both of the researches emphasize skills to formulate and solve open-ended problems.

A large three-year study made in the US on the impact of EC2000 (Engineering Criteria 2000) on engineering student learning outcomes and on organizational and educational policies and practices shows that EC2000 may have led to improved student learning outcomes. EC2000 is based on the criteria for accrediting engineering programs that were effective during the 2001-2002 ABET accreditation cycle. These criteria are common to every engineering programme and thus they are of a quite general nature. However, the demands for the non-technical skills can be applied to the different fields of engineering. The article lists the greatest differences in student learning after the application of EC2000 compared with the previous students and graduates. "Recent graduates have better:

- Understanding of societal and global issues;
- Ability to apply engineering skills;
- Group skills;
- Understanding of ethics;
- Professional skills". (Lattuca et al. 2006, p. 13)

It is easy to realize that all these are important achievements in learning results.

2.1.5 Other European Research on Competence Needs

The EUR-ACE Framework Standards for the Accreditation of Engineering Programmes (EUR-ACE 2008) establish guidelines for engineering education in Europe in bachelor and master levels. The focus is on the outcomes of an accredited programme and it is not evaluated how these outcomes are realized. The EUR-ACE standards have been divided into three parts:

1. Programme outcomes for accreditation
2. Guidelines for programme assessment and programme accreditation
3. Procedures for programme assessment and programme accreditation

For the first part the standards lists six programme outcomes (Standards, p. 4):

- "Knowledge and Understanding;
- Engineering Analysis;
- Engineering Design;

- Investigations;
- Engineering Practice;
- Transferable Skills".

According to the standards the second part, guidelines for assessment and accreditation, must at least consider the following items (Standards, p. 8):

- "Needs, Objectives and Outcomes;
- Educational Process;
- Resources and Partnerships;
- Assessment of the Educational Process;
- Management System".

The third part lists the steps the assessment and accreditation should follow. The procedure is based on self-assessment followed by external assessment. The idea is the same as in the case of quality system audits. The EUR-ACE Framework Standards concern engineering education in general and thus the application to PD work in mechanical engineering is limited.

The study of the Association of German Engineers VDI is the most important quality demand study in engineering in Germany according to Meerkamm et al. (2009), especially when working in the field of R&D or E&D. Figure 8 shows the results of this VDI study. It is interesting to note that personal skills as well as soft skills are evaluated as less important, especially in R&D work.

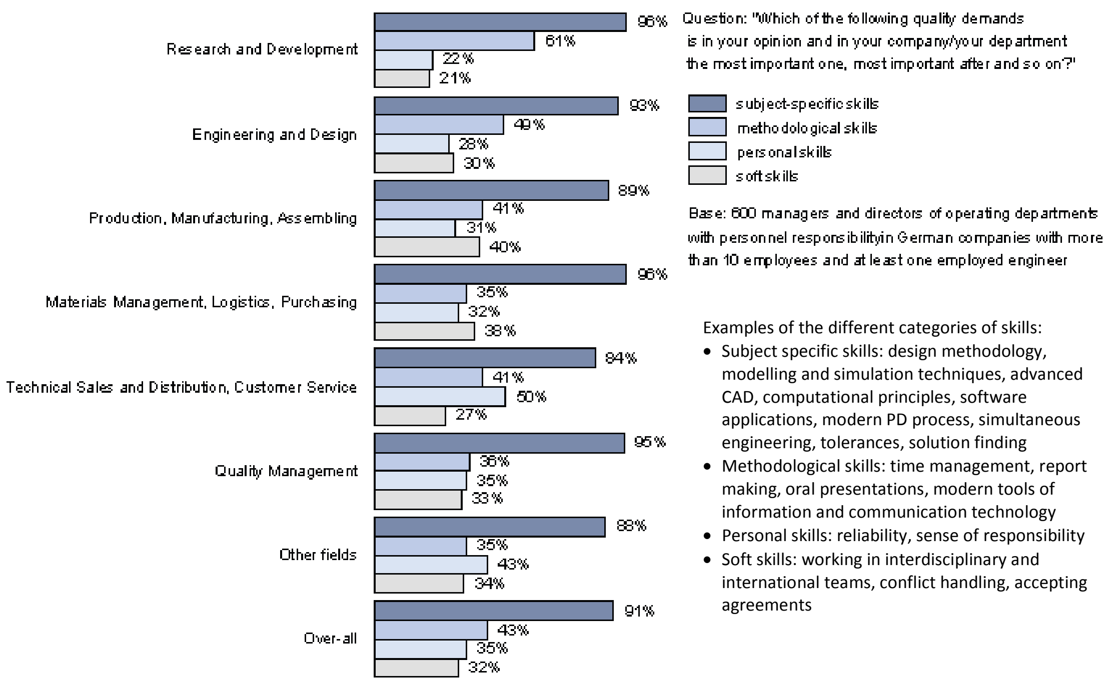

Figure 8. *Quality demands on engineers according to the VDI study (Meerkamm et al. 2009, p. 37and 38).*

The UK standard for professional engineering competence (UK-SPEC) by the Engineering Council (2010) is a registration process for technicians, bachelors of engineering and masters of engineering or science. The official three categories in the standard are: Engineering Technician (EngTech), Incorporated Engineer (IEng), Chartered Engineer (CEng). The standard lists the competences, and associated ways to demonstrate these, for all three categories. The competence lists cover many engineering areas like design, manufacture, operation and so forth. So, it is quite general in nature and has limitations when applying it to mechanical designers working in PD.

2.1.6 Conclusion

There is a limited amount of Finnish research in the field of competence needs in mechanical engineering, especially those that have a focus on PD. On the other hand this subject has been widely researched internationally; especially in Australia and in the US. The main reason for this is the general worry in these countries about their products' loss of competitiveness, particularly in the US car industry in the 80's and 90's.

Although there are some commonalities in the results of the Australian and the US studies there are also a lot of differences. This is understandable because, for example: the industry structures in these countries are different and the general cultural differences (Lewis 2006) in the countries have an influence on the competence needs.

It is understandable that the competence needs of mechanical engineers in PD work in the Finnish industry are to a certain extent different from the needs in other countries; especially to those which are outside Europe. The only reliable way to find out these needs and the relative importance of each of them is to make a local study covering typical Finnish mechanical workshops. This kind of study is reported in chapter 3.

2.2 Research on Educational Methods of PD Engineers in Mechanical Engineering

There has been a lot of research into the field of educational methods and also into that which has focus on mechanical engineering and PD. Many articles and handbooks about the different teaching, learning and assessment methods in engineering education in Finland have been written in The Teaching and Learning Development Unit at Helsinki University of Technology.

The purpose of this thesis is not to create new educational methods. The idea of this research is to present existing and tested educational methods which could be successfully used in the education of PD engineers in mechanical engineering in Finland using a new teaching strategy development model. So, the focus of the literature review below is on presenting different teaching and learning methods and issues connected with them; not to make a critical comparison between the different methods. There are tens of teaching and learning methods and many variations of each. Here the emphasis is on active learning methods as is also argued in section 1.7.

When developing the learning methods in HEIs the needed resources must be taken into account. Nowadays universities in many countries are under severe financial pressure and the student numbers in teaching groups are increasing rather than decreasing. These financial pressures on universities are a threat; especially to active learning methods which usually require more resources per student than traditional lectures. These resources are not only the teaching hours but also, for example, well equipped laboratories.

2.2.1 Teaching, Learning and Assessment Methods

The handbook for teachers by Hyppönen and Lindén (2009) gives practical guidelines for teachers to develop the quality of teaching needed to achieve the best possible learning results. It is an extensive presentation about teaching and learning methods as well as teaching and learning assessment methods.

The emphasis of the handbook is to introduce alternative learning methods instead of the traditional lectures and examinations after the lectures. These have the risk of being a passive method and to lead to superficial learning results. The handbook has been made in cooperation with the teachers of Helsinki University of Technology and thus it is very suitable for teaching quality development in engineering education.

The handbook brings forth a total of 41 different teaching methods with the strengths and challenges of each. It has been realized, in general, that the more active methods (like exercises, PBL, case teaching, project work, learning by doing) give better and deeper learning results.

The handbook points out the importance of the definition of the learning outcomes set for the students at the beginning of the course. To reach these learning outcomes the teacher needs to plan not only the teaching and learning methods but also to select suitable assessment methods.

The handbook includes also a long list of literature and also an extensive list of sources used, which are both Finnish and international books and articles. Many of the Finnish language articles or books are available also in the English language and also many of them can be printed from the Internet.

2.2.2 Project-Based Learning

The work of a PD engineer nowadays includes much more than just the subject-oriented issues. The work is typically team-work and very often the teams are international. Therefore, for example, communication skills, language and cultural skills (Lewis 2006) and general problem solving skills are important in this work. These kinds of skills are best learned by doing real PD work during the studies. Many universities have developed these kinds of project-based learning methods to reach the learning outcomes needed.

The Institute of Product Development at the University of Karlsruhe has developed the educational project “Integrated Product Development and the continuous improvement of KaLeP” (Albers et al. 2006). KaLeP includes three educational phases with the courses in the second, sixth and ninth semesters (Figure 9). The first and second phases include general product development courses. The final phase includes the integrated product development course aimed at students specializing in product development and design. Student teams, of about 5 students each, make a four-month PD project given by an external cooperation partner company. The student teams compete with each other and try to convince the partner company’s management of the superiority of their own solution against that of the others. The number of students is smaller after each phase because of their more focused specialization.

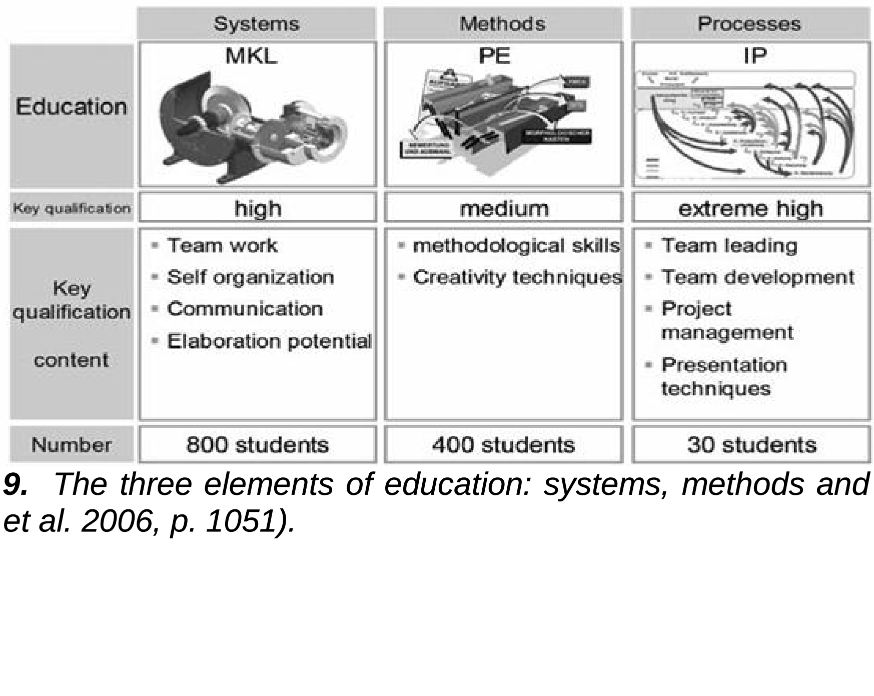

Figure 9. *The three elements of education: systems, methods and processes (Albers et al. 2006, p. 1051).*

Ponn et al. (2007) have developed a systematic evaluation method for single and group design projects in the Institute for Product Development at the Technical University of Munich. The projects suitable for this kind of evaluation can be “constructive, theoretical or experimental” in nature. The article gives three groups of relevant criteria for the evaluation of the design project (Figure 1, p. 3 in the article):

- How the project is carried out?
- How the project is documented?
- How the project is presented (oral presentation, only applicable for Master Thesis)?

Each of these three groups includes several questions for the evaluation and all evaluation questions are communicated to the students when the project is started.

Neighbour and Cutler (2007) have developed “a learner-centred practice (LCP)” to teach the PD process using a PBL-method. The PD process presented in the book by Ulrich and Eppinger (3rd edition, 2003) is recommended to be used by the student groups in their projects. The 10-credit course takes place in the final year of MEng and MSc modules. The method was first developed at the Institution of Mechanical Engineering and was later also included in other disciplines such as: electronic engineering, medical engineering and environmental technology. The basic idea is that each multidisciplinary student group provides new product ideas (market-pull type) and seeks approval to develop one idea. Every student group member has a specific role in the team, such as: the team leader, the finance or marketing executive. Each student team reports the progress of their project to the Chairman. It is important that the teaching team has significant industrial experience. This LCP method developed at the University of Hull, UK is a very active learning method and strongly supports deep learning results.

Perea (2008) focuses on the experience and feedback resulting from the introduction of a poster presentation as one of the two assessment elements in a project-based learning method used at London South Bank University. There were two cohorts of students, one from mechanical engineering and one from CAD. The learning method itself includes a real-world problem to be solved by the student team. “Students make a poster presentation with their initial design concepts and a project report on the seventh week of the course (Figure 10). All posters were pinned to the walls and each student describes their concept designs for 10 minutes to the other students and the teachers” (Perea 2008, p. 2). The feedback from the students was encouraging. They like the active learning method which makes them participate in the process and learn from each other. “For most of these students the poster presentation was the first time they had ever presented their ideas orally. Also English was not their first language, which made the presentation situation even more exciting” (Perea 2008, p. 4).

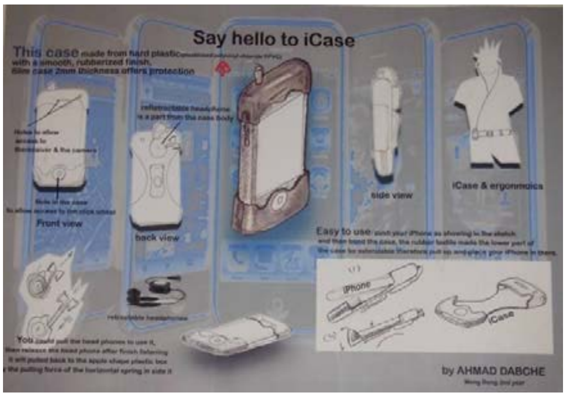

Figure 10. *The poster of a 2nd Year student, BEng Mechanical Engineering (Perea 2008, p. 2).*

The next project-based learning example is from the faculty of Mechanical Engineering at the University of Maribor, Slovenia by Novak and Dolšak (2008). Groups of five to seven students, appointed by the lecturer, select and carry out the project under the supervision of the lecturer. They use the PD guidelines of Pahl and Beitz (2nd edition, 1996). The students need to find a new solution to a problem. They develop this solution during their project. They work in a team and present their work to the teachers and to their colleagues at the end of the project. “It is very important that they learn how to present and defend their final solution with convincing arguments” (Novak and Dolšak 2008, p. 1). Figure 11 shows two examples of the final results of the projects.

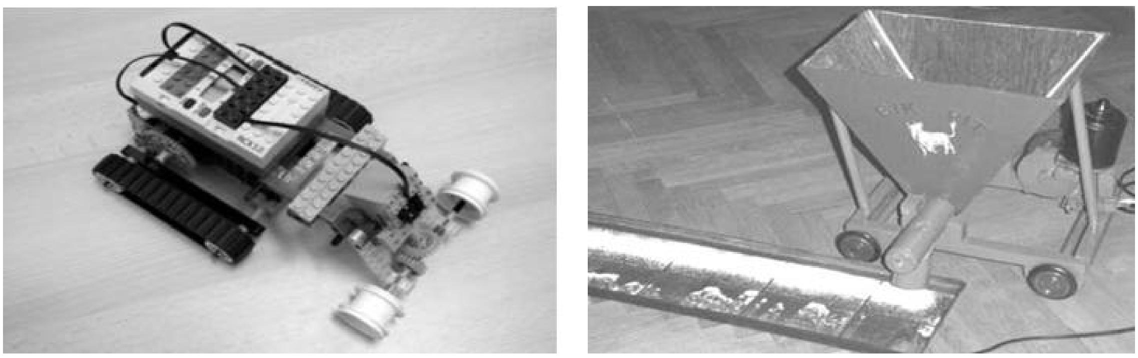

Figure 11. *Two examples of the final results of the projects (Novak and Dolšak 2008, p. 5).*

For the further development of the method Novak and Dolšak (2008) lists “some general guidelines resulting from their experiences:

- Members of the group and lecturer should have a friendly attitude towards each other.
- The possibility to define their own project usually increases the students' motivation.
- Project complexity should be extensive enough taking into account the number of group members.
- A well-defined reward (exam marks or payment) may increase the success of the projects.
- Objective project examination also motivates the students.
- Exact definition of milestones is essential.
- An optimistic approach of all members and the lecturer is required.
- Sometimes an excursion related to the project adds new élan.
- Financial support for project prototype improves the final result.
- It is a good idea to announce the competition and first place prize." (Novak and Dolšak 2008, p. 6.)

It can be seen that several guidelines in the list above are also valid in the industrial surroundings of engineers.

The last project-based learning example is the project workshop concept from the degree programme of Mechanical Engineering at the School of Technology at Seinäjoki University of Applied Sciences in Finland (Pajula et al. 2011). The basic idea is that student teams from the second or third study year solve real companies' assignments under the control of company representatives and the university teachers. These student teams use project working methods. One of the team members is the project manager and the others also have specific roles in the project. The assignments are typically pre-design and production or product development tasks. Depending on the task the team may also be multidisciplinary and even international. The main objective is that the students learn to work together on the project as well as carry out its written report. Before joining the project workshop team the student must pass a project management course as well as a communication course.

The experiences during the four years 2007-2011 on the application of this project workshop concept are:

- Students have high motivation when working with "a real company" and "a real problem".
- Students learn entrepreneurship.
- Students learn to solve open-ended problems.
- Teachers get up-to-date information about the current issues in companies and can utilize this information to update the teaching material.

- Companies may have fresh ideas from the student teams about the problems to be solved.
- Companies get to know the individual students during the studies which may lead to cooperation in thesis work and even to employment after the graduation of the student.

In total 117 projects have been made during the four years 2007-2011. This concept has become a part of the curriculum at the school of technology at Seinäjoki University of Applied Sciences.

2.2.3 Linking Design, Analysis, Manufacture and Test

The Department of Mechanical Engineering at Imperial College London, UK, has developed, for the second year students, a course which covers the design, analysis, manufacture and test of a hydraulic pump (Childs et al. 2010). All the student teams make all these phases by themselves. Each year the best team has the names of the team members added to the trophy which is displayed in the department. The authors list the specific learning objectives of the course as (Childs et al. 2010, p. 3):

- "To experience a design make and test project in all the stages from the design specification to manufacture and test and presentation of the results;
- To understand and experience the application of computer aided engineering in the design context;
- To develop an understanding of the application of machine components and their analysis;
- To understand the need to design for manufacture and assembly;
- To learn the basics of process planning and costing in a mechanical engineering context;
- To understand the interdisciplinary nature of design."

Also in this case the assessment is considered important with: the final report, the manufacture quality as well as the poster exhibition being assessed using self, peer and tutor assessment. The detail design phase is made in the same way as in a real industrial engineering project including: the assembly drawings, the bill of materials, the detailed engineering drawings for manufactured parts and CAD solid models for the CNC manufactured parts (see Figure 12).

Figure 12. *Example of a typical set of pump components manufactured by a student group (Childs et al. 2010, p. 5).*

This kind of learning process offers realistic experiences of engineering work to the students and is also demanding for the teachers.

2.2.4 Product and System Lifecycle Development and Deployment

At the beginning of the 21st century the four universities (Chalmers University of Technology in Göteborg Sweden, The Royal Institute of Technology in Stockholm Sweden, Linköping University in Linköping Sweden and Massachusetts Institute of Technology in Cambridge USA) formed an international collaboration to improve undergraduate engineering education in Sweden, the USA and worldwide (Berggren et al. 2003). “The three goals directed the alliance’s endeavours. They were to educate students to:

- Master a deep working knowledge of technical fundamentals.
- Lead in the creation and operation of new products and systems.
- Understand the importance and strategic value of their future research work” (Berggren et al. 2003, p. 49).

The CDIO (Conceiving – Designing – Implementing – Operating) Initiative was established and is nowadays used in several universities all over the world. In January 2004, the CDIO Initiative adopted 12 standards that describe CDIO programs. Standard 1 gives the programme description and also defines in more detail what the four CDIO stages include (CDIO Initiative 2004, p. 1):

- “A CDIO program is based on the principle that product and system lifecycle development and deployment are the appropriate context for engineering education;
- Conceive – defining customer needs; considering technology, enterprise strategy and regulations;

- Design – plans, drawings, algorithms that describe what will be implemented;
- Implement – manufacturing, coding, testing and validation of product;
- Operate – maintaining, evolving and retiring of product or system".

CDIO is an active learning method and an application of PBL. It means a new approach in curriculum and teaching and needs well-equipped laboratories. The book by Crawley et al. (2007) describes both the development and implementation of the CDIO approach.

2.2.5 Mechanical Design Learning in VR Environments

The distance education systems utilizing virtual learning environments like television or computer (web-based learning) have severe limitations in achieving successful learning results in mechanical engineering. As, for example, Mengoni and Germani (2008), p.2 states: "The face-to-face is more successful than distance learning in mechanical design where the understanding of the design principles requires a concrete experimentation of general principles." Similar challenges are also mentioned by Hyppönen and Lindén (2009).

In this section, only Virtual Reality (VR) laboratories as virtual learning environments for mechanical engineering are considered. Even though the VR technologies are still relatively young and under intensive development, they can be utilized in the teaching of some special subjects in mechanical engineering.

Mengoni and Germani (2008) highlight the potentialities of VR for improving the learning process of mechanical design principles. Their focus is on using VR in teaching functional design, assembly design and tolerances. They list the main advantages of using VR technologies in teaching as (abridged article list, p. 2):

- Improvement of spatial ability;
- Link between education and practice;
- Facilitation of knowledge sharing and collaboration in multidisciplinary teams;
- Achieving a sense of presence;
- Stimulate students' motivation and contribution as well as increase their sense of fulfilment.

The article states the four available VR technologies (visual, sound, haptic and motion) and only a combination of these technologies provides a deep involvement of all senses and is thus most suitable also in learning situations.

2.2.6 Mechanical Design Education using Hands-on Models

The first example of the use of a hands-on model in U.S. research was made in a consortium of three schools: the Massachusetts Institute of Technology (MIT), the Rochester Institute of Technology (RIT) and the University of Detroit Mercy (Frey et al. 2000). The idea was to give design challenges to student teams of 5…6 students to compete with each other. The students were bachelors of engineering starting their master's degree studies. The first competition in MIT included 10 teams and the time available for the teams was about 20…25 hours during four days. The competition in RIT was similar; except for the time available which was extended to two weeks. Both of the competitions also included PD lessons.

The learning objectives of this research were (p. 489 in the article):

- "Expose participants to an intense, multi-disciplinary system design / product development experience;
- Prompt participants to think about system architecture;
- Raise issues of organizational processes in an engineering context;
- Build the learning community of students, faculty, and staff".

The conclusion of this research was that a design challenge competition can work well as a first experience in PD studies in a master's degree programme. It clearly increased the interest and motivation of the students in the field of PD. One positive experience was also the cooperation between the institutions, because more resources were available for the planning and implementation of the hands-on design exercises.

Another example of the use of a hands-on model is by Field et al. (2009). They have made a large research into the spatial skills of mechanical designers. From an earlier survey of the Australian plastics industry the authors found that there is a need to enhance the training of die designers. To test a new learning approach they established a target group of 42 volunteer students in the Department of Mechanical Engineering at the University of Melbourne, Australia. The course covered the designing of a die set for an injection molding machine (Figure 13). The new learning approach included the use of wooden die set models to enhance the students' 3D visualization skills. Half of the students used the wooden models and the other half the conventional 2D drawings. The result was that the students with low spatial skills achieved greater learning outcomes when their training programme was built around the use of a physical model compared with a similarly skilled sub-group who were trained using conventional 2D drawing material. Another control group with high spatial skills, and including also two sub-groups (one used a physical model and other 2D drawings), achieved learning outcomes that were not significantly different.

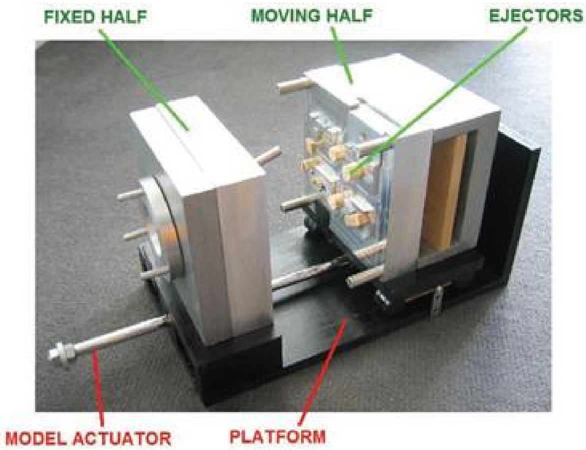

Figure 13. *A simplified model of an injection molding machine and a die set (Field et al. 2009, p. 51).*

A German research introduces the concept of an interactive machine part exhibition; to be used as a motivating and comprehensible learning method. In 2010 the concept was still in the implementation phase at Hamburg University of Technology and will contain fundamental machine parts like bearings, fasteners and shafts but also more complicated industrial examples like gearboxes. "The cornerstone of the exhibition is the idea that the students should have the opportunity to handle, touch and interact with all exposed objects to create a better comprehension of machine parts, a complex mechanical system and the process of designing" (Beckmann and Krause 2010, p. 4). The machine part exhibition can be utilized in the different mechanical engineering courses even before the course starts. The article summarizes the benefits to better learning outcomes as (p. 3-5 in the article):

- "Touch machine parts;
- Comprehend the functionality and design;
- Disassemble selected exhibits;
- Explanations using real objects;
- Industrial examples to increase industrial motivation".

Figure 14 illustrates the link between lectures and real objects. The hands-on experiences give better understanding of the virtual models.

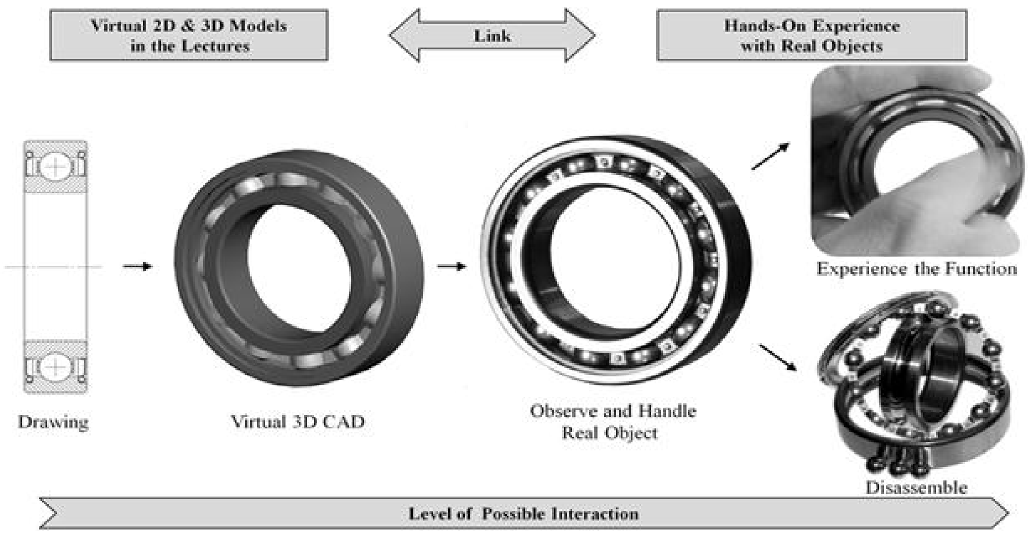

Figure 14. *The link between lectures and real objects (Beckmann and Krause 2010, p. 5).*

In 2010 it was too early to give detailed experiences or the evaluation of teachers and students, because the concept was still under development. However the university looks forward with positive and optimistic expectations to the possible advance in design education.

2.2.7 Sustainable Design Integration into Pedagogy and Curriculum

Sustainable design is nowadays an important part of PD in every field of engineering. Its importance will continue to grow in the future (Leppimäki and Meristö 2007). It is not limited only to the selection of material or recycling; it is much wider in nature. It is the responsibility of engineering educators to include it in the methods and contents of teaching.

Klein and Phillips (2011) have developed a curriculum model and a pedagogy for teaching the concepts of sustainability to the industrial design students at the Metropolitan State College of Denver. The model and pedagogy can be applied also to the teaching of students in other degree programmes, for example in mechanical engineering. The article (p. 13) lists the following learning objectives in this subject:

1. “Recall, discuss, and apply information about low-impact materials – renewable materials, awareness of material toxicity, and the relative embodied energy of materials.
2. Evaluate and choose design solutions that provide increased energy efficiency in transportation, consumer use of products, and manufacturing processes.
3. Identify and discuss components of life cycle assessment techniques and select design solutions for maximal product quality and durability.
4. Design products that facilitate their reuse and recycling at the end of their lifecycle.
5. Select product designs, materials, and processes that have a positive social impact.”

The authors of the article state that sustainable design should be assessed at the more “global” programme level, not only at the course level. When looking at the list of the learning objectives above it can be realized that mechanical designers have several courses which have an impact on these objectives. Material technology, manufacturing methods, strength of materials, mechanical vibrations and product development are some examples of these kinds of courses.

2.2.8 Case Study as a Teaching Method in Mechanical Engineering

Research by Yadav et al. (2010) has tested a case study as a teaching method in a mechanical engineering course. The target of this research was to compare the traditional lectures with the case study teaching method then evaluating the undergraduate mechanical engineering students’ conceptual understanding and their attitudes towards the use of case studies.

There were two student groups and two topics for both groups: thermal systems and fluid mechanics. The groups had in total 73 students (31 and 42). One of the two groups used case study in the thermal systems topic and the traditional learning method in the fluid mechanics topic. The other group also used the two learning methods but the opposite way around.

The results of this research show that the students had overall a positive attitude towards the use of case studies. They also felt that the case studies added realism to the class, were relevant to the course concepts and that they were more engaged when case studies were used. The results suggest however that using case studies did not have any significant impact on the students’ conceptual understanding, neither improving nor harming it.

There are three critical findings in this research concerning the use of case study as a teaching method (Yadav et al. 2010):

1. It is important for the engineering educators to gradually introduce case studies in order to have more time for the students to learn the method.
2. The type of case studies (problem-based, historical, scenario,…) used and how they are implemented play important roles in increasing students' conceptual understanding.
3. It is important to use such assessment tools which evaluate the students' learning outcomes in critical thinking and conceptual understanding.

The comparison of the traditional lectures with the case study teaching method in this research shows that they both have advantages and disadvantages. The use of the case study method as a pedagogical technique may offer new possibilities to the engineering educators through its focus on student-centred learning and engagement in authentic problem solving.

2.2.9 Student Learning as the Basis for Teaching Strategy

The book "Learning to Teach in Higher Education" (Ramsden 2003) is a thorough analysis of learning and teaching and gives practical guidelines to teachers. The basic idea of the book is that the best way to improve teaching is to do it by studying students' learning (learning about students' learning). Ramsden states the aim of teaching (p. 7): "it is to make student learning possible."

The main target of good teaching is to get students to understand (deep learning) the subject, not to reproduce (surface learning) information given by the teacher. Six key principles of good teaching in higher education are:

1. Interest and explanation (of teacher and students);
2. Concern and respect for students and student learning;
3. Appropriate assessment and feedback;
4. Clear goals and intellectual challenge;
5. Independence, control and engagement;
6. Learning from students.

Teaching includes the design of curricula, selection of contents and methods, teacher-student interaction methods and assessment. (Ramsden 2003, p. 93-98.)

Ramsden lists five issues to improve the practice of university learning using the “design for learning” approach (abridged, p. 119-120):

1. What do I want my students to learn (goals and structure)?
2. How should I arrange teaching and learning (teaching strategies)?
3. How can I find out whether students have learned (assessment)?
4. How can I estimate the effectiveness of my teaching (evaluation)?
5. How should the answers to issues 1-4 be applied to measuring and improving the quality of education (accountability and educational development)?

Even though this book does not include a comparison of different learning and teaching methods, PBL is mentioned as an example of active learning methods. Traditionally subject-based knowledge is taught separately from its application, but in PBL they are taught simultaneously. Anyhow, he realizes that “it is not the method, but how skilfully it is used, that matters” (Ramsden 2003, p. 162).

At the end of his book Ramsden quotes the old and famous Chinese proverb (p. 247): “I hear, I forget; I see, I remember; I do, I understand.” He also mentions the further development of this, suggested by a Hong Kong gynaecologist for his students: “I hear, I forget; I see, I remember; I make a mistake, I understand.”

2.2.10 Curriculum and Course Development Methods

The foundation of competence-based curriculum or individual course development is the students’ targeted competences. Therefore when universities use this method they need to pay a great deal of attention to correctly defining the competence needs of the graduated students.

Even though this kind of competence-based approach is widely used, the whole development process varies from one university to another. Watt et al. (2011) introduces an interesting course development model. The model has 4 stages as well as 4 milestones after each stage. However, there is no detailed task lists for each stage. The article also emphasizes the importance of customer identification and argues that “it is time for Universities and Colleges to fully embrace the concept of the student as a customer”. At the end of the article the authors note that at this point their work is still almost purely conceptual in nature and needs further development and testing.

The CDIO approach emphasizes the integrated curriculum development method, which means that the students learn several types of skills simultaneously (for example technical fundamentals, problem solving and team work). It also defines the key stakeholders of engineering education: students, industry, university faculty, society. The students are the immediate customers for the education and on the other hand industry is the customer for the graduated students. (Crawley et al. 2007, p. 16.)

2.2.11 Conclusion

The active learning methods are under strong development nowadays and there are various types and versions which have been tested in different universities. CDIO has established a strong foothold at universities all over the world. However, there are also other interesting and successful widely used PBL applications for PD education. Traditional lectures are still the most used in teaching in higher education, although often enhanced with exercises. Whatever learning and teaching methods are used, it is important that they are used in an effective way utilizing student learning studies for the improvement of teaching.

There are many examples of learning-by-doing methods in HEIs when developing mechanical design education. Sometimes the teachers give the student groups a problem to solve and sometimes the students themselves create the task to be solved. However the most interesting and realistic situation is achieved when real partner companies from industry give student groups problems to solve and also participate in the assessment of the results of the work. This gives the students an excellent view of their future engineering work and also activates the teachers to keep in touch with industry.

It is important to understand assessment as an essential part of teaching and learning. There are also a lot of different assessment methods and often more than one is used in each course. It is important for the students that they get feedback from the assessment. This is a very effective way of learning.

Web-based learning is still quite new utilizing information and communication technologies for different kinds of learning materials. It has been developed also in a more active direction so that for example the lessons and the seminars may be run on the Internet. The clear advantage of web-based learning is its flexibility when thinking of time and place. On the other hand there is a risk that the students are even more passive than when using traditional lectures and they are really alone without any real contact with the teacher and the other students of the group.

Some universities (for example Karlsruhe and Seinäjoki) have developed project-based learning methods which utilize real companies' assignments. The student's presentation skills are also developed when reporting the project results to the company representatives. It is very motivating for the students; giving them a taste of real engineering work.

The development of learning methods is firmly connected with curriculum development. CDIO (Berggren et al. 2003) and KaLeP (Albers et al. 2006) are good examples of this connection. It is necessary to consider different kinds of learning methods in different study years. There is also space for traditional lectures, but they also must be developed in such a way as to be interactive.

A competence-based approach is successfully used at universities for curriculum and course development. Watt et al. (2011) propose a conceptual model for course development. This model has 4 stages and milestones, but it is still at a very general level, for example without any details of the phase tasks.

Competence needs and learning methods are important tools for teachers to develop the curriculum and individual courses to reach good learning outcomes. However, there are also other elements (later defined) in teaching and learning development. All these elements are also linked to each other. This means that the development of courses should take place simultaneously with all of the elements. In this research there is a new approach in course development by defining the teaching strategy of a course as a service product including five elements, called modules. This research includes detailed definitions of the customer, product and process to develop a course teaching strategy.

When identifying customer needs for industrial products, it is important to see and analyse the use of the product in real customer environments. In the case of this research the graduated students, as the customers of the universities, use the engineering education product in industry. So, from the university point of view, industry is the customer's customer. The competence needs of PD engineers in mechanical engineering need to be identified in the industrial environment of companies. This is to be done in chapter 3.

3 Competence Needs of PD Engineers in Mechanical Engineering – Empirical Study using a Case Study Approach

This chapter describes the empirical data collection method used to find evidence for the descriptive RQ1 and RQ2 as well as the relational RQ3. The case study methodology used is from the book of Case Study Research by Robert K. Yin (2009). This process has been described in Figure 15.

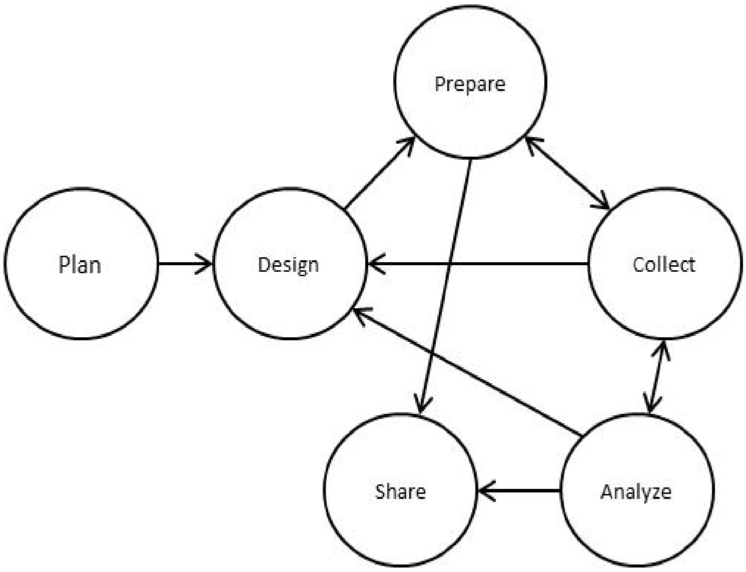

Figure 15. *Case study research process (Yin 2009, p. 1).*

When making case studies it is recommended and useful to first make a pilot case study, which was also made in this research. The purpose of the pilot case study is to test and develop the methods and the procedure of the case study rather than to obtain data (Blessing and Chakrabarti 2008; Yin 2009).

3.1 Planning of the Study

When planning the case study it is essential to identify the research questions as the starting point of the case study. Figure 3 shows the research questions (RQs). The plan is to find reliable evidence to the descriptive RQ1 and RQ2 to be able to derive answers to the relational RQ3.

The case study method has been selected instead of, for example, a sample survey or a questionnaire study; mainly to produce the most reliable results possible because of the 100% response rate of the selected companies. For this same reason, as also suggested by Yin (2009), a multiple-case study method has been selected instead of a single type. This means that several cases are included and several sources of evidence being used in each case.

3.2 Design of the Study

In 2010 there were 61 metal industry companies among the 500 largest Finnish companies (ranked according to turnover). Out of these 61 companies 12 were selected for this multiple-case study and in addition one smaller company was also selected. The criteria for the selection of the 13 companies was first that they had to have a large number of mechanical engineers as employees and then to include some companies which represented investment products and other companies which represented serial production products. The specific fields these companies represent in the metal industry sector are: agricultural machinery, elevators and escalators, machine tool manufacturing, mining and construction equipment, materials handling equipment, pulp and paper machinery, subcontracting and vehicle manufacturing. The key figures for these 13 companies together are (2010):

- Turnover 17 billion euros;
- Number of persons employed 87,000;
- Number of PD engineers 1,600;
- Number of mechanical engineers in PD 750;
- Product development cost 200 million euros.

Compared with the total figures of the 61 companies the turnover of the 13 companies is 40% and the number of persons employed is 49%. Both the turnover and the number of persons employed are the group level figures (group head office in Finland) whereas the other figures represent the operations in Finland. (Talouselämä 500 statistics 2011 and own case study identification information.)

Several sources of evidence are to be used. The evidence collection method itself includes 47 skills questions stated beforehand (see Appendix 1). The answers to these questions were given by the interviewee on paper during face-to-face interviews with the author at the company offices. Another possibility for the interview method was the use of the telephone for contacting and this was tested in the pilot case study. The list of skills questions was sent beforehand to the interviewee. All of the interviews were recorded to provide additional information for later analysis. Different kinds of observations during the interviews and the site visits increased the information value of collected evidence. Internet information of each participating company was also used.

3.3 Preparing of the Case Study

The protocol of the case study includes four sections: objectives, field procedures, questions and report outline of the case study (adapted from Yin 2009).

3.3.1 Objectives of the Case Study Project

The main objective was to collect evidence to RQ1 and RQ2:

RQ1: What are the most important competence needs of PD engineers in mechanical engineering in Finland?
RQ2: What is the current level of young mechanical engineers in the different PD competence areas in Finland?

Collecting and analysing the evidence to RQ1 and RQ2 formed the basis for finding the answers to the relational RQ3:

RQ3: What is the impact of RQ1 and RQ2 on the teaching of competences to PD engineers in mechanical engineering so they are able to achieve the best professional ability?

3.3.2 Field Procedures

The 13 companies of the study were selected as described in section 3.2. The persons contacted were the PD directors of these companies. Typically the PD organizations of the companies are such that PD directors have managers as their direct subordinates and these managers are the superiors of PD engineers. PD directors were asked to name the most suitable interviewee in the company. In some cases the selected person was the PD director himself and in some other cases a manager who reports to the PD director. In both cases the interviewee was asked to answer the questions thinking of the whole of the PD organization of the company.

3.3.3 Case Study Questions

The questionnaire list consisted of 47 skills questions about PD engineer competences (Appendix 1) and these questions were used for both PD engineer's work and for young (less than one year work experience) PD engineer's capabilities which means that every interviewee gave 94 answers in total. The individual questions are based on the author's own experience in industry, on his university teaching experiences and on the references in chapter 2. The author's active participations in national committees on education and research, (e.g. steering group member of MASINA programme of Tekes, the Finnish Funding Agency for Innovation) were also valuable sources of information for finding suitable questions (Tekes 2014). The questions were fine-tuned using the pilot case study. Even though the five point Likert scale is widely used (for example Ferguson 2010) in questionnaire studies the four point scale was selected for this research to avoid a central tendency bias.

The alternative choices for the importance and capability level to select answers were: high, rather high, rather low, low. Each interviewee answered the importance and capability questions at the same time. From a reliability point of view this is important when deriving the answers to the relational RQ3. In the analysis of the study the values between 4…1 were used corresponding to the four choices. The use of consecutive figures from 1 to 4 to indicate importance and capability is generally used in questionnaires (for example Ferguson 2010) and makes the analysis of the results easier. As a fifth alternative there was also a possibility to answer "I don't know". This choice was not taken into account in the summary results for the question. On the last page of the list interviewees were asked to write some additional competence needs if the interviewee felt that something important was still missing.

By recording and making notes during the interviews as well as walking around the PD facilities it was possible to get more evidence and a broader understanding of each case company and its PD work. A "free" discussion always followed the filling in of the questionnaire lists. Also asked were the titles of the persons who attended the recruitment interviews for new engineers at the PD department.

3.3.4 Outline of the Report

The average and the (sample) standard deviation of ranking for the importance and the capability of each competence were calculated from the information collected. The results from the questionnaire are presented as MS Excel charts. The additional competence needs and the capabilities mentioned besides the 47 skills listed were also collected and listed in the results analysis (section 3.5). The most important needs and the corresponding capabilities, according to the study, were listed separately as well as those competences where the gap between the importance and the capability was high.

3.3.5 Pilot Case Study

After planning, designing and preparing the procedure the pilot case study could be made. The scope of the pilot study was to test the substance content of the interviews, the site visits in general, as well as the methodology itself. The selected pilot case company represented a median size among the 13 companies in the study and was well-known by the author and easy to access.

Two managers in the PD department of the pilot company were interviewed separately at different times. The first face-to-face interview took place at the company offices and the second interview was by telephone. So, the two interview methods were tested in this pilot case. The two managers represented different areas of expertise in the PD department of the pilot company. They were both direct superiors of PD engineers. The comparison of the results can be used to evaluate the possible differences in the two scorings for the same PD department. The pilot case study report is in Appendix 2.

3.4 Collecting Case Study Evidence

The multiple-case study type was selected, and multiple sources of evidence were used, so as to produce broader and more reliable results. The most important source was the list of 47 separate skills questions, which were divided into 5 groups: Basic skills of PD engineer in mechanical engineering, NPD project skills, Communication skills, Analysing and problem solving skills, Other skills of a PD engineer.

The second source of evidence was a short visit around the PD facilities as well as the production plant whenever possible. The web-pages of the different companies was the third source used; both before and after the visits (information about the company structure, products and strategy).

The experience gained from the pilot cases was utilized in the actual cases. These experiences included the following findings:

- Send the list of skills questions to the interviewee a couple of weeks before the visit; so that they have time to go through the questions and possibly have internal discussions about them with the other staff.
- Always use face-to-face contacts (not for example contact by telephone or different types of contact in different case companies) to obtain more direct information and the possibility to explain the questions if needed.

This also meant that the same methodology was used for all of the participating companies and made site visits possible.

- Ask the interviewee about the possibility to record the interview; so that it is possible to concentrate on the event itself without making too many notes and all the information in the discussions is saved for later analysis.

All the 13 visits were made during the six weeks between the end of March and the beginning of May, 2011.

3.5 Analysis of the Results

This section covers the analysis of the case study results shown in Appendix 3. The 47 skills questions about the importance of PD engineers' skills and young engineers' capability in mechanical engineering are in 5 different groups. The analysis is made separately for each group and finally collected together. The ranking distributions of the highest ranked skills are shown. The highest ranked skills are such that the average value of importance in the PD engineers' work is higher than, or equal to, 3.5 (the evaluation scale was 1…4).

3.5.1 Group A – Basic Skills

In total there were four high ranked (avrg ≥ 3.5) skills in Group A. Figure 16 shows the distribution of their importance as well as the young engineers' capability in these four skills. Strength of materials is the fifth ranked with an importance of 3.46.

Only one company ranked the importance of the CAD skills as “rather high” (= 3) and the others as “high” (= 4). On the other hand the young engineer´s capability is also relatively high ranked with six times “rather low” and seven times “rather high”. The gap between the two averages is 1.38 (3.92 – 2.54).

PDM skills are generally understood as a part of computer aided design and also high ranked with a gap of 1.54 (3.69 – 2.15). One company gave the max gap of 3 between importance and capability for PDM skills and another says that the young engineers normally learn PDM very quickly.

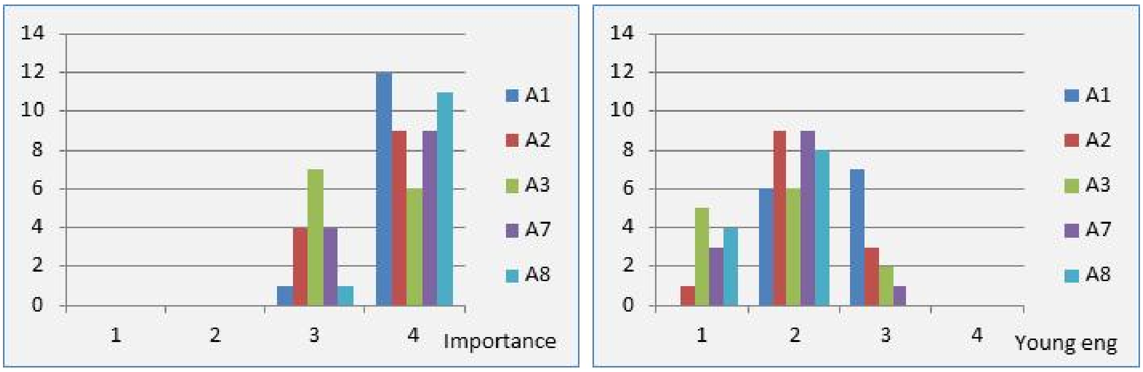

Figure 16. *Ranking distribution of the highest ranked skills of group A.*
A1. CAD (surface modelling, 3D)
A2. General product data management (PLM, PDM)
A3. Strength of materials
A7. Production technology
A8. Manufacturing cost management, DFM and DFMA

Strength of materials skills has the importance of 3.46 which is slightly below the “limit”, but on the other hand it has a relatively high gap of 1.69. So, it was also taken into the highest ranked skills in this group.

The competence gap in the production technology skills 1.84 (3.69 – 1.85) is significant. DFMA and DFM skills are in a close relation with the production technology skills, but the gap is even higher with a value of 2.25 (3.92 – 1.67). This gap is the highest of all the individual skills of the 47 questions. The interviewees pointed out the importance of practical training in mechanical workshops during the studies to achieve a higher capability level in these skills. It was also realized that cost-effective design is important to be able to compete with the low labour cost countries.

3.5.2 Group B – NPD Project Skills

In this group there were as many as five high ranked skills which were more than in any other group. On the other hand the number of questions was also higher than in the other groups as can be seen in Appendix 1.

Identification of customer needs has an importance of 3.46 which is just below the “limit”, but it has a high competence gap of 1.77 and thus is included in the list of the highest ranked skills.

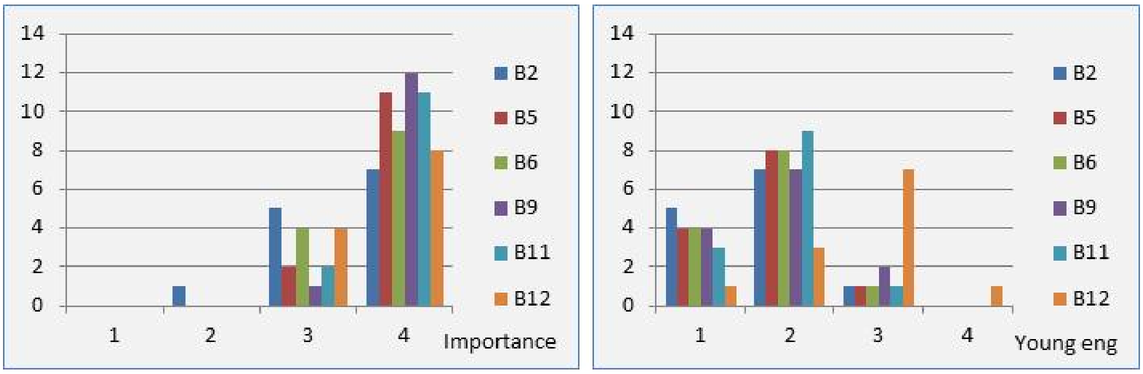

Figure 17. *Ranking distribution of the highest ranked skills of group B.*
B2. Identification of customer needs
B5. Product architecture, the modularization of the product
B6. Detail design (drawing with tolerances, tolerance chains)
B9. Quality assurance of new products together with production
B11. Time and time schedule management (realistic schedules and keeping those)
B12. General team work (including concurrent engineering)

The product architecture (together with the modularization of products) has on the one hand very high importance and on the other hand low young engineers' capability with a gap of 2.08 (3.85 – 1.77) on average. The comments were, for example, that this competence is learned by experience but on the other hand there are very few designers, even among the experienced ones, who manage this well.

Detail design skills were ranked as being a little less important than product architecture, with an average of 3.69. Young engineers' capability was ranked exactly at the same level in the two skills. The importance of different kinds of detail design skills was emphasized in the global design environment and especially with suppliers in low-cost countries. Also it was noted that in association with welded products the importance of detail design skills is not as high as it is with machined products (such as transmissions).

Product quality assurance together with production was very high ranked in importance to the value of 3.92 and the corresponding capability as 1.85; thus giving a gap of 2.07. It was interesting that the standard deviation 0.69 in the capability is relatively high. Once again changes in the supplier network and especially towards low-cost countries mean a high ranking in the importance of quality assurance.

Time and time schedule management skills have the key figures of 3.85 and 1.85 and so there is a gap of 2.00. For the supplier companies and the contract manufacturers the time schedules are extremely important to keep a high level of delivery reliability to the customer companies.

Team work skills are important (3.67) and also young engineers have a good level of capability (2.67) which gave quite a low gap of 1.00. The standard deviation 0.78 of the capability is exceptionally high. The interviewees feel that team work skills are learnt pretty well during the studies.

3.5.3 Group C – Communication Skills

This group has, perhaps a little surprisingly, only two high ranked skills. These are English language skills and own ideas highlighting skills.

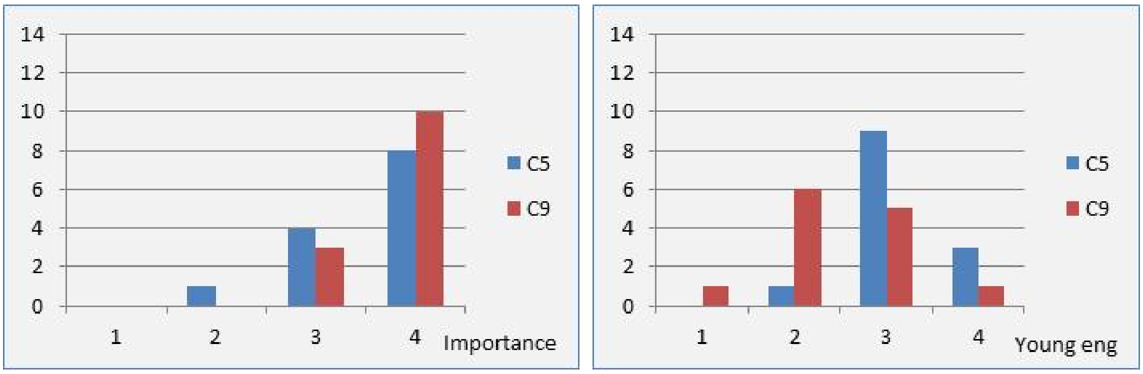

Figure 18. *Ranking distribution of the highest ranked skills of group C.*
C5. English language
C9. Own ideas highlighting

The English language skills have 3.54 and 3.15 as key figures which means that there is almost no gap at all. Young engineers are skilled in English language; typically more skilled than the older engineers. English language is nowadays regarded as a self-evident skill for engineers in Finnish companies. The importance of own ideas highlighting was ranked even higher than English language with a value of 3.77 and also the young engineers' skills are high with a value of 2.46, with a relatively high standard deviation of 0.78.

Clearly in this group the competence gap of the young engineers is very low. The interviewees told that the young engineers are typically better than the experienced engineers in communication and especially when English language is needed.

3.5.4 Group D – Analysing and Problem Solving Skills

There are four high ranked skills in this group, as can be seen in Figure 19. Problem formulating skills (3.69 / 2.00) and general problem solving (3.69 / 1.85) skills have practically the same key figures. The competence gaps of 1.69 and 1.84 are not the highest or the lowest in comparison with the other high ranked skills; but they are still significant. One company even has a special training programme for the designers in problem formulating skills. Koch and Sanders (2011) refer to many researches which state that problem solving is a basic skill in technology. Scott and Koch (2010) emphasize the importance of problem formulating and solving skills in the technical work environment. They also point out that the educators in the field of technology need to take into account the different individual students when teaching these skills.

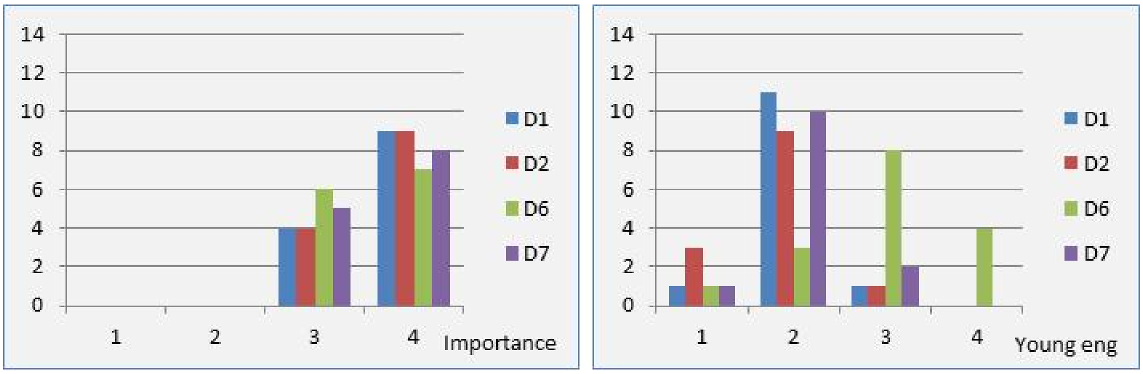

Figure 19. *Ranking distribution of the highest ranked skills of group D.*
D1. Problem formulating
D2. General problem solving
D6. Ability to retrieve information from various sources
D7. Perseverance in problem solving situations

The ability to retrieve information from various sources has a gap of 0.85 (3.54 – 2.69) indicating that young engineers have the ability to utilize information sources. The comments were such that young engineers are skilled at getting information from the Internet (generally better than experienced engineers) but they still have to learn how to use other information sources like books, standards and the experience of other engineers in the organisation.

Perseverance in problem solving situations has an importance of 3.62 and the capability of 2.08 giving a relatively low gap of 1.54. Comments were such that sometimes a young engineer is impatient to find solutions and to find arguments for the selected solution.

3.5.5 Group E – Other Skills

There were nine questions in this group of other skills. Only two of them achieved the ranking of average importance above or equal to 3.5.

The large and/or strongly international companies give high ranking to the importance of PD network management. This is because they have typically many PD partners and also foreign ones. The gap in this skill is 1.77 (3.62 – 1.85). Strongly international companies give lower ranking to the capability of young engineers. The standard deviation of the capability is 0.69, that is to say relatively high.

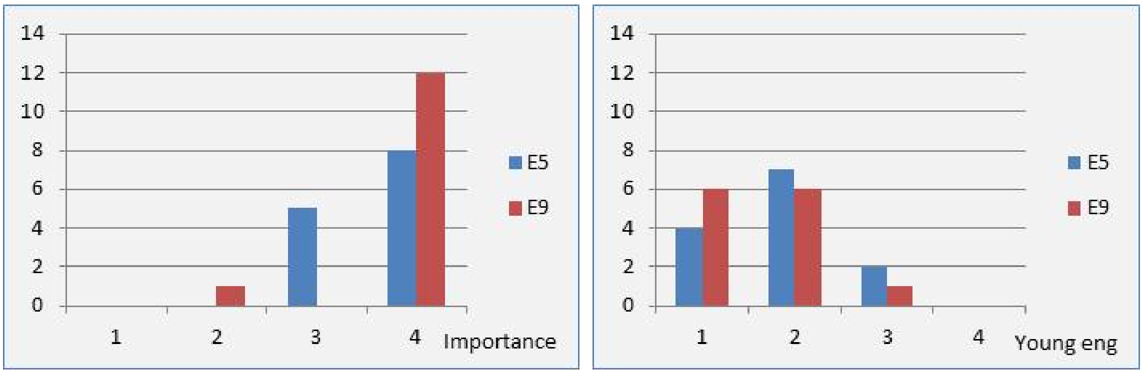

Figure 20. *Ranking distribution of the highest ranked skills of group E.*
E5. PD network management
E9. Special competences related to the products of our company

It is evident that the special competences related to the products of the company were high ranked (3.85) and equally evident is that young engineers' capability is low (1.62) giving a large competence gap of 2.23. The comments were mainly such that this is easy to understand, because the universities of applied sciences cannot devote a great deal of time in their teaching to the specific products of different companies.

PD skills in the development of service products have the highest standard deviation of 0.99 in importance among all of the 47 skills questions. The average importance is however only 2.85. Four companies ranked the importance of these skills as high (= 4) and they are all big companies producing investment products. Some other companies realized that the importance is growing all the time. Young engineers' capability in these skills was ranked at the lowest average value among all questions at 1.54 together with the failure analysis skills (FMEA, DFMEA) in group D.

Business skills were the lowest ranked in importance among all. The average importance is only 2.25 with the reasonable standard deviation of 0.62. The comments were typically such that the monthly reports are gone through and explained by the managers regularly and this does not need any major attention from the designers. The other comments say that the designers need to concentrate on the design work, not on making business calculations in their daily work.

3.5.6 Group F – Other Skills the Interviewees thought were Important

After answering the 47 skills questions there was always a discussion about other possible skills which the interviewee wanted to mention. Some of them were very close to the questions in groups A…E, but also some new ones were mentioned and these are listed in Table 2.

Table 2. *Other skills which the interviewees thought were important.*

F1.	Welded construction design skills
F2.	Hydraulics skills
F3.	Skills to proceed from idea to concept
F4.	Product legislation skills
F5.	General attitude to work
F6.	Skills to handle opposition
F7.	Ability to read and interpret standards
F8.	Ability to see the wholeness
F9.	Industrial data systems skills (CAD, PDM, ERP, CRM,…)

Most of the skills in Table 2 were mentioned by the different interviewees, only two of them, F2 and F9, were mentioned by two persons. Comparing this list with the list in Table 1, by Ferguson (2010), there is one common skill which is F7. Also F5 is close to the first attribute mentioned in the same Table (“Conscientiousness, a disciplined approach to work”). None of the skills in Table 2 are mentioned in the list of the most important PD related skills of the survey reported by Leppimäki and Meristö (2007), section 2.1.2.

3.5.7 Summary of the Case Study Results

Table 3 lists all of the 19 skills which had a high ranking (average ≥ 3.5 or close to that and with a high competence gap) of importance in the PD work of a mechanical engineer (presented in sections 3.5.1 – 3.5.5) as well as the two separately mentioned skills after the specific 47 skills questions. The eight skills having a competence gap higher than 1.80 among the 19 skills in the list have been marked in the colour grey.

It is very interesting to note (Appendix 3, Figure A3.3) that there is also one negative gap in communication skills: C4 = Office software skills (MS Word, Excel, PowerPoint, Project,…); 3.15 – 3.38 = -0.23. So, according to the case study, young engineers are more capable than needed in managing office software in their work.

Table 3. *The 19 highest ranked skills out of the 47 measured by importance in the PD work of a mechanical engineer and two additionally mentioned skills. Imp = average importance, Young = average capability of a young engineer, Gap = Imp – Young (evaluated by the 13 companies).*

Group	Skill	Imp	Young	Gap
A. Basic	A1. CAD skills (surface modelling, 3D)	3.92	2.54	1.38
	A2. General product data management (PLM, PDM)	3.69	2.15	1.54
	A3. Strength of materials	3.46	1.77	1.69
	A7. Production technology skills	3.69	1.85	1.84
	A8. Manufacturing cost management, DFM and DFMA	3.92	1.67	2.25
B. NPD project	B2. Identification of customer needs	3.46	1.69	1.77
	B5. Product architecture, the modularization of the product	3.85	1.77	2.08
	B6. Detail design (drawing with tolerances, tolerance chains)	3.69	1.77	1.92
	B9. Quality assurance of new products together with production	3.92	1.85	2.07
	B11. Time and time schedule management	3.85	1.85	2.00
	B12. General team work skills (including concurrent engineering)	3.67	2.67	1.00
C. Communication	C5. English language skills	3.54	3.15	0.39
	C9. Own ideas highlighting	3.77	2.46	1.31
D. Analysis and problem solving	D1. Problem formulating skills	3.69	2.00	1.69
	D2. General problem solving skills	3.69	1.85	1.84
	D6. Ability to retrieve information from various sources	3.54	2.69	0.85
	D7. Perseverance in problem solving situations	3.62	2.08	1.54
E. Others	E5. PD network management	3.62	1.85	1.77
	E9. Special competences related to the products of our company	3.85	1.62	2.23
F. Additional	F5. General attitude to work			
	F7. Ability to read and interpret standards			

It is significant that no fewer than half of the eight having the highest competence gap and also being in the high level of importance belong to group B, NPD project skills. Also one can see that three from the eight skills are closely related to production and manufacturing technologies. The two additional skills mentioned by the interviewees have been added to this summary list. The same two skills can be found also in Table 1 by Ferguson (2010) as mentioned in section 3.5.6.

The two skills, A6 “Integration of IT into mechanical design” and B3 “Cooperation with industrial design”, have the average ranking around 3.0. In section 1.2 it was mentioned that nowadays usability of a product as well as IT in embedded systems are new skills that are needed in mechanical engineer’s work. Even though these skills are new demands for mechanical engineers, they are not among the highest ranked skills according to this case study.

3.6 Discussion

A case study approach was used to clarify the competence needs of PD engineers in mechanical engineering and the capabilities of young engineers in these competences. This multiple-case study included visits and interviews at 13 companies in Finland in the field of mechanical engineering. Most of these companies are among the largest ones in Finland in this field of technology. The interviewee was either the PD director or manager of the company. The case study method was selected instead of, for example, a sample survey to ensure: a response rate of 100% among the selected companies, that the reasons for the answers to the 47 questions were given, to have a possibility for discussions about the questions and to be able to make recordings of the discussions for later analysis.

Several sources of evidence were used. The data collection method itself included 47 skills questions stated beforehand, which were answered and commented upon in face-to-face interviews between the author and the interviewee on the company premises. All the interviews were recorded so as to have additional information for later analysis. Looking around the PD facilities and the production plant during the site visits and by utilizing the author’s industrial experience the collected evidence gained additional value.

A pilot case study was made using two different types of interviews with two managers at one company. The final method used was tuned according to the experiences gained from this pilot case (report in Appendix 2). The case study itself was made by using exactly the same method at each of the 13 companies.

One can ask how well these 13 companies and thus the 13 persons interviewed represent the general opinions on the competence needs of PD engineers and the capabilities of young engineers in mechanical engineering in Finland. One answer is given by the key figures of the companies in section 3.2. Another note is that the highest ranked skills in Table 3 have generally very low standard deviations among the answers given by the 13 companies. A third kind of approach for the evaluation of a suitable number of interviewees can be made when comparing this kind of case study with the interviews to identify customer needs. A lot of research has been made in this subject for example by Griffin and Hauser (1993). Figure 21 shows that after 9 interviews of individual persons about 90% of customer needs have been identified. The results of Figure 21 are based on a QFD (Quality function deployment) application. The product category was for a complex piece of office equipment. The total number of customer needs analysed was 230.

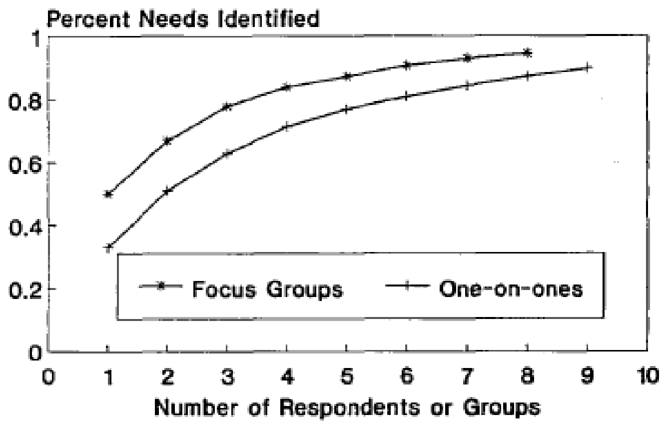

Figure 21. *Customer needs identified as a function of the number of interviews in the case of focus groups and one-on-one interviews (Griffin and Hauser 1993, p. 8).*

The results from a survey in Finland carried out in 2006 (Leppimäki and Meristö 2007) are presented in section 2.1.2. When comparing the results of that survey with the results of this case study the modularization of the product is the only competence need which has high importance in both. The environment and energy related skills have higher importance in the survey than in the results of this case study. This difference can be understood because the survey had the focus until the year 2020. As already mentioned in section 2.1.2 the survey was on a much more general level than this thesis' case study, when thinking about the competence needs of a mechanical designer in PD work, and so the results cannot be compared in detail. As stated in section 1.3 this thesis concentrates on the present skill needs of engineers.

The large study by Ferguson (2010) was focused on finding the most significant attributes for Australian mechanical engineers. When comparing the results of this Australian study (Table 1, section 2.1.3) with the results of this thesis it is important to note the following differences:

- The Australian study was focused on the work of mechanical engineers in general and this thesis was focused on the work of mechanical designers in PD.
- The industrial fields in the Australian study were: consulting engineering, transport manufacturing, electricity and gas supply, mining and quarrying, construction contract and maintenance, defence excluding those in the army services. The industrial fields in this thesis are: agricultural machinery, elevators and escalators, machine tools manufacturing, mining and construction equipment, pulp and paper machinery, subcontracting, vehicle manufacturing. The selected fields represent the most important areas in the mechanical engineering sector in both countries. There are only two common fields.

The research method in both cases is based on the case study approach, but there are some details which are different:

- The number of questions in the Australian study is much higher, 84 in total with three different categories in each giving 252 rankings altogether; compared with the 47 questions and the two categories or 94 rankings in total in this thesis.
- The interviews in the Australian study were made either face-to-face or by phone and in this thesis all the interviews were made face-to-face at the interviewee's company premises.

Taking into account the above mentioned differences and also the cultural (Lewis 2006) and other differences between the two countries, it is understandable that the results are also considerably different. Table 1 lists the 22 most significant skills in the Australian study and Table 3 the 21 most significant skills in the Finnish study (the study in this thesis). Table 4 includes those skills from Table 3 which can also be found in Table 1 of the Australian study.

Table 4. *The most important skills common in Australian and Finnish studies (Tables 1 and 3).*

Group	Skill	Imp	Young	Gap
B. NPD project	B11. Time and time schedule management	3.85	1.85	2.00
	B12. General team work skills (including concurrent engineering)	3.67	2.67	1.00
D. Analysis and problem solving	D1. Problem formulating skills	3.69	2.00	1.69
F. Additional	F5. General attitude to work			
	F7. Ability to read and interpret standards			

The two skills in the group of NPD project, time management and team work, emerge in this comparison as well as the problem formulating skills as the third common skill. The additional F skills are those which were mentioned after the listed 47 skills questions by the interviewees and can also be found in the most important skills in the Australian study (section 3.5.6).

It is also important to note that the general technological competence development of a person, like the development of general competences in other fields, is a lifelong process. It neither starts nor ends during university studies. Autio (2011) has made interesting case studies by following the technology competence development of certain persons in Finland. The study group in 2011 consisted of three persons: two of them aged 28 and one 29. The same three persons had also participated in technological competence research 15 years before the new research. Two of the three persons made their studies at a university of technology and one at a vocational school in the field of technology. The first two persons graduated with a master of science in technology and one of them continued onto doctoral studies and finished his thesis in 2010 (Subject 1). Figure 22 shows the development of the technological competences of these two persons. The curves are based on the interviews of the persons.

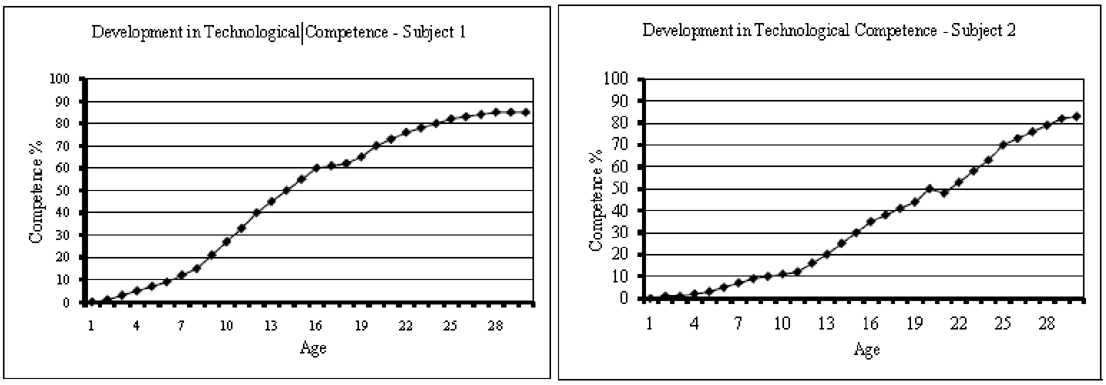

Figure 22. *Development in technological competence of the two persons in the case study (Autio 2011, p. 76 and 79).*

Both curves show that the primary, secondary and upper secondary levels (age 7-19) are important in the cumulative development of technological competence. The university studies started around the age of 20 and took about 5 years in the both cases.

3.7 Conclusion

In this chapter the answers have been presented to the research question RQ1 “What are the most important competence needs of PD engineers in mechanical engineering in Finland?”, RQ2 “What is the current level of young mechanical engineers in the different PD competence areas in Finland?” and RQ3 “What is the impact of RQ1 and RQ2 on the teaching of competences to PD engineers in mechanical engineering so they are able to achieve the best professional ability?”. The method used to find the answers is based on the case study approach with the 13 Finnish metal industry companies. Table 3 lists the answers to the three RQs: “Imp” (RQ1), “Young” (RQ2) “Gap” (RQ3).

The standard deviations of the 19 highest ranked skills (importance and young engineers’ capability) are very low and thus indicate a high reliability in the results. The most important competences according to this case study belong to the group of NPD project skills. Six of the 19 highest ranked skills of importance belong to this group with as many as four of the eight skills having the highest competence gap between experienced and young engineers belonging to this group.

As already mentioned in section 1.2 the PD engineer’s skills can be divided into three areas: technical substance, technical tools and non-technical. The 21 most important skills from Table 3 occur in each of these three areas:

- 11 non-technical skills: B2, B11, B12, C5, C9, D1, D2, D6, D7, E5, F5;
- 7 technical substance skills: A3, A7, A8, B5, B6, B9, E9;
- 3 technical tools skills: A1, A2, F7.

Out of the 21 most important skills at least the following nine are emphasized in the situation where the company has either PD, production or supplier activities (or a combination of these) in countries like China or India: A7, A8, B5, B6, B9, B12, C5, E5, F7. It should also be noted that the following five skills are important if a company’s own production has a high degree of automation: A7, A8, B5, B6, B9. So the importance of these listed skills will be even greater in future because of the two general trends noted in Finnish industry (chapter 2). It is interesting to note that all the five skills related to a high degree of automation are also in the other list of nine skills.

All the 21 skills listed in Table 3 form a basis for the educational efforts at UASs in Finland; so as to achieve the optimum learning results of PD engineers in mechanical engineering. This list can be utilized also in other fields of engineering, not only in mechanical engineering. The non-technical and technical tools skills are more general in nature and are needed in any field of engineering in PD work. It is important to note that both the contents and the teaching methods must support the learning process. These contents and methods, among other things, are discussed more in chapter 4.

The case study results of this chapter can be utilized also in other types of research, not only in finding evidence to RQ1, RQ2 and RQ3. For example these results can be used in the recruitment or the training of PD engineers in companies. These other possible utilizations of the results are however outside the scope of this thesis.

4 Model of Teaching Strategy Development

The target of this chapter is to present a teaching strategy development tool to create evidence for the RH, "The stage-gate type PD process, together with a modular service product concept, is an effective tool for the course teaching strategy development". The course teaching strategy is considered as a modular service product. When developing any kind of product identifying the customer needs forms the foundation stone for the success of the product. Still there are also other important tasks in the PD process before the final step, the production start, is achieved. The modular service product concept and the PD process model used in this thesis have been developed by the author utilizing the experiences of PD work made at Finnish mechanical workshops. However this PD process model is based on the stage-gate model first introduced by Robert G. Cooper (Cooper 2011, Preface p. xiv).

4.1 Teaching Strategy Concept

In this thesis the course teaching strategy includes the essential choices and targets to help students learn the subjects they need to learn (Ramsden 2003, Hyppönen and Lindén 2009). It includes the following five modules:

1. Targets for learning outcomes;
2. Contents of teaching;
3. Methods used for learning;
4. Learning assessment;
5. Teaching assessment.

It is important not to mix this modular service product structure with the modular curriculum structure. Defining the five modules of the course teaching strategy establishes the basis for the productisation of this service product. This productisation still needs the definition of the components of each module, later defined in chapter 5. Like in the case of physical products (Ulrich 1995) there are several reasons and benefits for splitting the service product into modules. The most important benefits, listed below, are related to the PD work and the product variations of the course teaching strategy (Nevaranta 2012):

- The work during the PD project can also be split into module levels.
- Utilization of module experts in the teaching strategy development is easier (for example an expert in learning methods in module 3).
- Modifications in one module do not necessarily cause modifications in other modules.

- Several teaching strategy variations can be created or configured using optional modules for different student groups (for example for different degree programmes or different teachers of the same course).
- Some modules can be used in other products; that is in other courses.
- PD of the next generation teaching strategy is easier and faster.
- The distribution of the PD work, in the case of cooperation of several universities, is easier.
- PD process management in general is more effective resulting in a more reliable project plan, shorter lead-times and the quality of the development project being better.

Each of the five modules has a specific function in the teaching strategy. The links or the interfaces between these five modules are relatively loose in nature except for the link between the first module and all the others as well as the link between the second and the third module. The module “Targets for learning outcomes” has a strong impact on all the other modules. Also the contents of teaching have an impact on the methods used for learning.

The course teaching strategy needs to be formulated by the teacher for each course and learning environment. There are and should be differences in the teaching strategies of different teachers at the same university. For example, the most suitable learning methods to be used also depend on the teacher. And as stated before in the section 2.2.9, it is very important that the teaching is skilfully carried out whatever methods have been selected.

4.2 PD Process as the Guideline for Teaching Strategy Development

The PD process is to be used for the development of the course teaching strategy defined in the previous section. This process is normally used for the development of physical products, but it can also be used in the development of service products. The course teaching strategy can be considered as a kind of modular service product. It is unusual to split service products into modules, as it is in the case of physical products. However, Böhmann et al. (2003), for example, introduced a modular concept application into IT services.

4.2.1 PD Process Description

Since Robert G. Cooper published the stage-gate type PD process in 1988, it has been used as the basic guideline in new product development projects in many companies. This PD process has been under active research by many scientists for more than 20 years. Even though there are some slight differences in the PD processes of different researchers they are all based on Cooper's original stage-gate idea. The PD project organization has specific phase tasks that must be done. These tasks and the main outcome of each phase must be accepted by the decision making organisation of the UAS (often known as the project steering committee) before continuing to the next phase. If the phase is not accepted, the project can be stopped or some additional work must be done before the project can continue. Quality assurance, coordination, planning, management and improvement of the PD process are significant benefits of the stage-gate model (Ulrich and Eppinger 2008, p. 12-13).

The PD process used can be seen in Figure 23. The tasks, outputs and other details of each phase are based on the author's own experiences when working in Finnish mechanical workshops. Even though the process looks simple, it needs a lot of work in every phase carried out by the PD project organisation.

Figure 23. *PD process phases (P1…P5) used in the development of the teaching strategy.*

When using this process in the development of the course teaching strategy specific adaptations are needed to be introduced. The first task is to clearly define the product and the customer of this service product.

4.2.2 Definition of the Product and the Customer

When developing physical products (for example a car, tractor, bicycle, printer and so on) the product definition is straightforward and clear. However the product definition of a service product needs to be carefully defined for the development organisation. The product in this case is "The course teaching strategy" including all of the five modules mentioned in section 4.1.

Identification of the customer and the customer segments is another important starting point of any PD project. Even in the case of a physical product this is not always self-evident. The customers of the product mentioned above are the students of the course for whom the teaching strategy product will be developed. Sheppard et al. (2008), in their article dealing with the 21st century engineer, define students to be the "primary customers" of an engineering education. Watt et al. (2011) as well as Crawley et al. (2007) point out the importance of customer identification and the concept of the student as a customer of the university (see section 2.2.10). The industrial companies, on the other hand, will be the customers of the engineering students.

4.2.3 Phase Tasks of PD Process in Teaching Strategy Development

The PD process of Figure 23 includes the five phases. Each phase has the specific tasks to be carried out by the development team. Now, these tasks are defined phase by phase introducing first the phase tasks in the PD project of a physical product and then the corresponding tasks of our service product.

Phase 1: Business Fit

Before the actual PD project starts, phase 1, a business fit study needs to be carried out. The organisation normally has many PD projects or other kinds of projects going on at the same time as well as other ideas for new projects. So, it is necessary to continuously evaluate the project portfolio to guarantee that the right projects are under development. The criteria of selecting the right projects include, among other things, the business impact, the strategic fit and the resource allocation of the projects from the company's point of view.

In the case of the teaching strategy product the company is the UAS with its business, strategy and resources. The teacher of the course in question needs to make a plan of the teaching development activities and fit that into the strategic targets of the UAS and indicate the resources to be used. The project manager is normally the teacher of the course and is also the main resource of the development project, but usually some other resources are also needed such as people and/or money. Probably there are also other curriculum development projects going on or starting at the same time. Like companies the UASs can also make only a limited number of development projects during a certain time period because of limited resources.

The outcome of the business fit phase is the updating of the UAS's project portfolio; or in the case of the project being at only one school then the project portfolio of that specific school in the UAS. The decision about the individual development project (start or not) must be made in the organisation, based on the proposals made by the teacher of the course. The development project need may have come from the students, the competition, industry, the teacher of the course, another UAS organisation or from a combination of these.

Phase 2: Pre-Design

Phase 2 includes: the identification of the customer needs, the development of alternative concept solutions based on these needs, the selection of the final product concept and finally, as the outcome of the phase, the project plan for the PD project. The project plan includes:

- Technical specification of the selected concept;
- Human and other resources needed for the project;
- Project time schedule;
- Project budget;
- First estimates of the cost and profitability of the new product;
- Project risks.

The success of the whole project depends very much on how well the customer needs are identified. There are a lot of ways to find out customer needs such as: surveys, questionnaire studies and case studies. However, it is important to see the real customer environment where the product under development is used. This gives a direct and realistic view of the use of the product and may produce real product innovations or at least innovations in individual product features.

The pre-design of the teaching strategy product means that the following tasks need to be done:

- Identifying students' needs for the course under development;
- Creating alternative teaching strategy solutions for the course to fulfil these needs;
- Selecting the best teaching strategy from the alternatives, based on the fulfilment of the customer needs and the needed resources;
- A rough description of the selected teaching strategy of the course;
    1. Human and other resources needed for the project;
    2. Time-schedule for the development project;
    3. Budget for the development project;
    4. First estimates of the cost effects of the selected teaching strategy implementation;
    5. Financial and other possible project risks.

The rough description includes the most essential information for the five tasks listed above. It needs to cover essentially the rough descriptions of the first three modules of the teaching strategy (targets for learning outcomes, contents of teaching and methods used for learning); because these modules have a major impact on the five tasks. Collecting the above mentioned items in the project plan for the development of the new course teaching strategy is the outcome of this phase.

Phase 3: Design

Phase 3, design, usually takes a large share of the total lead-time of the project (maybe 50% or even more). It includes the general layout drawings for the whole product, also known as the product architecture, and the list of product modules. Each module has a certain function in the whole product. The modules include the individual components which are also designed in this phase of the PD process. It is possible that there are also sub-modules between the main modules and the components.

The complete documentation (product architecture, module list, component drawings and BOM) of the product is the outcome of this phase. The first laboratory tests of the product modules together with the technical calculations also take place in this phase. The modules are tested in the laboratory under controlled conditions. The test results are compared with the results for existing products. Also other kinds of technical analyses, such as component cost estimates, production planning and product quality related analysis (like DFMEA), are made during this phase. The plan for the new product launch is made by the marketing people.

The architecture of the teaching strategy product used in this thesis is described as the module list in section 4.1. All five modules need their individual components' specifications. For example the learning assessment module may have several assessment types in the teaching strategy of a specific course and another course may have exactly the same content for the assessment module even though the other modules are different.

Some of the modules for the new teaching strategy of one course can be tested in other courses before the course under development is taught. It is important that the students in these other courses are as similar as possible to the students of the actual course (for example students of the same degree programme). The results of the new modules tested in the other courses are compared with earlier experiences for the same courses. After testing the modules in other courses any needed corrective actions must be made and tested before moving to the next phase.

The design phase 3 of the development of the teaching strategy product includes the following items:

- Module list of the teaching strategy product (section 4.1);

- The detailed contents (list of components) of the five modules of the teaching strategy;
- Description of all the components of the five modules;
- Update for the cost estimates of the new teaching strategy product implementation and a cost comparison with the existing teaching strategy;
- Testing of the teaching strategy modules or at least some of them in other courses.

The list includes the tasks to make “the technical specification of the product” or rather in this case of the service product, to produce the complete description of the product. The technical specification of our service product is illustrated in more detail in chapter 5.

Phase 4: Testing

In this phase the prototypes are made and tested. Usually after the first prototype tests some modifications to the construction are needed. The new tests must be made after the modifications. After successful test results the design quality of the new product can be verified. The product quality, in its wider sense, means how well the new product fulfils the customer needs. It is important to use different types of customers (customer segments) in these test runs so that the prototypes are tested in real environments.

Also in this phase the so called pilot-series of the product is made in the production plant. The idea of this pilot-series is to verify the quality of the production process. For this reason it is very important to use the final production methods and tools to make the pilot products. The component supplier network also needs to use the final manufacturing methods. After the pilot-series has been made successfully and a possible tuning for the production process has been made, the final production is ready to start.

The first prototype of the teaching strategy product is based on the tested modules of the previous stage. Normally in the UAS there are many student groups which have the same course in their curricula. However it is good to first implement the new teaching strategy of a course with one student group only. If the implementation of the course with this student group uses all of the UAS management tools, it serves as a pilot implementation as well. After the experiences with this group slight tuning of the teaching strategy could take place. To make the developed teaching strategy ready for full use the course description needs to be updated in the curriculum. Now the development project is ready to go to the final stage.

Phase 5: Launch and Production

When the design and production qualities have been assured in the previous phase, the new product can be launched and production begins. At the beginning of production the product volumes are limited in number so that the whole production chain can slowly reach full capacity. Finally the products are made in the needed volumes and the PD project ends. The product will then enter the follow-up process of the company; with customer feedback and any possible modifications needed based on this feedback being made.

The launch and production of the new teaching strategy product means that the new teaching strategy has been made known publicly in the UAS curriculum and will be used in the course under development. The collation of the student feedback is now very important when the new teaching strategy is in full use.

Finally before closing the teaching strategy development project the PD process model used is evaluated based on the project experiences. The process may need some modifications and the new model will then be used in the next project.

4.3 Conclusion

The PD process, together with a modular service product concept, has been tuned to the development of the course teaching strategy as proposed in RH. The course teaching strategy is a kind of service product and the application of the PD process in its development needs precise definitions for the product and the customer as well as for the other essential concepts of the process. These definitions have been made in this chapter.

Modules and components of the teaching strategy product are not as evident as they are in the case of a physical product. Also like in the physical product, the teaching strategy product of a specific course may have a different number and different types of modules and components compared with the teaching strategy of other courses. Defining the modules and components is often called the productisation of a service product.

Similar types of courses (for example statics, dynamics, strength of materials) may establish “a product family” in the sense of the teaching strategy needed for these courses. These courses may have similar modules and/or similar components in their teaching strategies. Thus the development results of one course can be used in the other courses of the same product family.

Figure 24 shows the main tasks during the PD project of the teaching strategy of a course and the main outcomes from each of the five phases of the process. The motivation for the need to develop a new teaching strategy may come from different sources, such as the following:

- The course teacher's experiences;
- Feedback from the students;
- Competitive situation at the UAS and/or at a specific school at the UAS;
- Costs of the present teaching strategy of the course;
- New possibilities in the teaching and learning environment.

The continuous development of the teaching strategies of courses is important from the point of view of the competitiveness of the university. When starting development actions it is important that the university has a development systematics which is well known by the teachers and other staff. The development model defined in this chapter is such a systematics.

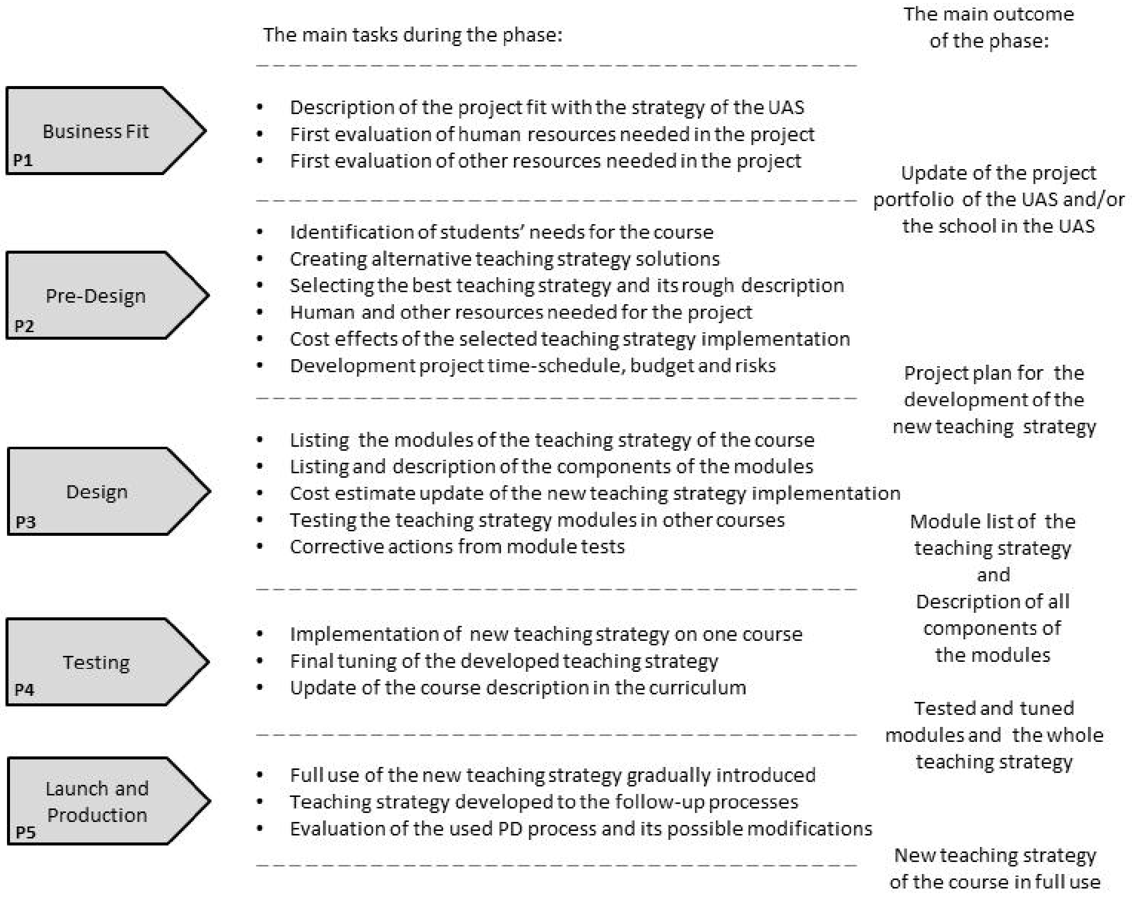

Figure 24. *The main tasks of the teaching strategy development project and the main outcomes from each project phase.*

After every phase of the project the go or stop decision must be made by the UAS organisation. A stop decision may mean that more information is needed to be acquired before any possible go decision can be made. It is also possible that the project is stopped and will be taken from the project portfolio. These kinds of critical reviews after each phase are important tools to improve the quality of the project. They are possible only in this kind of stage-gate model of the PD process. The general project management is also clearer for all participating people because of the specific phase tasks. In the next chapter, as an illustrative example, the PD process of Figure 24 is applied to the teaching strategy of a course relevant to the PD competences defined in chapter 3.

5 Teaching Strategy for the PD Education of Mechanical Designers

In this chapter the development model of the previous chapter is applied to the teaching strategy of a PD course of the mechanical engineering degree programme at a Finnish UAS. This relatively small course, with only 3.0 ECTS, has a special orientation to PD project work in Finnish engineering workshops. It gives the theoretical basis for the PD methodologies to be used in other courses, which are more practical in nature.

This application of the created development tool of chapter 4 illustrates the idea and the systematics aimed at in the RG of the thesis rather than presents the only correct teaching strategy of a PD course. The RG presented in section 1.3 is repeated here: “The systematics to develop a teaching strategy for the education of PD engineers in mechanical engineering at UASs in Finland”. However, first of all some general information about the UASs in Finland is given at the beginning of the chapter; especially from the point of view of the education of mechanical engineering.

5.1 Education of Mechanical Engineering at the UASs in Finland

In Finland, like in some other countries, there are two kinds of HEIs. One is the traditional science university and the other is the University of Applied Sciences (UAS). The number of UASs has decreased during the last few years after the fusions of some UASs. In 2011 there were 25 UASs under the Ministry of Education and Culture. In addition to these there are two special UASs outside this sector (Ministry of Education and Culture 2012).

The degrees at the UASs in the field of technology are bachelor of engineering and master of engineering (there is also a special on-site construction supervisor’s degree). The length of a bachelor degree is 240 ECTS with an additional 60 ECTS for the master of engineering degree (supervisors have 210 ECTS). This means a 4 year programme for the bachelor degree and an extra one year for the master degree. However, because the master degree programmes are normally taken when students are working in a company as an engineer, the study usually takes a couple of years.

Out of the 25 UASs in Finland there are 21 which have engineering education programmes. Out of these 21 UASs there are 17 which have mechanical engineering education programmes (in 2011). The total number of students in 2009 in the field of technology in the UASs of Finland was 39,025 and the number of new students was 10,919 (Statistics Finland 2010, p. 391).

Mechanical engineering is one of the biggest degree programmes in Finnish UASs and has represented a share of about 15…16% of the students in the field of technology during the last few years (Ministry of Education and Culture 2010). This means that the total number of students in mechanical engineering is about 6,000 and the number of new students entering yearly is about 1,700. These figures include both the full-time and part-time degree students. The location of the 17 Finnish UAS towns with mechanical engineering education in 2011 can be seen in Figure 25.

Figure 25. *UAS towns where mechanical engineering education took place in Finland in 2011.*

Typical specialization lines in mechanical engineering degree programmes in Finland are:

- Machine Design;
- Product Development;
- Production Systems;
- Machine Automation;
- Industrial Management.

The first two and the last specialization lines are closely related to the development of new products.

5.2 Development of the Teaching Strategy of a PD Course

The stage-gate process described in Figure 24 is used to develop the teaching strategy of a PD course. This PD course is taught during studies in the third academic year in the bachelor of mechanical engineering programme. The name of the course is simply “Product Development”.

The target is to develop a teaching strategy that is suitable for those Finnish UASs which have a similar course in their mechanical engineering education programmes. Again it is important to remember that a suitable teaching strategy depends on the environment where it is used; such as on the facilities at the UAS and the personal characteristics of the teacher. On the other hand the developed teaching strategy can be utilized, at least at module level, in other UAS courses, but especially in courses which are similar in nature to the course under development; as explained in the conclusion of chapter 4.

5.2.1 Phase 1: Business Fit

UASs in Finland carry out continuous development work to keep a high teaching quality. They set demanding targets in their strategies for high quality teaching. This means that from the strategic point of view this kind of teaching strategy development project fits very well into the project portfolio of the UASs.

As stated in the previous chapter the main human resource of the project is the teacher of the course under development. This teacher can also make the module tests during phase 3. Likewise other teachers can and are recommended to make these module tests in their own courses in order to have a broader view of the test results. The amount of working time resource needed in the project depends mainly on two questions:

- How much work has already been done and how much is still needed to do during the development project to identify the customer needs?
- How well does the teacher of the course know the different teaching and learning methods?

The possible resources for the project, other than human ones, depend mainly on the selected teaching and learning methods. So it is difficult to estimate the quantity of these resources at the beginning of the project. However, it is necessary to make an estimate of the resources needed and these are based on the first ideas for the project. These resources could be for example some investments in laboratories (for example a rapid prototyping machine).

Based on the above mentioned descriptions of the strategic fit and the needed resources of the project the teacher makes a project proposal. If the proposal is accepted by the relevant decision making organisation at the UAS or the School the project is taken into the project portfolio of the UAS and/or School.

5.2.2 Phase 2: Pre-Design

The first task, and a very important task in this phase, is the identification of the customer needs. This is a continuous process at the UAS. The identification of competence needs forms the basis for the development of education. This identification work, in this case, needs to be focused on the supposed working environments of the graduated mechanical engineers; that is mechanical workshops in Finland. The environment of the customer's customer gives the best point of view on how the product under development is used and how it could be further developed to be even more effective.

The case study research of chapter 3 was made in the mechanical engineer's real working environment. The most important competence needs from this case study are summarized in Table 3. The 21 most important competence needs of Table 3 can be divided into three categories as mentioned in section 3.7 and are:

- 11 non-technical skills: B2, B11, B12, C5, C9, D1, D2, D6, D7, E5, F5;
- 7 technical substance skills: A3, A7, A8, B5, B6, B9, E9;
- 3 technical tools skills: A1, A2, F7.

The degree programme for the bachelor of engineering in mechanical engineering includes several courses which have a direct impact on these competence needs. Among these 21 skills there are six which are taught in special courses (courses like CAD, strength of materials, production technology, machine design). These six skills are: A1, A2, A3, A7, B6 and F7. The PD course teaching strategy under development has major impact on the other 15 skills listed in table 5.

Table 5 is the list of the most important customer needs for the teaching strategy development project for the PD course. It is very useful for the development team if the customer needs can be somehow ranked in importance. However, this kind of ranking is a demanding task and may lead to misinterpretations. In Table 5 the six grey coloured skills are ranked higher than the other nine skills; which, in any case, are also important to take into account. There are three skills which have a competence gap less than or equal to 1.00 (B12, C5, D6). So these three skills are generally well managed by young graduated engineers.

Table 5. *The 15 skills out of the highest ranked skills of Table 3 on which the PD course under development has a major impact. Imp = average importance, Young = average capability of a young engineer, Gap = Imp – Young (evaluated by the 13 companies).*

Group	Skill	Imp	Young	Gap
A. Basic	A8. Manufacturing cost management, DFM and DFMA	3.92	1.67	2.25
B. NPD project	B2. Identification of customer needs	3.46	1.69	1.77
	B5. Product architecture, the modularization of the product	3.85	1.77	2.08
	B9. Quality assurance of new products together with production	3.92	1.85	2.07
	B11. Time and time schedule management	3.85	1.85	2.00
	B12. General team work skills (including concurrent engineering)	3.67	2.67	1.00
C. Communication	C5. English language skills	3.54	3.15	0.39
	C9. Own ideas highlighting	3.77	2.46	1.31
D. Analysis and problem solving	D1. Problem formulating skills	3.69	2.00	1.69
	D2. General problem solving skills	3.69	1.85	1.84
	D6. Ability to retrieve information from various sources	3.54	2.69	0.85
	D7. Perseverance in problem solving situations	3.62	2.08	1.54
E. Others	E5. PD network management	3.62	1.85	1.77
	E9. Special competences related to the products of our company	3.85	1.62	2.23
F. Additional	F5. General attitude to work			

The next task is to create alternative solutions for the teaching strategy of the course. The descriptions of these alternatives are in this phase of the project at a general level: including mainly targets for learning outcomes, contents and methods used on the course. These descriptions are often referred to as product concepts. The targets for learning outcomes need to reflect, as well as possible, the list of skills in Table 5. The contents and methods used on the course are selected to fulfil these targets and thus the skill needs.

The list in Table 5 shows that the NPD project or product process skills are very important and must be strongly supported by the selection of the targets, contents and methods used in the PD course. Analysis and problem solving is another important group of skills. These four skills have a strong connection to the learning methods used and to the student's level of activity during the independent learning actions on the course. Together these two groups of skills cover 9 out of the 15 skills in the Table.

Out of the remaining 6 skills the first on the list (A8) has the highest importance of all (together with B9) and the highest gap of all. So it is necessary to include these into the contents of the course. It is also a good theme for possible course exercise work and this way it supports the student's learning by doing.

The two communication skills have relatively low gaps: English language having the lowest gap of all. However, it is necessary to teach the special PD related terminology in English. It is also necessary to give information about the English language course material, which is extensively available. The other communication skills (own ideas highlighting) are supported, for example, by the presentation of possible exercise work and/or tasks during the lessons.

PD network management skills have many different dimensions. PD network may include national and international partners and its management has a strong connection with communication skills. It is also connected to product quality assurance (B9). Even though E9 skills are highly ranked and have also a high competence gap they are difficult to support on the PD course. The most obvious reason is that the product spectrum of companies is very large and there are only a limited number of opportunities to show examples of specific products during the course. Finally the skill of the “general attitude to work” is very much related to the generic type of skills (or non-technical), but it can be supported by the teacher’s own attitude and by the teacher’s requirements concerning students’ performance during the course.

Now, the concept solution, including the descriptions of the first three teaching strategy modules, is selected from the alternative concepts. Here only the final selected concept is presented. The first module, targets for learning outcomes of the PD course under development, includes the following components which the student needs to know and to be able to deepen this knowledge after the course:

- Modern NPD process model;
- Tools for identification of customer needs;
- Designer and production co-operation in NPD;
- Methods of problem solving;
- Working in PD network.

Table 6 is a matrix which shows in its rows the selected contents and methods used for the course under development and in its columns the skills in Table 5 (comp. with quality function deployment or QFD matrix). The matrix shows which parts of the contents and the methods used have an impact on each of the skills. The above list of components of the first module and the lists of the components of the other two modules in Table 6 form the selected concept for the course in this pre-design phase of the project. Normally, these kinds of lists should already exist from the previous years the course was conducted and only need to be updated. This updating means finding new alternatives for: the targets, contents and methods to be used to better fulfil the skill needs. These new alternatives are compared with the existing ones using the matrix in Table

6. As mentioned in Figure 24, the detailed module list and the detailed description of the modules and components for the teaching strategy are determined in phase 3, which is the design phase. So, in this pre-design phase the course description – the skills matrix is more suggestive in nature. The number and location of the impact crosses in the matrix also depend on the detailed descriptions of the components.

Table 6. *The course description – the skills matrix of the PD course under development. The impact of the components of the two modules (contents of teaching and methods used for learning for the PD course) on the skills needed; major impact = xx and minor impact = x.*

Skills → **Course description ↓**	**A8**	**B2**	**B5**	**B9**	**B11**	**B12**	**C5**	**C9**	**D1**	**D2**	**D6**	**D7**	**E5**	**E9**	**F5**
Contents of teaching:	-	-	-		-	-	-	-	-	-	-	-	-	-	-
PD process (Stage-gate model)				x	xx	xx							x		
PD organisation						x							x		
Identification of customer needs		xx							x	x	x	x			
Concept creation and selection									x	x					
Technical specification of product				x						x					
Layout design			xx												
Industrial design	x			x											
Production-friendly design	xx									x			x		
Prototypes				xx											
Intellectual property rights											x				
PD in supplier company	x												x		
Methods used for learning:	-	-	-		-	-	-	-	-	-	-	-	-	-	-
Traditional lessons			x			x	x	x	x				x	x	
Exercises during lessons	x	x	x	x		x		x	x	x	x	x			
Exercise work, independent	xx				x	x		xx	x	x	xx	x			xx
Company visit													x	x	x

It is important to make a critical analysis of the impact marks in the matrix to evaluate the selected concept. It can be seen, for example, that intellectual property rights in the contents of the course has only one mark, and so it only has a minor impact on the ability to retrieve information from various sources (D6). One can ask if this part of the contents is needed or not; especially since the D6 skills have a relatively low competence gap. At the very least this means that only a minimum amount of resources are needed on intellectual property rights during the course. On the other hand the PD process and identification of customer needs in the course contents both have six crosses, and thus impact on many skills. This means that more resources are needed for these. It is also interesting and important to note that as many as 13 crosses are on the row of exercise work. Making course exercise work is independent learning and belongs in the learning by doing methods. It is important for the teacher to carefully plan in detail this part of the course during design phase 3 of the project, when the component descriptions are made.

Human and other resources, as well as the project time-schedule, also need to be estimated during this phase. These depend very much on the course contents and methods selected when compared with the existing ones. If the changes are small, the needed resources are small (only the teacher of the course) and the time-schedule is typically one academic year. In the case of major changes the needed resources may be large and the time-schedule is typically two academic years; especially if some new investments are needed in the university laboratories, then the time-schedule may even be more than two academic years.

The development project budget also very much depends on the selected course contents and methods and how much these differ from the current ones. The costs include mainly personnel costs and any possible laboratory investments. In the simplest cases there are no extra costs and the project fits into the normal course development work of the teacher. It is also important to consider if there are possibilities to have some financial support for the project. This may be possible, for example, in the case where some new teaching and learning methods are developed during the project and these methods have a general interest outside the university.

Another kind of cost evaluation is also needed; it is the cost of the course implementation using the new selected course concept solution. This may be larger, smaller or the same as the current implementation cost. The cost of traditional lessons is easy to evaluate. If the course implementation includes, for example, laboratory exercises, learning by doing actions or activities outside the university, these mean additional costs. Also these costs are usually easy to estimate.

In the project plan (the main outcome of the phase) it is still necessary to estimate the possible risks of the project. The biggest risks are usually connected to the customer acceptance of the new product. In the case of the teaching strategy product the learning outcomes show how well the new concept is accepted by the students and how well the targeted skills are achieved. The risks connected to the student acceptance can be estimated based on the teacher’s previous experiences at the university. The financial risks usually come from the possible laboratory or other major investments. If these investments are not accepted, the project results cannot be at the level planned.

5.2.3 Phase 3: Design

Before continuing the project the main outcome of the previous stage must be accepted by the project steering committee. It is possible that the project plan for phase 2 needs to be reworked before acceptance. This kind of iteration between each consecutive phase is typical for the stage-gate model used.

The teaching strategy module list

The first task in this phase is the final teaching strategy module list for the course under development (Figure 24). In this case the final teaching strategy module list is the same as already stated in section 4.1:

- Targets for learning outcomes;
- Contents of teaching;
- Methods used for learning;
- Learning assessment;
- Teaching assessment.

Sometimes, in the case of physical products, the module list in the design phase is different from the list in the pre-design phase. The reasons for these differences may come for example from details in the product construction or from the component suppliers. In the case of service products these differences are also possible.

Component list of the modules

Next, it is necessary to determine what kind of components these modules have. The components of each module are listed on the columns in Table 7. The components of the first module are already listed in section 5.2.2 in the pre-design phase and the components of the second and third module are already listed in Table 6.

Also the components can be different from those in the pre-design phase. The reasons for these differences might be because of, for example: a different module list structure, cost analysis of the new teaching strategy or module test results.

Table 7. *The components of the five teaching strategy modules.*

Targets for learning outcomes; what to know after the course	**Contents of teaching**	**Methods used for learning**	**Learning assessment**	**Teaching assessment**
Modern NPD process model	PD process	Traditional lessons	Exam	Questionnaire lists for students
Tools for identification of customer needs	PD organisation	Exercises during lessons	Exercise work assessment	Oral student feedback
Designer and production co-operation in NPD	Identification of customer needs	Exercise work, independent		Teacher's feedback from student feedback
Methods of problem solving	Concept creation and selection	Company visit		Peer teacher assessment
Working in PD networks	Technical specification of product			
	Layout design			
	Industrial design			
	Production-friendly design			
	Prototypes			
	Intellectual property rights			
	PD in supplier company			

The component list of a module gives the basis for the function of the module. However, to define the final specification of the whole product, more precise component descriptions must be made.

Component descriptions

In the case of a physical product the component descriptions correspond to the drawings of the product. The components of the first four modules (targets, contents, methods, learning assessment) and the descriptions of these components need to reflect the competence needs listed in Table 5 and thus the results of the case study research shown in chapter 3. The components of the last module (teaching assessment) and their descriptions need to support the continuous development of the course implementation. The component descriptions are shown in Tables 8…12 in the following sections together with discussions about the components.

Targets for learning outcomes

The component descriptions in Table 8 give a deeper definition for the learning targets. Table 5 is the information source for these targets and descriptions. It is important that the student creates a basic understanding of these targets and is able to apply and develop this understanding in PD work as an engineer.

Table 8. *The component descriptions of the "Targets for learning outcomes" module.*

Targets for learning outcomes	**After passing the course the student has a basic understanding of the listed items below and is able to further deepen this understanding when working as an engineer in a PD organisation (reference to Table 5).**
Modern NPD process model	• NPD process model • PD organisations • PD project time schedule and its management
Tools for identification of customer needs	• Various methods to gather customer needs and the processing of the data • Customer process as a source to identify real customer needs
Designer and production co-operation in NPD	• Manufacturing and assembly cost management • Quality assurance of new products • Product architecture and modularization of the product
Methods of problem solving	• Formulating and solving the problem • Open-ended problems
Working in PD networks	• Supplier cooperation in PD • PD network management

As stated in section 3.7 many of the most important competences, according to the case study, belong to the group of NPD project skills. So, the component descriptions of the targets for learning outcomes module also reflect these skills.

Very often engineering problems are open-ended and thus there is not one single answer to the problem. Engineers need to know how to formulate (define) the problem, find several possible solutions, compare the solutions and finally select the best one.

Contents of teaching

Table 9 lists the component descriptions of the contents of teaching module components so that the outcome targets could be achieved as well as possible. These component descriptions strongly support working in NPD projects.

Table 9. *The component descriptions of the "Contents of teaching" module.*

Contents of teaching	**The course content covers the learning outcomes targets (reference to Table 5 and 8).**
PD process	• The stage-gate NPD process model • Tasks in the stages in the NPD process • Main outcomes for the stages in the NPD process
PD organisation	• Functional, project and matrix organisations • Connecting outside resources to PD projects, PD networks
Identification of customer needs	• Questionnaire methods and interpretation of the answers to customer needs • Customer clinics • Analysis of the customer process as a method to understand customer needs
Concept creation and selection	• Definition of product concept and the purpose of concepts • Methods to create product concepts; brainstorming, TRIZ, open-ended problems • Concept comparisons and selection for further development
Technical specification of product	• BOM, drawings and other kinds of product specifications • Standard components
Layout design	• Product architecture, modular product
Industrial design	• Tasks of industrial designers and their connection to the tasks of technical designers
Production-friendly design	• DFM and DFMA in product cost reduction and quality assurance
Prototypes	• Purpose of prototypes, prototype reviews
Intellectual property rights	• Patent and patent application • Trademark, registered design, utility model, company name registration
PD in supplier company	• Costs and benefits to the supplier company for joining the PD work of the customer company • Work distribution, confidentiality aspects

These components and their descriptions form the basis for the table of contents of the course. Depending on the extent of the course in ECTS credit points (3.0 in the course under development) the teacher needs to adjust the volume of each component to optimise the learning results in the time available for the course implementation.

Methods used for learning

This module, methods used for learning, utilizes among other things the methods described in section 2.2. As already mentioned in section 2.2.9, Ramsden (2003) states the aim of teaching as: "teaching is to make learning possible" and "it is not the method, but how skilfully it is used, that matters". So, for example traditional lessons can be implemented in many different ways, some of which are interactive whilst some are not.

Table 10. *The component descriptions of the "Methods used for learning" module.*

Methods used for learning	**The aim of the methods used for learning is to make students' active participation as high as possible.**
Traditional lessons	• Interactive lecturing, questions to the students • Examples from industry
Exercises during lessons	• Closed and open-ended problems • Practical, industrial examples in exercises
Exercise work, independent	• Group work: Project plan of a PD project including open-ended types of tasks • Time-schedule and its management in exercise work performance • Working group presentations of the results to the other students and the teacher
Company visit	• Excursion to a local company and learn about its PD work • Analysis of the PD work at the company during the lessons after the visit

The list of components and the component descriptions of this module in Table 10 depend more than the others on the teacher's personal characteristics and experiences. Some teachers are good in traditional lessons, some in PBL methods and others in learning by doing based methods and so on.

Learning assessment

Learning assessment is a powerful tool to motivate students to achieve good learning results. So, it is important to inform the students at the beginning of the course's implementation of the assessment criteria being used in the course.

Table 11. *The component descriptions of the "Learning assessment" module.*

Learning assessment	**The aims of learning assessment are to motivate the students' learning and give them feedback from the learning results.**
Exam	• Closed and open-ended questions, teacher assessment • Weighting 80%
Exercise work assessment	• Teacher, peer student and self-assessment; contents, written report and presentation • Weighting 20%

The exam should include also open-ended questions. The exercise work is done in student groups to learn team working skills (Table 5, skill B12). The relative weighting of the different assessment methods depends on the amount of work in each part.

Teaching assessment

As mentioned in section 2.2.9, the basic idea in the book "Learning to Teach in Higher Education" (Ramsden 2003) is "learning about students' learning". This means that it is useful and important to utilize learning outcomes and student feedback in the development of the course.

Table 12. *The component descriptions of the "Teaching assessment" module.*

Teaching assessment	**The aim of teaching assessment is to have information for the further development of the teaching strategy of the course.**
Questionnaire lists for students	• A questionnaire list of 10…15 questions, using the four point Likert scale + "I don't know", free comments (Appendix 4)
Oral student feedback	• Discussions about the course implementation with participating students during the course
Teacher's feedback from student feedback	• The last lesson is to be used to show the averages and standard deviations of the questions to the students, also free comments when not personal • Teacher – students discussions about the questionnaire results
Peer teacher assessment	• Peer teacher assessment to evaluate the teaching strategy of the course • Peer teacher to participate in some lessons

The questionnaire method here is in principle the same as in the case study research in chapter 3. The list is shown in Appendix 4. The results are shown to the students in a similar way as the case study results in Appendix 3. It is useful to gather oral student feedback during the implementation of the course. The peer teacher assessment is challenging because of the time resources needed for the assessing teacher. However, this may also give valuable information for the teaching strategy development of the peer teacher's courses.

Cost estimate update for the implementation of the new teaching strategy

The first two tasks of phase P3 have now been completed and there are still three tasks to carry out. Cost estimate update for the implementation of the new teaching strategy is the next task and is now more precise than the cost estimate in P2, because the final specifications are available. It is practical to compare the new teaching strategy with the old one and calculate the additional or reduced cost components. This way a relative cost comparison is calculated in a reliable manner. In this particular teaching strategy there is only one unusual cost component, which is the company visit. This however should not be a large cost, because the company should be located near the university.

Module tests in other courses

Module tests and corrective actions from these tests form the final task of phase P3. At least some of the modules can also be tested in other courses at the university. The three relevant modules for these kinds of tests are those in Tables 10…12. The other two modules are either substance oriented or need feedback from the whole course implementation and thus cannot be tested in other courses. So, even now in design phase P3 tests for these three modules can be carried out and valuable information obtained for any possible modifications needed to the components and the component descriptions before the project is finished.

5.2.4 Phase 4: Testing

In this phase the developed teaching strategy is tested by implementing the PD course in its entirety in the mechanical engineering degree programme. Now it is important to follow precisely the specifications of the new teaching strategy (modules, components, component descriptions). It is now especially important that the teaching assessment module described in Table 12 is carefully carried out, because it probably provides some modifications which need to be done before the newly developed teaching strategy is fully used. So, this testing phase (as, in principle, with all other phases) may lead to iteration, which means that it would be necessary to go back to phase P3 and redesign things. After the redesign modifications a new decision must be made to go ahead to phase P4. This means that there is a risk that the project time-schedule will be delayed. The main outcome of this phase is the tested and fine-tuned teaching strategy of the PD course and this establishes the basis for the update of the course description in the curriculum.

This developed teaching strategy was tested in the spring semester in 2012 by the author at the UAS where the author works. The participants of the PD course were the third year students in the mechanical engineering degree programme. These students are so-called mature students. They are working in companies whilst studying; so the company visit in module 3 was not carried out. Also, the list of questions for the students used in module 5 was the normal list used by the university; which is a little shorter than the list in Appendix 4.

5.2.5 Phase 5: Launch and Production

Now the teacher responsible for the project (“the project manager”) needs to inform the colleagues at the UAS about the project results. This is valuable information for them, because they may utilize at least some of the results in their own courses.

Now in P5 the developed teaching strategy for the PD course in the mechanical engineering degree programme is ready for full use. It is now moved to the so called “follow-up” process, which means the feedback information is still gathered from the students. This can be done following the first three component descriptions of the teaching assessment module (Table 12) and any possible modifications in other modules and components are made accordingly.

As the final task of the whole development project it is necessary to evaluate the development process used. This process is described in Figure 24. The experiences from this particular project may cause some process modifications which need to be updated in this process description.

5.3 Conclusion

In this chapter the PD process model of chapter 4 has been applied to develop the teaching strategy of a PD course to illustrate the idea and the systematics aimed at in the RG. The phases of the process together with their tasks and main outcomes have been presented. Key input information for this development project for the PD course in mechanical engineering comes from chapters 2 and 3.

The main idea of this chapter is to show how the model of chapter 4 is to be used. The concept of the course teaching strategy as a modular service product together with the components of the modules has been presented as an example. The phase tasks of the stage-gate model of chapter 4 have also been described phase by phase.

Figure 26 shows the illustrative BOM of the teaching strategy product. Detailed analysis has been presented about the modules, components and component descriptions of the teaching strategy for the PD course under development. The component descriptions in Tables 8…12 correspond to the drawings (and other possible specifications) of a physical product. The developed teaching strategy was tested in practise in the PD course of third year bachelor students in mechanical engineering at a UAS in the spring semester in 2012.

Course and curriculum development is vitally important to every university. So, in this field there are a lot of development models, which have different approaches and emphases. It is useful and important to analyse these existing models and compare with the model of this thesis. This is to be done in the next chapter. The analysis and comparison cover in total eight development models which were presented in eight books published between the years 1992…2013.

Teaching strategy of the PD course

- **Targets for learning outcomes**
  - Modern NPD process model
  - Tools for identification of customer needs
  - Designer and production co-operation in NPD
  - Methods of problem solving
  - Working in PD networks
- **Contents of teaching**
  - PD process
  - PD organisation
  - Identification of customer needs
  - Concept creation and selection
  - Technical specification of product
  - Layout design
  - Industrial design
  - Production-friendly design
  - Prototypes
  - Intellectual property rights
  - PD in supplier company
- **Methods used for learning**
  - Traditional lessons
  - Exercises during lessons
  - Exercise work, independent
  - Company visit
- **Learning assessment**
  - Exam
  - Exercise work assessment
- **Teaching assessment**
  - Questionnaire lists for students
  - Oral student feedback
  - Teacher's feedback from student feedback
  - Peer teacher assessment

Figure 26. *Illustrative BOM of the teaching strategy of the PD course in mechanical engineering. The three levels are: product, module and component.*

6 Review of Course and Curriculum Development Models

Now, after defining the course and curriculum development tool presented in this thesis in chapter 4 and its illustration in chapter 5 a more detailed analysis of existing models can be made. This analysis covers the frontline publications in the field during the last twenty years. After this analysis a comparison of the models in these publications with the model presented in this thesis is made.

6.1 Analysis of Existing Models

There is a lot of literature in the field of course design (some of them already referred to in chapter 2). Journals and conference papers normally focus on smaller issues and not on comprehensive course design models. On the other hand there are some books which introduce more holistic models. In the following sections these books are analysed in the order of the publication year.

Improving the Quality of Student Learning (Gibbs 1992)

The book is an outcome of the "Improving Student Learning" project undertaken by the Oxford Centre for Staff Development. The target of the project was to improve the quality of student learning in Polytechnics and Colleges in the UK. The book points out the importance of deep learning approach and assessment to support deep learning. The appropriate course design, teaching methods and assessment can foster a deep learning approach (p. 10-11):

- Motivational context;
- Learner activity;
- Interaction with others;
- A well-structured knowledge base.

Several strategies for fostering a deep learning approach have been presented (p. 12-18), such as: independent learning, PBL, learning by doing, project work.

In total ten case studies from different polytechnics and colleges in the UK have been presented in the book. Each case study describes one innovation to support deep learning. There were several fields of applied sciences among these case studies: engineering, business, law, geography, accounting, oceanography, physiotherapy, and graphic information design.

As conclusions from the ten case studies the following observations were made (p. 162-169):

1. A surface approach is very common.
2. Different courses reveal very different patterns of learning. It seems clear that the wide variations in students' approaches were due to differences between the courses and not so much due to differences between student groups.
3. Individual differences in approach are extremely wide. However the students were likely to adopt a common approach within the group.
4. Students' approach to studying can be highly volatile; changing from an extreme surface approach to an extreme deep approach.
5. Changes in the students' approach to studying are not due to maturation and thus whether a student adopts a deep or a surface approach has little to do with the extent of their earlier experience of higher education.
6. Most students seem capable of adopting either a surface or a deep approach on different courses.
7. It is possible to change students' approach. The author of the book considers this to be the most important conclusion of the study.
8. It is easier to change students' approach early in a course than towards the end. It is difficult to change students' approach adopted from the earlier parts of the course.
9. Intrinsic motivation, which comes from individual students, is crucial.
10. Assessment dominates students' thinking to a considerable extent. It needs to be in line with learning targets.
11. Some assessment systems clearly reward a surface approach. A deep approach must be rewarded and thinking of students' motivation (item 9 above) it is very important for them to know what is rewarded.
12. Successful teaching and learning innovations may have only local or short-lasting impacts. Students' approaches are not stable and depend very much on learning context.
13. It is possible to have a pervasive impact on students. The engineering students (one case study) did not tolerate being taught conventionally after experiencing a problem-based course.
14. The appropriate focus of attention in improving the quality of student learning is course design and process rather than teaching and content. The way in which students are engaged in learning is crucial.
15. It takes skill and fine-tuning to make methods work. For example it was successful in the engineering case study to test the methods first with a pilot group of only six students.
16. The conceptual framework offered here provides a powerful tool for improving the quality of learning. The project reported in the book illustrates a way for lecturers to become excellent teachers by using a new approach to teaching and learning.
17. Perhaps the most important finding in the long term in this project was that educational researchers are not necessary. Lecturers are perfectly capable of researching their own teaching.

Gibbs (1992) introduces important and tested teaching and learning methods to support deep learning. Points 14 and 15 in the list above give a clear message for the need to develop a comprehensive systematics to develop the whole teaching and learning process of a course. However, this systematics has not been introduced in the book.

Understanding Learning and Teaching: The Experience in Higher Education (Prosser and Trigwell1999)

This book has its focus on the students' experience of learning and it links ideas from that research to the teachers' experience of teaching in higher education (p. vi). It includes a lot of research references in the field and is kind of an extension of the student learning researches by Ramsden (1992) and by Marton and Säljö (1997). A model of student learning as well as a model of the experience of teaching has been introduced (see Figure 27). Detailed analysis of these models, especially of the student learning model, constitutes the whole contents of the book.

There is a relation between the prior understanding of the subject and the new learning situation. Even though student's prior experiences about the subject learned is important, the new situation in teaching and learning may change the learning outcomes. What makes the teaching challenging is that the variations in students' prior experiences and understandings are wide.

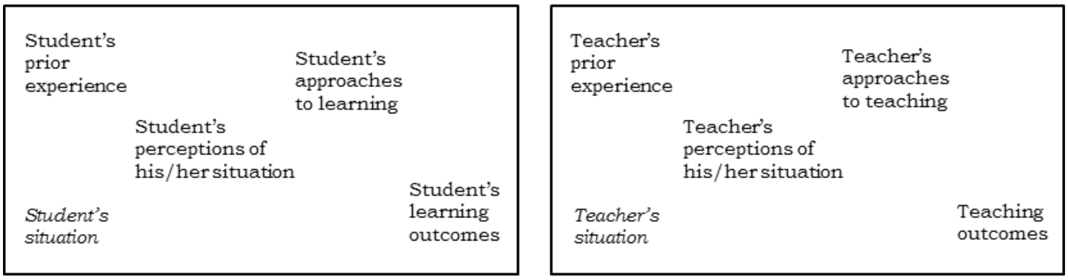

Figure 27. *A model of student learning and a model of the experience of teaching (p. 21 and 24, reproduced).*

The next item in the student learning model is "Student's perception of his/her situation". To be able to successfully develop teaching university teachers need to look at their designs through their students' eyes (p. 59). Students' perceptions are strongly related to their approaches to learning. To develop a deep approach to study is important, but it is not sufficient. Teachers also need to determine how the students perceive the teaching and learning situation (p. 82).

About student's approaches to learning the book clearly emphasizes the importance of a deep approach. A lot of research to support this has been presented. However, memorizing is also important and it is not the same as rote learning. Marton et al. (1995) define these two types of memorizing as memorizing meaning and memorizing words respectively (p. 93).

In the student learning model (see Figure 27) the three elements (student's prior experience, perceptions of his/her situation and approaches to learning) are internally related and university teachers need to use these relations to improve learning. So, all these three elements are important to the teacher to understand and thus create a deep approach to learning. That will produce successful learning outcomes. The well-known SOLO taxonomy (see Figure 30), originally introduced by Biggs and Collis (1982), has been presented as the most important research into variation in the structure of learning outcomes (p. 118-135).

Similar elements can be seen in the model from the teacher's point of view (Figure 27). The book does not deal very much with this part of the model. For the lecturer it is important to adopt an approach based on what the students do, not on what he/she does. The book lists four key principles of practice for good teaching (p. 160):

1. "Teachers need to become aware of the way they conceive of teaching and learning within the subjects they are teaching.
2. Teachers need to examine carefully the context in which they are teaching and become aware of how that context relates to or affects the way they teach.
3. Teachers need to be aware of and seek to understand the way their students perceive the teaching and learning situation.
4. Teachers need to be continually revising, adjusting and developing their teaching in the light of this developing awareness."

In the book's summary of the authors' views on learning and teaching they mention the following items (p. 164-175):

- Good teaching is a continuous process of looking at learning and teaching from the student's perspective.
- Good learning and teaching are contextually dependent. So, what works in one learning and teaching context does not necessarily work in another. Also what works in one discipline may not work in another.
- Good teaching includes that we need to be aware of students' perceptions of those teaching technologies we use.
- Good teaching includes that we are aware of student diversity in classrooms.

- Good teaching includes that we have continuing efforts to evaluate our teaching for improved learning.

The book introduces a kind of model of student learning together with a model of the experience of teaching. The student learning model includes four elements. It has been emphasized that these elements are strongly related with each other, that is they are linked together (see section 4.1 of the thesis). A lot of practical advice for each element has been given to develop good teaching. However, the book does not include a proper teaching development model.

Rethinking University Teaching: A conversational framework for the effective use of learning technologies (Laurillard 2002)

When the book was published the author was head of the e-Learning Strategy unit at the Department of Education and Skills and a visiting professor at the Open University and the Institute of Education, London (p. i). She has grasped at the very challenging and rapidly developing field of e-learning media. Part I analyses students' learning needs in general and especially their challenges for the new e-learning technologies. This part of the book includes several quotations from the research in the field, for example by Ramsden.

Part II is a thorough analysis of the new learning and teaching media. It is however more than ten years since the publication of the book and educational technologies in this field have undergone intensive development during that time. According to the title of the book a conversational framework for the effective use of learning technologies has been presented (see Figure 28).

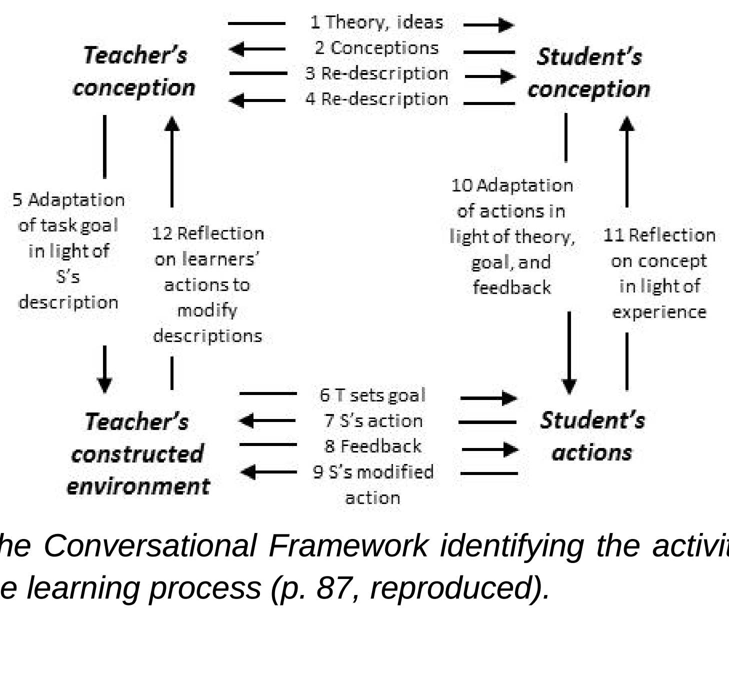

Figure 28. *The Conversational Framework identifying the activities necessary to complete the learning process (p. 87, reproduced).*

The following types of media have been introduced and compared against the Conversational Framework in Figure 28 (p. 174):

- “Narrative: print, TV, videocassette
- Interactive: CD, DVD or Web-based resources
- Communicative: Web-based conferencing, asynchronous / synchronous
- Adaptive: manipulable model on disc or Web
- Productive: tools for student to create models or descriptions, on disc or Web

The clear conclusion is that improvements in university teaching are more likely to be achieved through ‘multiple media’, appropriately balanced for their pedagogic value, than through reliance on any one learning technology.”

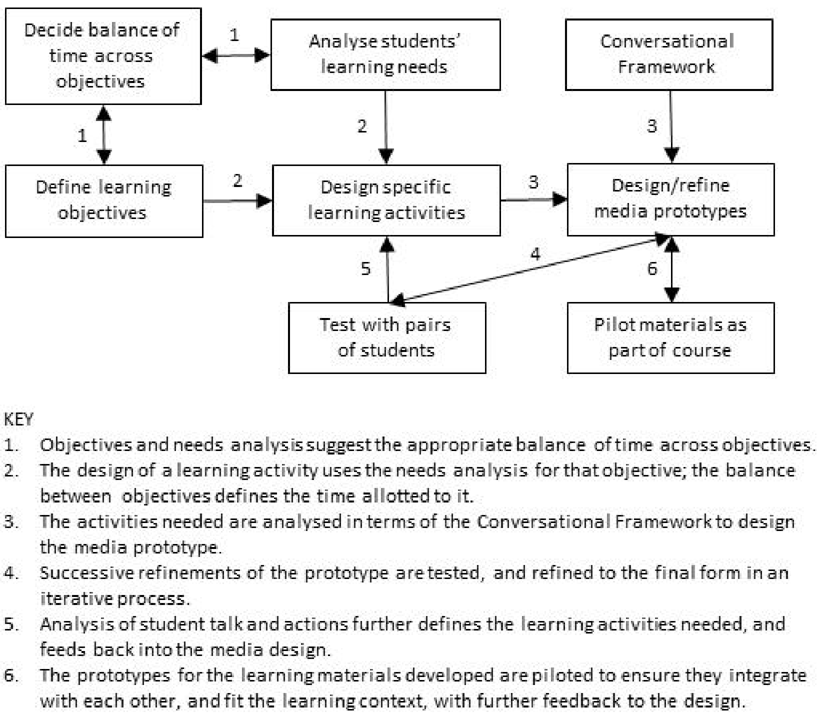

Figure 29. *The sequence of stages in the learning design process (p. 198, reproduced).*

In the final part of the book, Part III, a learning design process model has been developed and introduced (see Figure 29). The iterations between the different stages as well as the needed actions can be seen in the figure.

The book is strongly focused on the rapidly developing field of e-learning technologies. A kind of learning design process is also introduced (Figure 29). This process is a combination of teaching and e-learning media development.

Learning to Teach in Higher Education (Ramsden 2003)

This book is already included in the reference material in chapter 2 (section 2.2.9). The main message of the book is: Understanding students' experiences of learning is the best way to become a good teacher. The target group of the book is mainly the teachers of undergraduate students in higher education. Teaching is defined in a broad sense including: the aims of a course, the methods of presenting the knowledge those aims embody, assessing students' achievements and evaluating the effectiveness of the whole process (p. 11).

The book also emphasizes the importance of assessment in student's learning. "The methods we use to assess students are one of the most critical of all influences on their learning. There are two related aspects to consider: the amount of assessed work and the quality of the tasks" (p. 67). It is recommended to use more than one assessment method after the course completion especially when PBL method has been applied.

The final part of the book deals with teaching evaluation methods. The most important areas to evaluate are (Ramsden 1998, according to p. 216):

- "Positive attitude towards students;
- Ability to communicate well with other people;
- Lively interest in improving teaching through reflection and action."

Ramsden (2003) is a book that is quoted a great deal in the field of learning and teaching in higher education. It offers excellent guidance for teaching development. It can be realized that the book defines teaching in a proper way from course targets to assessment and evaluation. The book does not clearly define the customer, product and process in teaching development.

Understanding by Design (Wiggins and McTighe 2006)

Curriculum, assessment and instruction design, focused on developing and deepening understanding of important ideas is the focus of this book (p. 3). It is important to distinguish understanding from knowledge and skill. Understanding is deeper and cannot be assessed using fact-focused testing alone. Real understanding means that we (p. 84)

- Can explain – why and how that is so?
- Can interpret – what does it mean?
- Can apply – how and where can we use this knowledge?
- Have perspective – what are the strengths and weaknesses of the idea?

- Can empathize – how does it seem to you?
- Have self-knowledge – what are the limits of my understanding?

The authors clearly define students as the primary clients of a school or university. They also introduce the term “Backward Design”, which includes the following three stages to be made in this order (p. 18):

1. Identify desired results.
2. Determine acceptable evidence.
3. Plan learning experiences and instruction.

This means that before making a teaching and learning plan you need to list the desired results and determine the learning assessment methods. The book emphasizes the use of national standards of learning goals in different subject areas.

“Essential questions” are useful and important teaching and learning tools, when deep understanding is aimed at. The essential questions are such that they create more questions, discussions, analysis of alternatives, and so on. The authors state that the purpose of curriculum and course design is to help students draw inferences, not to give direct answers.

The book analyses in detail the assessment of understanding and gives a lot of practical instructions on how to do that. Planning for learning is the final stage of the backward design process. A good plan for learning has been defined as follows (p. 195): “It must be engaging and effective”. The book includes a course and curriculum design process, which has three stages. The course or curriculum is the product to be designed. Even the students are defined as customers or more precisely as clients. National standards are recommended when defining learning goals and thus there is no specific process introduced to identify customer needs.

How Learning Works: Seven Research-Based Principles for Smart Teaching (Ambrose et al. 2010)

This book is a practically oriented analysis of learning and teaching in a college environment. It is a synthesis of empirical research evidence and research-based learning theory. It introduces seven learning principles, one in each of the seven chapters of the book. The structure of every chapter is similar: first a couple of fictional stories about the subject, then a research review of the subject and finally a list of recommended strategies to the teachers for course design.

The seven important principles of learning analysed in detail in the book together with some key notes of each principle are (p. 4-6, chapters 1-7):

1. *“Students’ prior knowledge can help or hinder learning*.” It is recommended to assess what students know and believe at the beginning when conducting a course.
2. *“How students organize knowledge influences how they learn and apply what they know.”* Sequential knowledge organisation is typical of novice students and expert students are able to connect knowledge structures.
3. *“Students’ motivation determines, directs, and sustains what they do to learn.”* The subjective value and the expectancies of the goal create high learning motivation, which leads to goal-directed behaviour and further supports learning and performance.
4. *“To develop mastery, students must acquire component skills, practice integrating them, and know when to apply what they have learned.”* The four stages in the development of mastery are (from the lowest to the highest level): unconscious incompetence, conscious incompetence, conscious competence and unconscious competence.
5. *“Goal-directed practice coupled with targeted feedback enhances the quality of students’ learning.”* Practice and feedback cycle: practice leads to performance and this allows feedback, which again guides practice. All three components of the cycle are connected with the learning goals.
6. *“Students’ current level of development interacts with the social, emotional, and intellectual climate of the course to impact learning.”* Seven “vectors” of developmental changes students experience through the college years (Chickering 1969, according to p. 160-162) are: developing competence, managing emotions, developing autonomy, establishing identity, freeing interpersonal relationships, developing purpose, developing integrity.
7. *“To become self-directed learners, students must learn to monitor and adjust their approaches to learning.”* A cycle of students’ self-directed learning includes the following steps: assess the task, evaluate your strengths and weaknesses, plan your approach, apply strategies to the plan and monitor performance, reflect and adjust and restart the cycle if needed.

The conclusion of the book, “Applying the Seven Principles to Ourselves”, is very interesting. Its message is that the seven principles described in chapters 1-7 and referred to above, can be applied also to teachers and teaching development. The authors conclude (p. 217): “These principles explain and predict a wide range of learning behaviours and phenomena and hence aid the design of courses and classroom pedagogy.” There is guidance for designing courses, but the book does not introduce a course development model as such.

Teaching for Quality Learning at University (Biggs and Tang 2011)

This fourth edition of the book draws on the experiences of the authors' consulting work with regard to teaching and learning in Australia, Hong Kong, Ireland and Malaysia. The focus is on the design of a teaching and learning system. The nature of the book is practical in the important course and curriculum design work. It is mainly aimed at teachers but also at staff developers and administrators. A common concern is that even today people are allowed to enter the university teacher profession without any formal qualification in teaching (p. 302).

The central idea of the book is how to design constructively aligned outcomes-based teaching and learning. The constructive alignment here includes the methodology how to put together its three components: writing intended learning outcomes, designing teaching/learning activities, assessing and grading students' performance.

Part 1 deals with effective teaching and learning for today's universities. It is a kind of introduction to the constructive alignment methodology. Student's learning has been analysed in detail. An interesting addition to the Chinese proverb mentioned in section 2.2.9 in this thesis (Ramsden 2003, p. 247) is that the highest level of learning is achieved, when people teach someone else (p. 63, original source William Glasser, 1988). Another interesting note is that "Teaching is, if you like, a service activity" (p. 74). The well-known SOLO (Structure of the Observed Learning Outcome) taxonomy, defining the levels of student's understanding, has been presented in Figure 30.

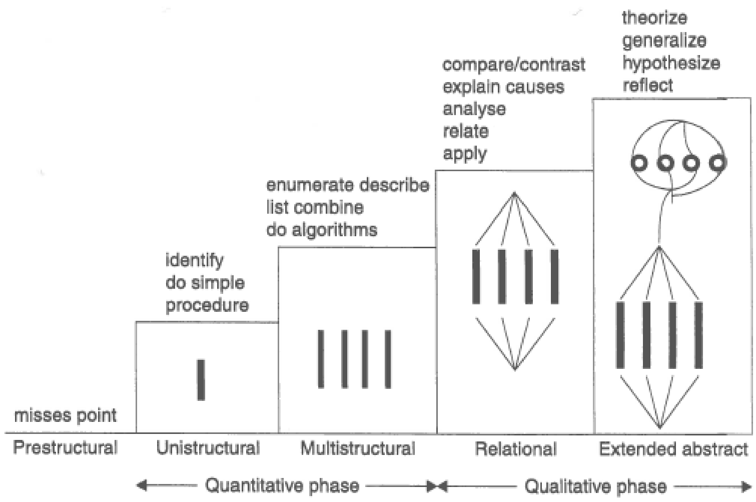

Figure 30. *SOLO taxonomy, a hierarchy of verbs that may be used to form intended learning outcomes (p. 91).*

Part 2 includes guidance for designing constructively aligned teaching and learning. Defining intended learning outcomes is the first task. This kind of outcome statement can be made at three levels: the institutional level, the degree programme level and the course level. Biggs and Tang (2011) state that often the intended learning outcomes are addressed by several courses in the degree programme (see section 5.2.2 of this thesis).

The second task is designing the teaching/learning activities for these intended learning outcomes. Many teaching and learning methods are introduced: traditional lectures, case study, group work, PBL, and so on. Whatever teaching and learning method is used, an interactive approach is important. It is very important what the students are doing while the teacher is teaching.

The third task is aligning the assessment tasks with the intended learning outcomes. The book covers a huge number of assessment practices (p. 191-277). Both formative (feedback during learning) and summative (feedback after teaching has been completed) assessments need to be used. The book analyses a great deal of assessment practices and the problem of plagiarism is thoroughly discussed.

Part 3 includes implementing, supporting and enhancing constructive alignment and its connection with continuous development in the quality systems used at the university. The authors also state that constructive alignment is useful as a framework for decision making and design (p. 306). The book presents some examples of constructive alignment as implemented in nine different areas, one of which is engineering (p. 331-334). The course is “Engineering Principles and Design” taken during the first year of a three-year bachelor programme in the College of Science and Engineering at the City University of Hong Kong.

First it is necessary to list the intended learning outcomes of the course. “On successful completion of this course, students should be able to (p. 332):

1. *Apply* the principles of mechanical kinetics to single degree of freedom vibration systems.
2. *Outline* the fundamental theory of friction and wear and its applications in engineering.
3. *Describe* the basic theories of fluid mechanics and heat transfer.
4. *Apply* the basic engineering mechanics principles to the design and implementation of a simple engineering system (such as a projectile machine) and the evaluation of its performance.
5. *Work* effectively as a team member in a small-scale engineering project.”

The second task is to design the teaching and learning activities (abridged, p. 333):

- *Large class activities consist of lecturing and student activities. Major focus is on the intended learning outcomes 1 and 2, minor on 3.*
- *The laboratory exercises are designed to supplement the taught materials such as friction, fluid mechanics and heat transfer. Major focus is on the intended learning outcomes 1 and 2.*
- *Student-centred activity* is a project that utilizes the subject material of the courses "Mechanics" and "Engineering Principles and Design" to design a simple mechanism. Major focus is on the intended learning outcomes 4 and 5.

The third task is to define the assessment tasks and activities: final examination, laboratory report and student-centred activity project. Table 13 shows the weighting of these assessment tasks with respect to the intended learning outcomes 1…5.

Table 13. *Weighting of the three assessment tasks in engineering with respect to the intended learning outcomes (p. 333 adapted).*

<table>
<tr><th>Assessment tasks →
Intended learning outcome ↓</th><th>Examination</th><th>Laboratory report</th><th>Student-centred activity</th><th>Total (%)</th></tr>
<tr><td>1</td><td>25</td><td rowspan="3">} 10</td><td>-</td><td>30</td></tr>
<tr><td>2</td><td rowspan="2">} 30</td><td>-</td><td rowspan="2">} 30</td></tr>
<tr><td>3</td><td>-</td></tr>
<tr><td>4</td><td>-</td><td>-</td><td>36</td><td>36</td></tr>
<tr><td>5</td><td>-</td><td>-</td><td>4</td><td>4</td></tr>
<tr><td>Total (%)</td><td>50</td><td>10</td><td>40</td><td>100</td></tr>
</table>

This engineering application of the constructively aligned system of teaching and learning shows in practice the idea of Biggs and Tang (2011). The model emphasizes the connections between intended learning outcomes, teaching/learning activities and assessment. It does not clearly define the customer, product and process in its teaching development model and there is no methodology to identify customer needs.

Creating Significant Learning Experiences: An Integrated Approach to Designing College Courses (Fink 2013)

The main message of the book is that good teaching and learning are based on three major ideas: significant learning, integrated course design and better organizational support (p. xii). As the title of the book indicates, the focus is on college teaching and learning. So, from the point of view of this thesis, the integrated course design is the most interesting item of the three mentioned above.

When aiming at significant learning experiences, the teachers nowadays are faced with several changes taking place in higher educational environments. The four major “forces” are (Newman et al. 2004, according to p. 14-15):

- Development of information technology and its applications to online course offering;
- Rapid emergence of new providers (companies) of educational services;
- Globalization of higher education coming from the two above mentioned “forces”;
- Increase in new kinds of students, especially mature students which have part-time or even full-time jobs.

The author of the book has a clear view of the most important bottleneck to better teaching and learning, which is also the theme of this thesis: “If faculty can learn how to design their courses more effectively, students are much more likely to have significant learning experiences, the kind that are being called for in many parts of society today” (p. 29). Good courses are ones that challenge students, use active learning methods, have caring and interacting teachers and have good feedback and assessment systems (p. 32-33).

The key components of the integrated course design, introduced in the book can be seen in Figure 31. The situational factors in the figure mean such things

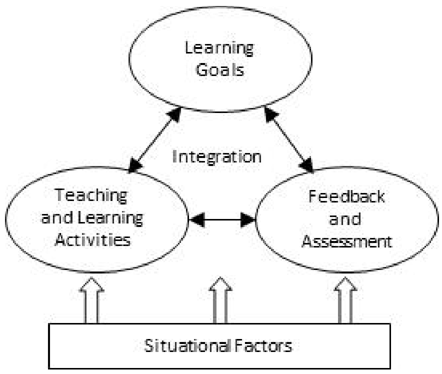

Figure 31. *Key components of integrated course design (p. 70, reproduced).*

as: number of students who participate in the course, knowledge level of the students, full-time or part-time students, prior experiences of the teacher in the subject, teacher’s knowledge and skills of the teaching process, and so on. The author also refers to the two books analysed above in this chapter (p. 69). This integrated course design model has similarities with Wiggins and McTighe model (2005) known by the term “Backward Design” as well as with Biggs and Tang (2011) model known by the term “Constructive Alignment”.

The book also points out the importance of better organizational support for faculties. Many national organizations who make evaluations of HEIs in the US are listed. ABET is mentioned as a very important accrediting association for engineering programmes to enhance high-quality learning in HEIs (see also section 2.1.4 of the thesis).

Chapter 7 summarizes the message of the book. The three contexts in which we all learn are:

- Individual, Informal Learning;
- Individual, Intentional Learning;
- Formal Learning Programmes.

The first belongs to our everyday life experiences. The second context is such that we learn typically by reading books. The universities and colleges are examples of the last context, but there are a lot of other institutions that offer this kind of educational and training services.

A new metaphor for teaching is offered by the author (p. 278): "the teacher as helmsman for the learning experience." The integrated course design has been divided into three phases. The first phase, called the initial phase, can be seen in Figure 31. The complete course design model of the book includes twelve tasks in the three phases as follows (p. 281).

"Initial Phase: Build Strong Primary Components for the Course

1. Carefully analyse the situational factors.
2. Identify and set significant learning goals.
3. Create significant forms of feedback and assessment.
4. Create effective teaching and learning activities.
5. Integrate the four preceding components.

Intermediate Phase: Assemble These Components into an Overall Scheme of Learning Activities

1. Identify the thematic structure for the course.
2. Create or select a powerful instructional strategy.
3. Integrate the structure and the teaching strategy into an overall scheme of learning activities.

Final Phase: Finish Up the Remaining Tasks

1. Develop a fair grading system.
2. Debug possible problems.

3. Write the course syllabus.
4. Plan an evaluation of the course and of your teaching."

This is a holistic course design model, however not including definitions of the customer and the product in the process. It is necessary to mention that the teaching strategy introduced in the intermediate phase here means the combination of learning activities when conducting the course. In the thesis the course teaching strategy has been defined as a service product including the five modules defined in chapter 4.

6.2 Comparison of the Developed Model with Existing Models

The eight books analysed above in section 6.1 belong to the frontline publications in the field of course design and development. Even though the approaches and emphases are somewhat different in these books, there are also many common conclusions:

- Course and curriculum design is crucial to successful learning results.
- Student's learning perspective creates the basis for good teaching development.
- Course assessment is an important learning activity and it should include more than one method.
- Targets, activities and assessment of learning are strongly related to each other.

The list above is very much in line with the core contents of this thesis. The RG of this thesis (Figure 3) fully supports the first item. The second item is supported by the three RQs and by the contents of chapters 2 and 3. The model of teaching strategy development introduced in chapter 4 and illustrated in chapter 5 closely relates to the last two items on the list.

These books include different kinds of course design instructions. However it is difficult to find a clear course development model which defines separately the product under development and the process how to make this development work. Only Wiggins and McTighe (2006) mention course or curriculum as the product under development and separately the "Backward Design" as the process. Biggs and Tang (2011) also mention that teaching can be a kind of service activity, but they do not consider it as a service product.

A comprehensive or holistic course development model is a clear target in all these books. However they do not include any activities to identify the customer needs (student's needs). Again only Wiggins and McTighe (2006) clearly define students as the primary clients of the universities, but they do not mention any activities to identify client needs. They, like many others, rely on national standards to identify learning goals.

To be able to conclude this comparison it is useful to repeat here the core ideas of this thesis. In the course and curriculum development model presented in this thesis the course teaching strategy has been defined as a modular service product having five modules. These modules have been further divided into components. In this way the BOM of the service product has been defined. The stage-gate type PD process has been used in the development of this modular service product. The case study methodology has been used to identify the customer needs (competence needs of the students).

This course development model includes:

- Identifying students' needs for the course under development;
- Definition of the course teaching strategy as a modular service product;
- Definition of the components of the modules of the service product;
- Definition of the component descriptions of the modules of the service product;
- The stage-gate type PD process systematics for the development of this product.

This kind of approach has several benefits in the important course and curriculum development at the universities, for example:

- It is a comprehensive systematics to develop the whole teaching and learning process of a course.
- It is a tool which has been described in details for clear and flexible use.
- It is a transparent methodology, which is easy to follow by the relevant personnel at the university.
- It gives a clear basis for the university to manage the project portfolio.
- It gives a project prioritization tool for universities under financial pressure.
- It is a strongly customer oriented model.
- Continuous development of the process is included in the model itself.

So, as a conclusion to the comparison, the development model presented in this thesis differs from any other analysed in this chapter. The major differences come from the definition of product and process separately as well as from the process of the identification of students' needs. The general concept of the service product defined with its modular structure, components and component descriptions offers a new kind of approach to course and curriculum development. These are significant differences compared to the existing course development models.

Figure 32 shows the whole process of the teaching strategy development. There are several reasons for the need to start a development project. Case study is the first task and gives the needed input information for the project itself. The new teaching strategy is the result. It is also useful to utilize the project experiences to consider any possible process modifications.

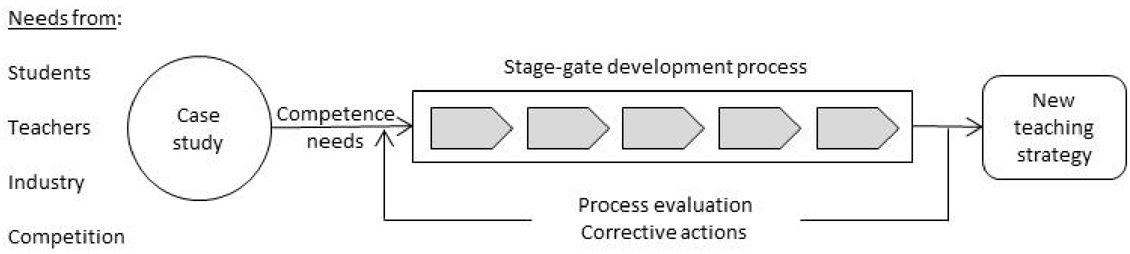

Figure 32. *Comprehensive teaching strategy development model.*

The next chapter discusses the research methods used and the results achieved in this thesis. The evaluation of the research is also discussed in the chapter and among other things this evaluation summarizes the novelty of the research. Finally, chapter 8 concludes this research.

7 Discussion

The research methods, the answering of the research questions as well as the results and the contribution of the research are discussed in this chapter. Also the evaluation of the research and the author's own contribution are discussed.

7.1 Research Methods

The research goal (RG) was the defining of the systematics needed to develop a teaching strategy for the education of PD engineers in mechanical engineering at UASs in Finland. The most important PD competence needs and the capabilities of young engineers to meet these needs established the essential input information for this development process.

A case study approach was used to find these competence needs and capabilities. The multiple-case study included 13 Finnish companies, most of which are among the largest mechanical workshops in the country. Several sources of evidence were used: 47 specific skills questions using a four point Likert scale, a PD facilities tour and the companies' web-page information. The interviewees were PD directors or managers. All the interviews and discussions took place at the company premises using face-to-face method.

Why was the case study method used to find out the competence needs and capabilities? The main reason to select this method was to have the best possible chance to produce reliable results. Also the large number of case companies and their size increased its reliability as well as making face-to-face interviews and using site visits.

The author has 20 years PD work experience in Finnish companies and for most of that time has been a PD director. The PD responsibilities for the plants in Finland, Brazil and Portugal gave valuable experience in international engineering work. The modern stage-gate type PD process has been successfully used and developed in the industry for tens of years and it is one of the key processes used in companies. It is a systematic and transparent way to develop physical as well as service products. It also helps the top management of the company to evaluate the importance of individual projects and their financial impacts on the business. Because of these reasons the PD process model, together with a modular service product concept, was proposed in the RH as the development tool for the teaching strategy of a course to reach the RG of the thesis. This tool was applied to the development of one specific PD course relevant to a multitude of the most important competence needs found in the case study.

7.2 Answering the Research Questions

The research questions derived from the RG have been defined as follows:

> RQ1: What are the most important competence needs of PD engineers in mechanical engineering in Finland?
>
> RQ2: What is the current level of young mechanical engineers in the different PD competence areas in Finland?
>
> RQ3: What is the impact of RQ1 and RQ2 on the teaching of competences to PD engineers in mechanical engineering so they are able to achieve the best professional ability?

The case study research was made to find the answers to the descriptive questions RQ1 and RQ2. RQ3 is a relational type of research question. The analysis of the case study gives the statistics for the answers to RQ1 and RQ2 and the gap between these two supply answers to RQ3. The case study research included among other things 47 specific skills questions for both RQ1 and RQ2 (94 answers in total). These questions were divided into five groups: basic skills, NPD project skills, communication skills, analysing and problem solving skills and other skills. In addition to these specific skills questions the interviewees were asked to mention other additional skills, if they felt that something important was still missing. Table 3 is the summary of the case study results and thus the summary of the answers to the three research questions RQ1, RQ2 and RQ3.

7.3 Summary of the Results

As a result of the case study Table 3 lists the 21 most important competence skills for a mechanical designer in PD work. Out of these 21 skills 11 belong to the category of non-technical skills, 7 to technical substance skills and 3 to technical tools skills. Out of the 8 skills having the highest competence gap (importance / RQ1 – capability / RQ2) 4 belong to the group of NPD skills.

In this thesis the PD process model, based on the author's experiences in the Finnish mechanical workshops, has been developed to be used in the development of the course teaching strategy. A modular service product concept has been used for the course teaching strategy in this PD process. The stage-gate PD process model includes 5 phases. The stage by stage comparison has been made of the PD process of this service product and that of a physical product. The main tasks and the main outcome of each phase are listed in Figure 24.

As an illustrative example the developed PD process model was applied to the teaching strategy development of a PD course in the bachelor degree programme for mechanical engineering. The illustrative BOM of the teaching strategy product of the course has been presented in Figure 26. It includes the module list and the component list of each module. The component descriptions have also been presented (Tables 8…12) and they correspond to the drawings and other possible specifications of a physical product.

The developed teaching strategy has been tested in the PD course of third year students in mechanical engineering at a UAS in the spring semester in 2012.

7.4 Research Contribution

Reaching good learning results is the aim of every teacher. It is important for the success of the students, teachers and universities. This thesis introduces an industrial, well-proven PD process as a tool to develop the whole teaching and learning process of a course using a modular service product concept.

Even though the case study method to identify the customer needs takes a lot of time, and is also in other ways cumbersome, its results have a high level of reliability; especially when using it as described above in section 7.1. The other studies of competence needs in mechanical engineering have been reviewed in sections 2.1.1…2.1.6. These studies have a more general level of mechanical engineering as their target group than the level in this study which is focused on the PD work of mechanical designers in Finnish companies. Also the research methods of these other studies are not the same as the methods used in this thesis. The main reasons for the differences in competence needs and their relative importance between countries are national cultural differences (Lewis 2006) as well as the structural differences in their respective industries.

The companies, especially mechanical workshops, can use the results of this case study in training programme planning as well as in recruitment planning. Also other fields of technology outside of mechanical engineering at UASs can utilize the results in the development of their courses; especially in those courses related to PD work.

There is a lot of research about teaching and learning methods as well as teaching and learning assessment methods used at universities (sections 2.2.1…2.2.10). However comprehensive and systematic methods to develop the whole teaching and learning process of a course have not been under equally active research. In chapter 6 some frontline course and curriculum development models are presented and compared with the model presented in this thesis. The comparison shows that those existing models do not introduce a methodology which includes clear definitions of the customer, product and process. Also they do not include any specific process to identify students' needs. Here a PD process model has been developed and used in the development of a service product. The course teaching strategy has been defined in detail as a modular service product. Modular architecture has been generally used by industry for physical products and it is still unusual to use it in the case of service products. Even though the general PD process model is best known in the field of engineering the systematics developed in this thesis can be applied in principle to other fields of education and to other levels of education as well. In any case the PD process model must have customer needs as essential input information and if this information is not available, it must be acquired. However, there are many reasons why the model is most suitable for the development of engineering courses:

- The stage-gate type PD process as well as the modular product structure are usually known to engineering teachers;
- The courses in engineering are generally very much target orientated in nature just like industrial PD projects;
- The universities in the field of technology work in close cooperation with industry and thus have a lot of information about the competence needs of engineers;
- Many courses in the engineering curriculum are similar in nature, for example analytical, and thus the development results of one course can also be utilized in other courses.

The benefits of using modular architecture for this service product are listed in section 4.1. The working environment at UASs in Finland has lately come closer to the typical environment found in companies. So, these kinds of business tools and applications have a great potential in the successful development of UASs.

7.5 Evaluation of the Research

The main focus in the evaluation of research is on the results and on their reliability. In this section the evaluation of the topic, the theoretical basis, the methodology used, the results and finally the novelty of the research are evaluated. This evaluation is made by asking relevant questions and giving answers to each of the mentioned items.

Thesis topic

The topic of this thesis is “Competence Needs and a Model for the Teaching Strategy Development of Mechanical Designers in Product Development”. *Is this kind of topic clear, useful and well defined?* To clarify the topic: the teaching strategy has been defined to cover five modules from the targets for the learning outcomes to the learning and teaching assessments (section 4.1). Engineers’ product development skills are very important, especially in highly industrialized countries like Finland. The science universities and the universities of applied sciences need to develop their course offerings continuously to respond to industry needs. This development work needs to cover the whole teaching and learning process, not only, for example the content of the course or the teaching methods used on the course.

Is the course development too limited a scope for the research; should it be curriculum development? As already stated in section 1.2, PD competencies are taught in many courses, not only in specific PD courses. This means that the whole curriculum is under development. However, the course development is at the core of the curriculum development.

Theoretical basis

Does the thesis contain a clear problem, questions, hypothesis and goal and the logic between these? These items have been stated in sections 1.2…1.4. Figure 3 shows the logic from RQ1 and RQ2 to RQ3 together with RH and on to the RG. This logic also forms the theoretical basis and defines the structure of the thesis; RQs in chapter 3, RH in chapter 4 and RG in chapter 5.

Methodology

The methods used have already been discussed in section 7.1. Here a more detailed discussion is made of the research techniques used in these methods.

Why were only the current competence needs asked in the case study? To develop the education of future PD engineers it is very important also to anticipate the future competence needs. The main reason for using this selection is so as to have the best possible reliability in the research. Making forecasts is always less reliable than seeing today’s facts (Drucker 2011, p. 90-97, 124). The answers to the anticipation of future needs tend to be on a general level reflecting the global trends like energy, environment and green values (Leppimäki and Meristö 2007). The answers to questions E1…E3 (Appendix 1 and 3) show that these issues have not yet become the most important ones, but on the other hand it is evident that their importance is growing. Also there are a lot of stable competence needs which are important today and will remain important in the future as well, as can be seen from the case study results in Table 3.

Are the 13 companies interviewed in the case study a big enough sample and do they represent Finnish mechanical workshops well? Even though the number of companies is quite small, most of them are large companies as can be seen from their key figures shown in section 3.2. The companies represent the main sectors among Finnish mechanical workshops. Some of them produce investment products and others serial production products. This kind of a competence needs study can also be compared with customer needs studies. Figure 21 shows that more than 90% of customer needs are identified in 13 interviews.

Are the 47 specific skills questions the right ones and is the number of questions large enough? The individual questions are based on the author's own experience in industry and on the references in chapter 2. The questions were fine-tuned using the pilot case study. The skills questions have been divided into five groups; each of which has 8…12 specific skills questions. In addition to this there was the sixth group for any possible additional skills questions and answers made by the interviewees. The number of skills questions must be limited so that the time taken to go through each question carefully is sufficient. Answering these questions took about one and a half hours; that is a couple of minutes per question. This proved to be a suitable time for the interview to keep the two persons involved, sharp and active.

Is the stage-gate type PD process used in the service product development of the teaching strategy too complicated a tool for those teachers who are not familiar with PD work? The RG of this thesis has the focus on the education of PD engineers in mechanical engineering. So, the teachers involved in this kind of education need to be familiar with the PD process. *Is the use of this development model only limited to the education of PD engineers in the field of technology?* The model of the teaching strategy development has been explained in detail in chapter 4 and the application of the model has been made in chapter 5. Even though the experience in the field of PD makes the use of the model easier, any teacher in the field of technology may become familiar with this tool through these two chapters. On the other hand the use of the model in fields other than technology is also possible, but the lack of a PD oriented way of thinking in these fields may cause problems in implementation.

Why use the modular service product concept in a model for the development of a course teaching strategy? The modular product concept has been widely and successfully used in industry for physical products. The most important benefits of also using this concept in the case of a service product have been listed in section 4.1. These benefits are mainly connected to more efficient PD project work and further development of the product.

Results

Is the application of the PD course relevant or not, because the PD course does not cover all of the 21 important competence skills listed in Table 3? There is no single course that covers all of these 21 skills. Out of the 21 skills listed there are 15 skills (in Table 5) on which the PD course has a major impact. So this kind of course is very important in the education of PD engineers.

Is the final result of the developed teaching strategy for the PD course relatively conventional when comparing it, for instance, with the teaching and learning methods in chapter 2? On the one hand “it is not the method, but how skilfully it is used, that matters” (Ramsden 2003, p. 162). This means that for instance a lecture can be interactive or not depending on the execution of the lesson. Practical exercises during the lessons work well to activate the students. The independent exercise work as well as the company visit gives a practical approach to the PD theories. The optimum teaching strategy of any course depends, among other things, on: the size of the course in ECTS credit points, the teacher, the university environment and the student group. The main purpose of chapter 5 is to illustrate the methodology and the thesis tool, not to give the only correct teaching strategy.

Is it necessary always to make a new case study to update the competence needs? Is the use of the development model for the teaching strategy of a course too large and time-consuming? Most of the engineer’s competence needs do not change over the years. A smaller study is enough to check any possible changes in the needed skills. This can be made as a part of the regular cooperation between the university and companies. When using the model for the first time it may seem to be very time-consuming. The following projects take much less time and still give valuable results for the development of courses. This can be compared with the PD of a physical product. When a successful product has been developed for the market, any further development actions during the following years are much less time-consuming than the original development project was. It is also important to remember that the results can be utilized in many other courses, not only in the one under development. This is also a good tool to raise discussions among the teachers in the whole of the university because of the transparent development methodology used.

Novelty of the research

This research introduces a systematic model to develop a service product, a PD course teaching strategy. The stage-gate PD process model, successfully used in industry for the development of physical products, has been defined and applied in the university environment. As the input information the model uses the customer needs defined by the case study methodology. The service product under development has been divided into modules and these modules further divided into components. This way the BOM of the service product has been defined.

The novelty of this research lies in the new way of using the industrial PD methods mentioned above in the university environment. The service product concept as a modular structure with components for each module is also a new approach in the universities' important course development work. Additionally, the development model presented includes a comprehensive process for course development starting from the identification of the customer's needs to the execution of the course. Thus, the detailed definitions of the customer, product and process to develop the course teaching strategy have been introduced. In chapter 6 the analyses of existing course development models and their comparison with the model developed here has been made. These prove that the model presented in this thesis is significantly different from those existing ones, as explained in section 6.2.

7.6 Author's Own Contribution

The author's long experience with PD work in Finnish mechanical workshops offers a solid basis to evaluate both the competence needs and young engineers' skills in this kind of work. This experience was also important when organizing the case study research in the largest Finnish workshops. The case study has been completely carried out by the author; from the planning stage to the analysis of the results, including the field procedures. To maintain the most reliable study results the data collection was also carried out by the author using exactly the same method with every case company. The discussions with the PD professionals during the interviews were highly interactive. A pilot case study was also used to fine-tune the data collection method. As a whole the case study was unique when thinking of its execution and the participating companies. The case study as the empirical part of the thesis gives answers to the three RQs.

Selecting the stage-gate type of PD process for the tool to develop the teaching strategy for a course is also a natural choice, but not usual in the university environment. The basic idea for this kind of PD process was first introduced by Robert G. Cooper in 1988 (Cooper 2011, Preface p. xiv). In this thesis the tasks, outputs and other details of each stage are based on the author's work experiences and the whole process has been fine-tuned for the development of this service product. The author is familiar with modular product architecture and with the benefits it offers a physical product in PD and in production. The modular service product also has similar types of benefits even though it is still seldom used today. In this thesis the author has developed the modular concept for the teaching strategy of a course. This is a new approach in the development of engineering education. The constructive part of the thesis introduces strong evidence for the RH.

The author's current work as the dean at the school of technology at a Finnish UAS offers excellent possibilities to impact the teaching and learning processes in the education of engineers. The teaching experience of several years, still continuing in PD related courses, provides personal testing possibilities for the developed model.

8 Conclusions

A course provided at a university is similar to a company providing a service product and like any product it needs continuous development. The customer (the student at the university) needs change over time and this is due mainly to the fact that the needs of the customer's customer (industry in the case of an engineering student) change over time.

In this thesis a model has been produced for the teaching strategy development used in the product development (PD) education of mechanical designers. Teaching strategy as a concept has been defined to include the whole of the teaching and learning process of a course; from the learning outcome targets to the learning and teaching assessments.

The first problem in developing the teaching and learning process of a course is to know the competence needs of the students. A case study approach has been used to find the most important competence needs of mechanical designers in PD work in Finnish mechanical workshops as well as the capabilities of young engineers to meet these needs. This information is needed in the model to identify the students' needs. The model was applied to the development of the teaching strategy used in a PD course in mechanical engineering at a Finnish university of applied sciences.

Another problem is that the development of a course is often limited to the contents or methods available for the course. In this thesis the course teaching strategy has been defined as a modular service product and the bill of materials (BOM) of this product has been introduced in the case of a PD course in mechanical engineering at a Finnish UAS. The stage-gate type PD process, commonly used in industry, has been introduced and applied to the comprehensive development of the PD course. It is also a straightforward and systematic way to develop this kind of service product. The teachers familiar with PD in general have an advantage in that they are able to use the model fluently. Other teachers may first need to get involved in the methodology used in the PD process. This process has been explained phase by phase comparing the features of a teaching strategy product with the features of a physical product. The use of the developed model is not limited to a specific type of course such as PD. It can also be used for other kinds of engineering courses as well as courses outside engineering sciences. Even though the model has its main focus on the individual courses, it also includes tools for the more general curriculum development.

For further research it would be important to make more tests of the model utilizing the teacher's experiences and student feedback. It would also be important to apply the model to other courses relevant to the competence needs of mechanical designers in PD work. In this way the systematics of the model would be applied to the development of the curriculum. The next steps in the application of the model could be in other areas of technology and also in other fields of applied sciences. New case study research, to find appropriate competence needs, should also be made in these other areas and fields before the application of the model can take place.

Universities and colleges normally have some kind of steering groups to evaluate teaching quality. This evaluation is very important development work and the limited resources should be allocated so as to obtain the best results. In Finland FINHEEC,Finnish Higher Education Evaluation Council, is the national organisation assisting universities and universities of applied sciences in matters related to evaluation and quality improvement of higher education (FINHEEC 2014). One further research area could be on the application of the presented case study concept and development model in this evaluation and quality improvement work. From FINHEEC's point of view the comprehensive teaching development model of the thesis could be a kind of bottom up tool.

It would also be useful and interesting to make a similar case study as the one made in this thesis in some other countries, for example in Germany. A comparison of the results from the case studies as well as the teaching strategies at the universities involved in the study could reveal valuable information.

One other interesting possibility for further research is to utilize the case study results in other kinds of research. A comparison of the answers between different kinds of companies could be one application. The results could also be useful when developing the PD engineers' recruitment process or for training programme planning in companies.

References

(Advisory Panel 2008)	Design Skills Advisory Panel (2008). High-level Skills for higher Value. Design Blueprint. (Design Skills Advisory Panel, London 2008). http://www.innovationunit.org/sites/default/files/High-level%20skills%20for%20higher%20value.pdf
(Albers et al. 2006)	Albers A, Burkardt N, Meboldt M (2006). The Kartsruhe Education Model for Product Development "KALEP", in Higher Education. International Design Conference – Design 2006, p. 1049-1056.
(Ambrose et al. 2010)	Ambrose S A, Bridges M W, DiPietro M, Lovett M C, Norman M K (2010). How Learning Works: Seven Research-Based Principles for Smart Teaching. Jossey-Bass, San Francisco, 301 p.
(Autio 2011)	Autio O (2011). The Development of Technological Competence from Adolescence to Adulthood. Journal of Technology Education, Vol. 22, No. 2, 2011, p. 71-89.
(Beckmann and Krause 2010)	Beckmann G, Krause D (2010). Improving the Mechanical Design Education by Hands-on Experience with Machine Parts. International Conference on Engineering and Product Design Education 2010 (E&PDE 10), 6 p.
(Berggren et al. 2003)	Berggren K-F, Brodeur D, Crawley E, Ingemarsson I, Litant W, Malmqvist J, Östlund S (2003). CDIO: An international initiative for reforming engineering education. World Transactions on Engineering and Technology Education, Vol. 2, No. 1, 2003, p. 49-52.
(Biggs and Collis 1982)	Biggs J B, Collis K F (1982). Evaluating the Quality of Learning: The SOLO Taxonomy, Academic Press, New York.
(Biggs and Tang 2011)	Biggs J, Tang C (2011). Teaching For Quality Learning at University, What the Student Does, 4th edition. Open University Press, Maidenhead, 389 p.

(Blessing and Chakrabarti 2008)	Blessing L T M, Chakrabarti A (2008). DRM, a Design Research Methodology. Springer, 397 p., ISBN 978-1-84882-586-4.
(Böhmann et al. 2003)	Böhmann T, Junginger M, Kremar H (2003). Modular Service Architectures: A Concept and Method for Engineering IT services. Proceedings of the 36th Hawaii International Conference on System Sciences 2003, 10 p.
(CDIO Initiative 2004)	CDIO Initiative (2004). The CDIO Standards. 9 p. http://www.cdio.org/implementing-cdio/standards/12-cdio-standards
(Chickering 1969)	Chickering A (1969). Education and identity. Jossey-Bass, San Francisco, 541 p.
(Childs et al. 2010)	Childs P, McGlashan N, Gosling G, Auricchio M (2010). Linking Design, Analysis, Manufacture and Test in the Engineering Student Experience. International Conference on Engineering and Product Design Education 2010 (E&PDE 10), 6 p.
(Confederation of Finnish Industries 2012)	Internet page http://www.ek.fi/ek/fi/tietografiikka/innovaatiot/index.php
(Cooper 2011)	Cooper R G (2011). Winning at New Products, 4th edition. Basic Books, A member of the Perseus Books Group, New York, NY, 408 p.
(Crawley et al. 2007)	Crawley E, Malmqvist J, Östlund S, Brodeur D (2007). Rethinking Engineering Education: The CDIO Approach. Springer Science+Business Media, LLC, New York, 286 p.
(Drucker 2011)	Drucker P F (2011). Innovation and Entrepreneurship. The Classic Drucker Collection. Routledge, New York, 253 p.
(Engineering Council 2010)	Engineering Council (2010). UK Standard for Professional Engineering Competence (UK-SPEC). Engineering Council, London, 32 p. www.engc.org.uk

(EUR-ACE 2008)	EUR-ACE Framework Standards for the Accreditation of Engineering Programmes (2008), 14 p. http://www.enaee.eu/eur-ace-system/eur-ace-framework-standards
(European Communities 2009)	ECTS User's Guide (2009), 64 p. http://ec.europa.eu/education/lifelong-learning-policy/doc/ects/guide_en.pdf
(Ferguson 2010)	Ferguson C (2010). Developing Attributes in Australian Mechanical Engineers. A role based study of Australian mechanical engineer attributes and the technologies used to deliver them through proximal and distance education. VDM Verlag, Saarbrücken, 367 p.
(Field et al. 2009)	Field B, Burvill C, Alirezaee (2009). Using 3-D Models to Train Engineering Designers. International Conference on Engineering Design 2009 (ICED 09), p. 47-56.
(FINHEEC 2014)	Internet page http://www.finheec.fi/en
(Fink 2013)	Fink L D (2013). Creating Significant Learning Experiences: An Integrated Approach to Designing College Courses. John Wiley & Sons, 334 p.
(Frey et al. 2000)	Frey D D, Smith M, Bellinger S (2000). Using Hands-On Design Challenges in a Product Development Master's Degree Program. Journal of Engineering Education, Vol. 89, No. 4, 2000, p. 487-493.
(Gibbs 1992)	Gibbs G (1992). Improving the Quality of Student Learning. Technical and Educational Services Ltd., Bristol, 204 p.
(Griffin and Hauser 1993)	Griffin A, Hauser J R (1993). The Voice of the Customer. Marketing Science, Vol. 12, Winter 1993, 27 p.
(Hyppönen and Lindén 2009)	Hyppönen O, Lindén S (2009). Handbook for Teachers – Course Structures, Teaching Methods and Assessment. Helsinki University of Technology, Teaching and Learning Development Unit, 110 p., ISBN 978-952-60-3035-7 (electronic). http://opetuki.tkk.fi/fi/julkaisut/

(Kaplan and Norton 2001)	Kaplan R S, Norton D P (2001). The Strategy Focused Organization. Harvard Business School Publishing Corporation, 400 p.
(Klein and Phillips 2011)	Klein D, Phillips K (2011). Sustainable Design: An Educational Imperative. The Journal of Technology Studies, Vol. XXXVII, No. 2, 2011, p. 9-17.
(Koch and Sanders 2011)	Koch D, Sanders M (2011). The Effects of Solid Modelling and Visualization on Technical Problem Solving. Journal of Technology Education, Vol. 22, No. 2, 2011, p. 3-21.
(Lattuca et al. 2006)	Lattuca L R, Terenzini P T, Volkwein J F (2006). Engineering Change: A Study of the Impact of EC2000, Executive Summary. ABET, Inc. 30 p. www.abet.org
(Laurillard 2002)	Laurillard D (2002). Rethinking University Teaching: A conversational framework for the effective use of learning technologies, 2nd edition. RoutledgeFalmer, New York, 268 p.
(Leppimäki and Meristö 2007)	Leppimäki S, Meristö T (2007). Tulevaisuus haastaa osaajat. Kone- ja metalliteollisuuden näkemyksiä alan kehittämistarpeista Suomessa ja maailmalla vuoteen 2020 (in Finnish). Teknologiateollisuus ry, The Federation of Finnish Technology Industries 2007, 32 p.
(Lewis 2006)	Lewis R D (2006). When Cultures Collide, Leading Across Cultures, 3rd edition. Nicholas Brealey Publishing, 600 p.
(Marton and Säljö 1997)	Marton F, Säljö R (1997). The Experience of Learning: Implications for Teaching and Studying in Higher Education, 2nd edition. Scottish Academic Press, Edinburg.
(Marton et al. 1995)	Marton F, Watkins D, Tang C (1995). Discontinuities and continuities in the experience of learning: an interview study of high school students in Hong Kong. The 6th European Conference for Research on Learning and Instruction 1995.

(Meerkamm et al. 2009)	Meerkamm H, Stockinger A, Tremmel S, Wartzack S (2009). Realization of Modern Educational Concepts in Engineering Design. International Conference on Engineering Design 2009 (ICED 09), p. 35-46.
(Mengoni and Germani 2008)	Mengoni M, Germani M (2008). Mechanical Design Learning Environments Based on Virtual Reality Technologies. International Conference on Engineering and Product Design Education 2008 (E&PDE 08), 6 p.
(Ministry of Education and Culture 2010)	Ministry of Education and Culture (2010). AMKOTA Statistics 2010.
(Ministry of Education and Culture 2012)	Ministry of Education and Culture (2012). http://www.minedu.fi/OPM/Koulutus/?lang=en
(Neighbour and Cutler 2007)	Neighbour G, Cutler G (2007). Creating a Learner-centred Approach in Product Innovation. International Conference on Engineering and Product Design Education 2007 (E&PDE 07), 6 p.
(Nevaranta 2012)	Nevaranta J (2012). Teaching Strategy as a Modular Service Product in Comprehensive Course Development. International Conference on Engineering Education 2012 (ICEE 2012), p. 117-122, ISBN 9789522163158.
(Newman et al. 2004)	Newman F, Couturier L, Seurey J (2004). The Future of Higher Education. John Wiley & Sons, Jossey-Bass, San Francisco, 284 p.
(Nguyen 1998)	Nguyen D Q (1998). The Essential Skills and Attributes of an Engineer: A Comparative Study of Academics, Industry Personnel and Engineering Students. Global Journal of Engineering Education, vol. 2, No. 1, 1998, p. 65-76.
(Nicolai 1998)	Nicolai L M (1998). Viewpoint: An Industry View of Engineering Design Education. International Journal of Engineering Education, Vol. 14, No. 1, 1998, p. 7-13.

(Novak and Dolšak 2008)	Novak M, Dolšak B (2008). Project-Based Product Development Education. International Conference on Engineering and Product Design Education 2008 (E&PDE 08), 6 p.
(Oswald 2010)	Oswald D (2010). Towards A Redefinition of Product Design and Product Design Education. International Conference on Engineering and Product Design Education 2010 (E&PDE 10), 6 p.
(Pahl and Beitz 2007)	Pahl G, Beitz W (2007). Engineering Design: A Systematic Approach, 3rd edition. Springer, 617 p.
(Pajula et al. 2011)	Pajula J, Nevaranta J, Kitinoja K, Huhtamäki P (2011). SeAMK Projektipaja® - Project Workshop in Seinäjoki University of Applied Sciences. Innovative Partnerships between Universities and Private Sector. Conference Proceedings p. 125-139, ISBN: 978-604-62-0601-9.
(Perea 2008)	Perea E (2008). Does The Introduction of Project-Based Learning to The Teaching of Engineering Design increase Student Engagement? International Conference on Engineering and Product Design Education 2008 (E&PDE 08), 6 p.
(Perttula 2007)	Perttula A (2007). Challenges and Improvements of Verification and Validation Activities in High Volume Electronics Product Development. Dissertation thesis. Tampere, Finland: Tampere University of Technology, 157 p., ISBN 978-952-15-1713-6, ISSN 1459-2045.
(Ponn et al. 2007)	Ponn J, Kreimeyer M, Lindemann U (2007). Methodical Evaluation of Single and Group Projects. International Conference on Engineering and Product Design Education 2007 (E&PDE 07), 6 p.
(Prosser and Trigwell 1999)	Prosser M, Trigwell K (1999). Understanding Learning and Teaching: The Experience in Higher Education. The Society for Research into Higher Education & Open University Press, Buckingham, 198 p.
(Ramsden 1992)	Ramsden P (1992). Learning to Teach in Higher Education. Routledge, London and New York, 290 p.

(Ramsden 1998)	Ramsden P (1998). Learning to Lead in Higher Education. Routledge, London, 288 p.
(Ramsden 2003)	Ramsden P (2003). Learning to Teach in Higher Education, 2nd edition. RoutledgeFalmer, Taylor & Francis Group, London and New York, 272 s.
(Scott and Koch 2010)	Scott S, Koch D (2010). Teaching University-Level Technology Students via the Learning Preferences and Problem-Solving Approach. The Journal of Technology Studies, Vol. 36, No. 1, 2010, p. 16-23.
(Sheppard and Jenison 1997)	Sheppard S, Jenison R (1997). Examples of Freshman Design Education. International Journal of Engineering Education, Vol. 13, No. 4, 1997, p. 248-261.
(Sheppard et al. 2008)	Sheppard S, Pellegrino J, Olds M. On becoming a 21st Century Engineer. Journal of Engineering Education, Vol. 97, No. 3, 2008, p. 231-234.
(Statistics Finland 2010)	Statistics Finland (2010). Statistical Yearbook of Finland 2010. Multiprint Oy, Helsinki Finland.
(Talouselämä 500 statistics 2011)	Internet page http://www.talouselama.fi/te500/ (in Finnish)
(Tekes 2014)	Internet page http://www.tekes.fi/en/tekes/
(The Federation of Finnish Technology Industries Statistics 2012)	Internet page http://www.teknologiateollisuus.fi/en/services/endustrial-work-force.html
(The Federation of Finnish Technology Industries Year Book 2012)	The Federation of Finnish Technology Industries (2012). Year Book 2011. http://www.teknologiateollisuus.fi/en/services/year-book.html
(Ulrich 1995)	Ulrich K T (1995). The role of product architecture in the manufacturing firm. Research Policy, Vol. 24, p. 419-440 (1995).

(Ulrich and Eppinger 2008)	Ulrich K T, Eppinger S D (2008). Product Design and Development, 4th edition. McGraw-Hill 368 p.
(Watt et al. 2011)	Watt C, Ely P, Chapman D (2011). A Service Approach to Course Development. International Conference on Engineering and Product Design Education 2011 (E&PDE 11), 6 p.
(Weber 2010)	Weber C (2010). Enhancing Virtual Engineering by Audio-Visual Product Models. Seminar presentation, 42 p., September 23, 2010, Tampere University of Technology, Tampere Finland.
(Wiggins and McTighe 2006)	Wiggins G, McTighe J (2006). Understanding by Design, expanded 2nd edition. Association for Supervision and Curriculum Development, Alexandria, VA, USA 371 p.
(Yadav et al. 2010)	Yadac A, Shaver G M, Meckl P (2010). Lessons Learned: Implementing the Case Teaching Method in a Mechanical Engineering Course. Journal of Engineering Education, Vol. 99, No. 1, 2010, p. 55-69.
(Yin 2009)	Yin R K (2009). Case Study Research – Design and Methods. Applied Social Research Methods Series. SAGE Publications Inc. 219 p.

Appendices

Appendix 1: The List of Skills Questions in the Case Study Questionnaire

THE INTERVIEWEE AND HIS EMPLOYER'S IDENTIFICATION INFORMATION

This information will not be published together with the corresponding replies. These are needed for the possible, subsequent summaries and analyses.

1. The company and interviewee information

The name of the company	
The address of the company	
The name of the interviewee	
The task of the interviewee in the company	
The phone number of the interviewee	

2. The company figures in 2010

Turnover, million EUR (whole group)	
Number of the entire personnel (whole group)	
Total number of engineers in operations in Finland	
Product development (PD) staff in Finland	
Mechanical / other engineers in PD staff in Finland	
Bachelor / Master of Eng. ratio among mechanical engineers in PD in Finland	
Product development costs, million EUR in Finland	

3. Recruitment of new PD engineers

In the last 3 years, the number of recruited in Finland	
Persons involved in the recruitment interview, titles of persons included	

INSTRUCTIONS FOR REPLYING TO THE QUESTIONS

All questions relate to the product development (PD) work of mechanical engineers.
Mechanical engineers include in this case all product development engineers who make mechanical design work in a workshop.
Bachelors of engineering are the main targets in this study.

The questions are divided into five groups as follows:

A. Basic skills of PD engineer in mechanical engineering
B. NPD project skills
C. Communication skills
D. Analysing and problem solving skills
E. Other skills of PD engineers

In addition in section F you are asked to provide other important requirements you think a mechanical engineer working in PD needs and which are not included in A …E.

You have in total of 47 questions and the answer to the question is given in the form of the four scale selection according to the importance in the PD work of a mechanical engineer and the capability of young engineer in this skill. The young engineer means an engineer with less than one year work experience.
The scale is "High, rather high, rather low, low". There is also the alternative "I don't know".

Read all the questions of each group first before you start to answer the questions of the group.

A. Basic skills of PD engineer in mechanical engineering

A1. CAD skills (surface modelling, 3D)

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

A2. General product data management (PLM, PDM)

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

A3. Strength of materials (understanding what is needed to calculate)

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

A4. Mechanical vibrations and noise analysis (understanding what is needed to analyze)

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

A5. Material technology

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

A6. Integration of information technology into mechanical design (control of mechanical system)

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

A7. Production technology skills

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

A8. Manufacturing cost management, DFM and DFMA

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

A9. Customer interface management (ability to ask marketing when needed)

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

B. NPD project skills of PD engineer in mechanical engineering

B1. One's own project portfolio management (designer participates several projects simultaneously)

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

B2. Identification of customer needs (ability to understand customer needs)

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

B3. Cooperation with industrial design

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

B4. Project plan contents and preparation skills

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

B5. Product architecture, the modularization of the product

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

B6. Detail design (drawings with tolerances, tolerance chains)

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

B7. Laboratory tests of products (understanding what is needed to test)

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

B8. Field tests of products (understanding what is needed to test)

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

B9. Quality assurance of new products together with production

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

B10. Project management skills (ability to lead people in PD projects)

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

B11. Time and time schedule management (realistic schedules and keeping those)

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

B12. General team work skills (incliding concurrent engineering)

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

C. Communication skills of PD engineer in mechanical engineering

C1. Written reporting

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

C2. Oral reporting

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

C3. Presentation skills

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

C4. Office software skills (MS Word, PowerPoint, Excel, Project, …)

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

C5. English language skill

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

C6. Foreign cultures knowledge and skills in communication

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

C7. Negotiation skills

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

C8. Meeting practises (effective meeting implementation)

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

C9. Own ideas highlighting

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

D. Analysing and problem solving skills of PD engineer in mechanical engineering

D1. Problem formulation skills

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

D2. General problem solving skills (ability to find alternative solutions and to select the best one)

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

D3. General mathematical skills

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

D4. Creativity

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

D5. Ability to learn new things quickly (change willingness)

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

D6. Ability to retrieve information from various sources

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

D7. Perseverance in problem solving situations

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

D8. Failure analysis skills (FMEA, DFMEA)

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

E. Other skills of PD engineer in mechanical engineering					
E1. Consideration of environmental viewpoints					
	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐
E2. Energy technology in products					
	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐
E3. Product lifecycle consideration					
	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐
E4. Quality related issues in design work (like product quality control, supplier audit)					
	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐
E5. PD network management					
	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐
E6. Entrepreneurship skills					
	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐
E7. Business skills (like understanding of financial calculations and reporting)					
	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐
E8. PD skills in the development of service products (e.g. after sales and maintenance)					
	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐
E9. Special competences related to the products of our company					
	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

F. Other skills you keep important for a mechanical engineer in PD work

F1.

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

F2.

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

F3.

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

F4.

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

F5.

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

F6.

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

F7.

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

F8.

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

F9.

	High	Rather high	Rather low	Low	I don't know
Importance	☐	☐	☐	☐	☐
Young engineer	☐	☐	☐	☐	☐

Appendix 2: Pilot Case Study Report

A2.1 Pilot Case Study Design

It was designed to use three types of data collection methods. The most important source of evidence was the list of skills questions (Appendix 1). Firstly the interviewee received the list at the beginning of the interview. Secondly during the site visit direct observations of the facilities were also made. Thirdly the web-pages of the company were a source of evidence as well. Two types of contact methods were designed and tested: face-to-face and contact by telephone.

The main criteria used to select the pilot case were: easy to access, being well-known to the author and of an average size when compared with the other case study companies. Two managers (selected by the PD director) at the PD department in the same pilot case company were interviewed.

After the interviews the collected evidence, including the recordings of the discussions, were examined by the author. The results of the 47 skills questions including the ranking of both their importance in a PD engineer's work as well as the capability level of an engineer with less than one year work experience (in total 94 rankings) were compiled in an Excel database. In the analysis the values between 4…1 were used correspondingly for the four choices high, rather high, rather low, low". There was also a fifth alternative of "I don't know". This choice was not taken to the summary results of the specific question. The final results were presented in graphical form as average values and standard deviations of the answers (as in Appendix 3).

A2.2 Pilot Case Study Field Procedures

At the beginning of the face-to-face interview the author asked and got permission to record the whole of the discussions. The first action was to go through the lists of skills questions in Appendix 1; this took one and a half hours. After that a free discussion took place dealing with the questions and the method in general. Finally a short site visit was made both in the PD facilities and in the production plant. The whole visit to the company took about three hours and a full day when the travelling was included.

The other pilot interview was made by phone. The same skills questions were gone through and together with the free discussion this took about one hour.

A2.3 Lessons learned from the Pilot Case Study

It was evident that the company figures on the first page must be collected separately, not during the interview. Also the instructions on the second page needed to be clarified and shortened from those in the pilot case version. Some of the 47 skills questions themselves were also clarified and extra explanations were added in parentheses. It was also better to send the list of skills questions (Appendix 1) to the interviewee beforehand (a couple of weeks before) so that he had the possibility to understand the questions better before answering them and also be able to fill in the company and other information on page 1 before the interview. The recording of the interview gave the interviewer more time to concentrate on the event itself; even though the time spent transcribing the recordings was quite long.

When comparing the two contact methods the face-to-face one was selected instead of the telephone contact method for the actual studies. According to the experiences obtained in the pilot case by using this way it was possible to get more reliable and deeper information and also it included the possibility of site visits. Of course the time spent using the face-to-face case study was considerably more for each company; one day compared with the one hour using the telephone contact method. A mixed method using face-to-face contacts with some of the case study companies and contact by telephone with some others (as used for example in Ferguson 2010) was not used so as to have an equal level of reliability between all the companies.

Appendix 3: Case Study Results

This Appendix shows the case study results in the form of Excel charts. The five charts represent the five groups of questions: Basic skills of a PD engineer in mechanical engineering, NPD project skills, Communication skills, Analysing and problem solving skills, Other skills of a PD engineer. In total there were 47 skills questions in these five groups.

The importance of different skills in the mechanical engineer's work in PD as well as the capability of a young engineer in each of the skills was ranked by the interviewee. The four point Likert scale was used: high, rather high, rather low, low. In the analysis the numeric values between 4…1 were given corresponding to those rankings. In each chart the average value and the (sample) standard deviation value of each ranking are shown.

These results are analysed and discussed in sections 3.5 and 3.6.

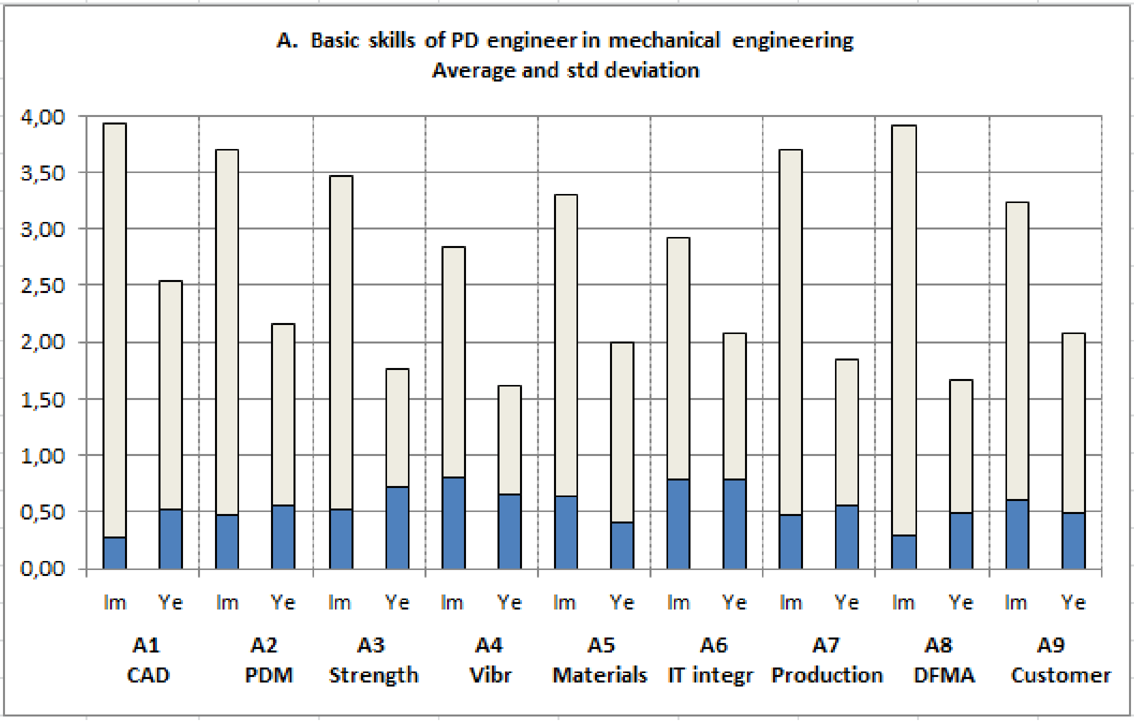

Figure A3.1 *Averages and standard deviations for the answers to the group A questions by the 13 companies.*

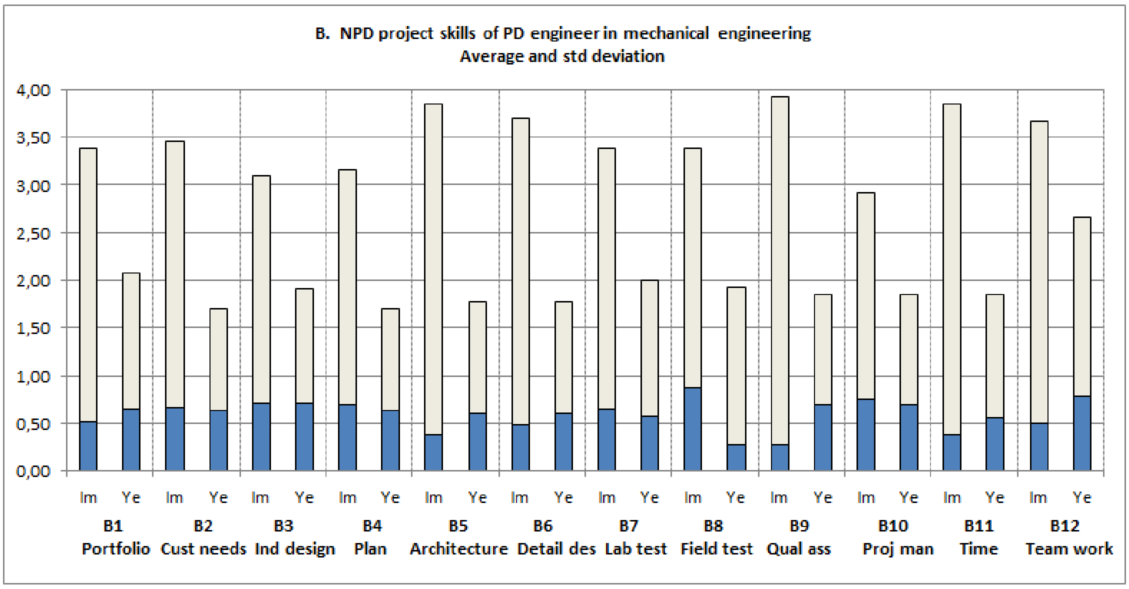

Figure A3.2 *Averages and standard deviations for the answers to the group B questions by the 13 companies.*

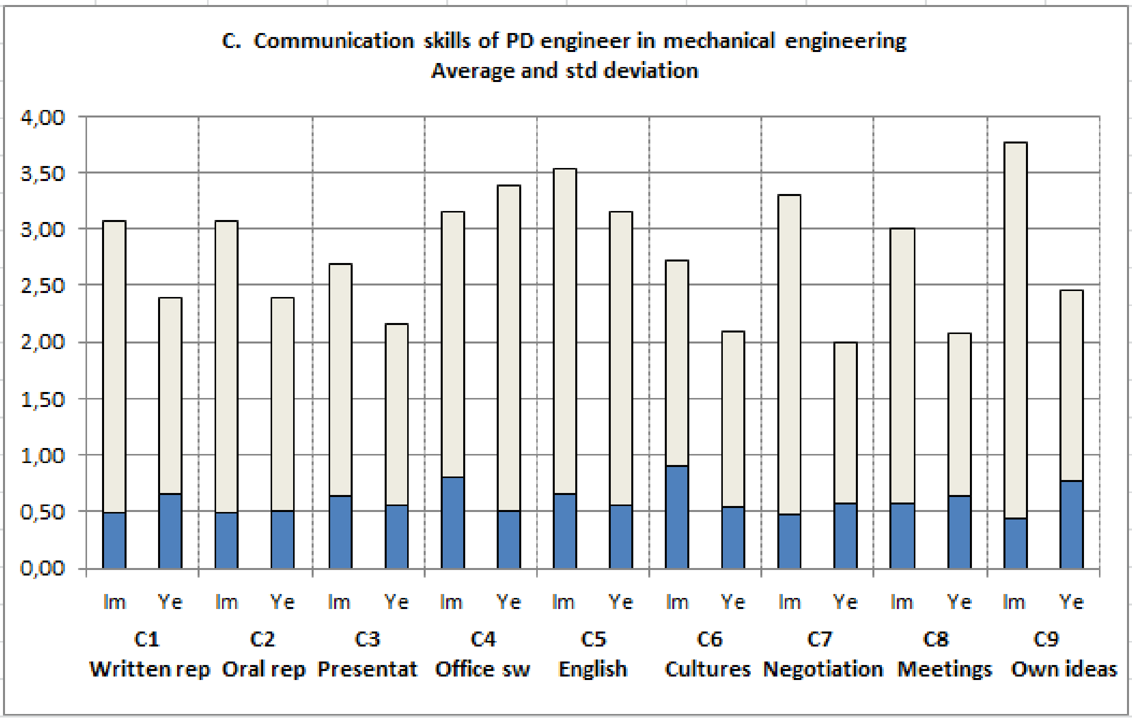

Figure A3.3 *Averages and standard deviations for the answers to the group C questions by the 13 companies.*

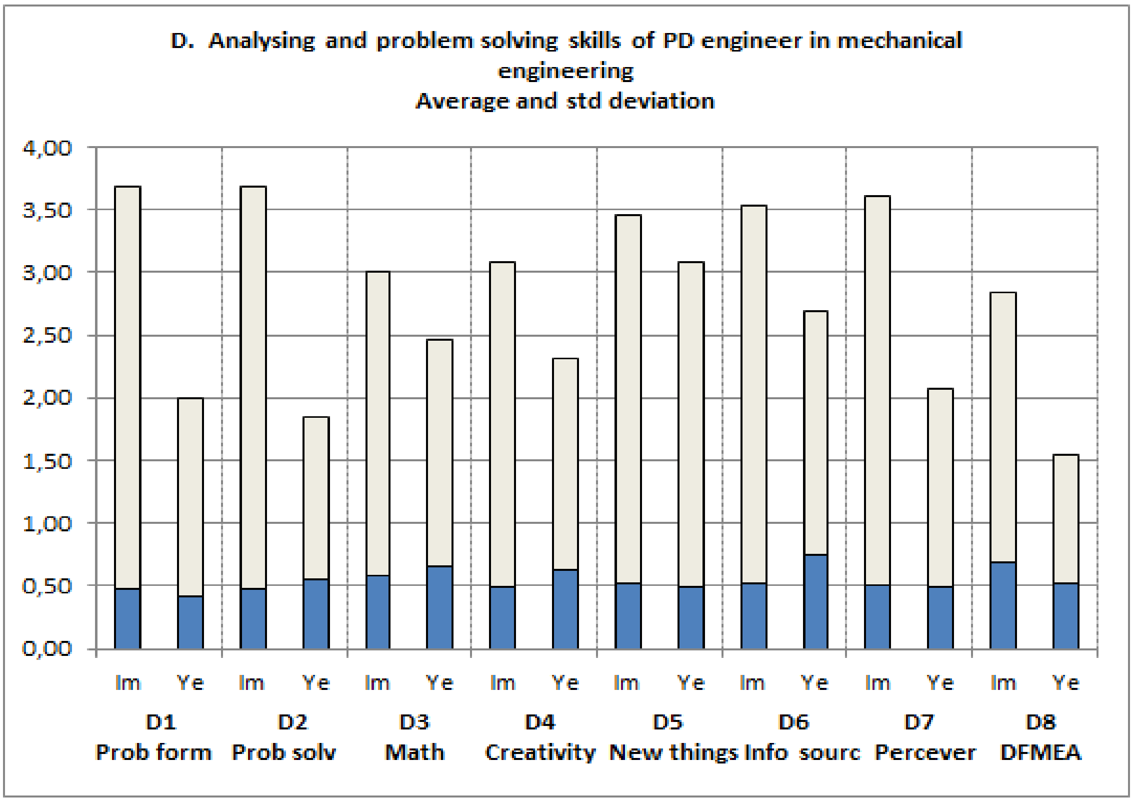

Figure A3.4 *Averages and standard deviations for the answers to the group D questions by the 13 companies.*

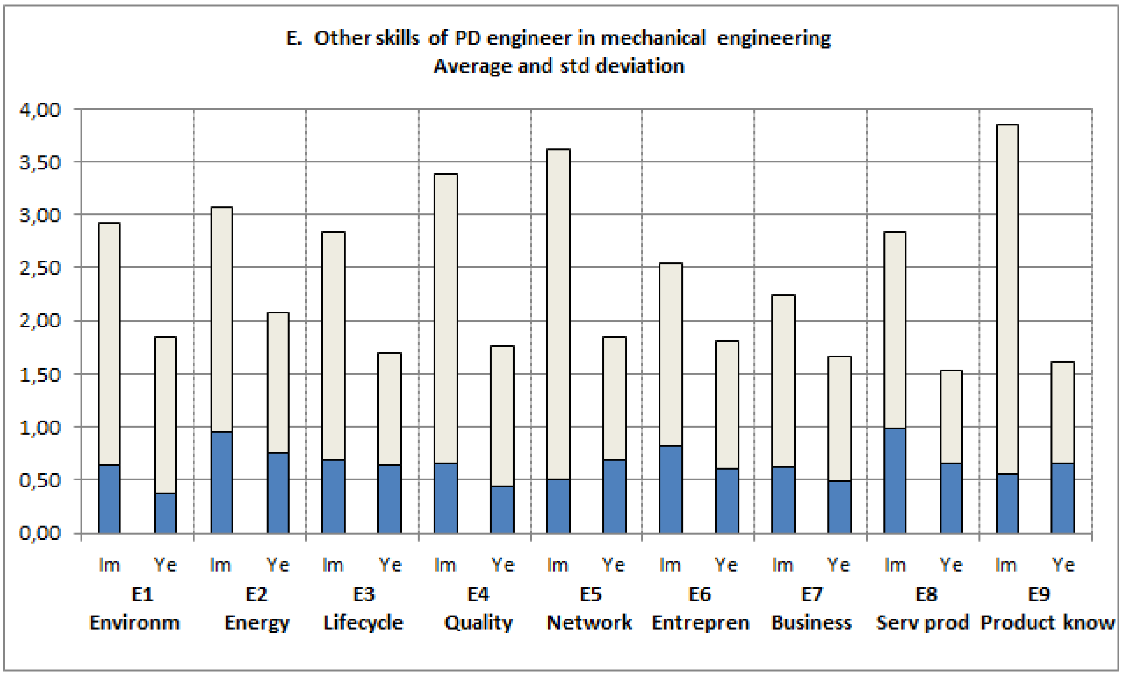

Figure A3.5 *Averages and standard deviations for the answers to the group E questions by the 13 companies.*

Appendix 4: The List of Questions on the Student Feedback Questionnaire

COURSE FEEDBACK

Course:		Date:	
Degree programme:			
Student Group:			

Your evaluation to the following questions

	Fully disagree 1	Disagree 2	Agree 3	Fully agree 4	I don't know 0
1. Course targets clearly presented	☐	☐	☐	☐	☐
2. Interesting course content	☐	☐	☐	☐	☐
3. Useful course content	☐	☐	☐	☐	☐
4. Interactive lecturing	☐	☐	☐	☐	☐
5. High expertise of the teacher	☐	☐	☐	☐	☐
6. Good presentation skills of the teacher	☐	☐	☐	☐	☐
7. Easy to get help and guidance from the teacher	☐	☐	☐	☐	☐
8. Good course material	☐	☐	☐	☐	☐
9. Useful exercise work	☐	☐	☐	☐	☐
10. Exam questions measured competences	☐	☐	☐	☐	☐
11. Good studying atmosphere	☐	☐	☐	☐	☐
12. Total workload corresponds to ECTS credits	☐	☐	☐	☐	☐
13. Your own participation was active	☐	☐	☐	☐	☐
14. Your participation percent in lectures:	%				

Estimate your ability to participate in the product development work in your future job on the scale 1…4 (1 = low, 2 = rather low, 3 = rather high, 4 = high, 0 = I don´t know): ☐

- Your strengths: ______________________
- Your weaknesses: ______________________

Your free comments

Lectures: ______________________

Course material: ______________________

Exercise work: ______________________

Others: ______________________

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