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Just an Aluminium Trolley – A Case within the Frame of Problem-based Learning: Linking Strategy, Innovation, Product Development and Design in a Dynamic Concept between the Academic and Professional World.

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ABSTRACT: This paper presents what an engineering school at a university may do to stimulate engineering excellence. Problem-based education methods in connection with project and group-organised studies as a link between the academic and professional world is presented in the frame of Mechanical Engineering and Industrial Design curriculums. Innovation as suggested is the creation of a new product-market-technology-organisation-combination (PMTO-combination) consisting of three key elements: 1) Innovation is a *process* and should be managed as such, 2) the result is at least one new element in the company's *PMTO-combinations*. 3) The extent to which the innovation is *new* may range from incremental, small step innovation, through synthetic innovation, i.e. the creative recombination of existing techniques, ideas or methods, to discontinuous, radical, quantum-leap innovation. Often new means: new, somewhere on the continuum. The company in this case - a very small business - wanted just an aluminium trolley.

Introduction – just an aluminium luggage trolley

When you have invested a large amount of money in building a new airport characterized by the use of glass and aluminium solutions, you do not want to spoil the overall impression by using a luggage trolley made of galvanised steel, said the manager of a very small company (approx 35 employed) KS-group. A costumer chose another supplier because the KS-group did not have the competence, resources and technology readiness to develop and design a new trolley made of aluminium. In a co-operation between the KS-group, Aalborg University (final projects) and Hydro Aluminium it was decided to develop a luggage trolley prototype for further test and development.

The development of the prototype is a good example of how work is carried out in teams: where research, education and communication are carried out in integrated interaction with industry.

There will always be an academic debate to whether product development and design should be taught primarily by establishing a foundation of theory, or by engaging students in loosely supervised practice. For a broader activity of product design and development, both approaches are rejected at Aalborg University when taken to their extremes. Theory without practice is ineffective because there are exceptions and subtleties to be learned in practical settings, and because some necessary tasks simply lack sufficient theoretical underpinnings. Practice without guidance can too easily result in frustration and can fail to exploit the knowledge that successful product development professionals and researchers have accumulated over time. It is attempted to strike a balance between theory and practice through our emphasis on the unique use of problem-based education methods in connection with project and group-organised studies.

The aim of the co-operation is that students, university and the industry achieve a high degree of

- Competence development.
- Innovative solutions.
- Attention to development issues.
- New tools and methods.
- Updating of knowledge.
- New point of views.
- Cross-functional discussions.
- Promotion

Focus will mainly be on the project-based educational programme and first innovation and its three key elements will be discussed as an element of a dynamic concept. Then the innovative problem-based learning and the project work-study form will be presented. Afterwards we shall introduce and suggest a process-based model for contingency will be suggested– as a dynamic approach - for reflection of and identification of the human, the social and the technical dimensions. Then experience and results from the dynamic approach will be pointed out between the academic and professional world. Finally, the conclusion will be presented.

An aluminium luggage trolley – "Innovation –What innovation?"

In [1] Boer and During describe the creation of a new product-market-technology-organisation-combination (PMTO-combination where:

- Products are the tangible or intangible output of organisations.
- Markets are composed of (groups of) customers – external as well as internal.
- Technology is; the 1) knowledge, experience and skills of people ('human ware'), 2) methods, techniques (software) and 3) tools and equipment (hardware) companies need to perform their production, support and management processes.
- Organisation is the whole range of structural, cultural and physical arrangements through which the work in the company is divided and co-ordinated.

This combination suggests that three key elements exits:

- Innovation is a *process* and should be managed as such. Key activities in innovation management are: goal formulation, designing and organising the process, monitoring progress and, if necessary, adjusting the goals, the process and/or its organisation.
- The result is at least one new element in the company's *PMTO-combinations*. Product innovation, for example, involves the development, production and commercialisation of new

products and may require the development of new process technology or market segments. Technological innovation, i.e. the in-house development of new process technology, or the adoption and implementation of technology developed elsewhere, usually also requires organisational adaptation, but need not be linked to new product or new market development.

- The extent to which the innovation is *new* may range from incremental, small step innovation, through synthetic innovation, i.e. the creative recombination of existing techniques, ideas or methods, to discontinuous, radical, quantum-leap innovation see e.g.[8]. Another aspect regards the who for which the innovation is new. This may range from new to the world, a country/society or an industry, a company or an individual. In the present paper, new means: new, somewhere on the continuum, to the *company* involved.

In relation to innovative development, theoretical concepts, methods and tools only give sense when linked to praxis in a real company as illustrated in figure 1.

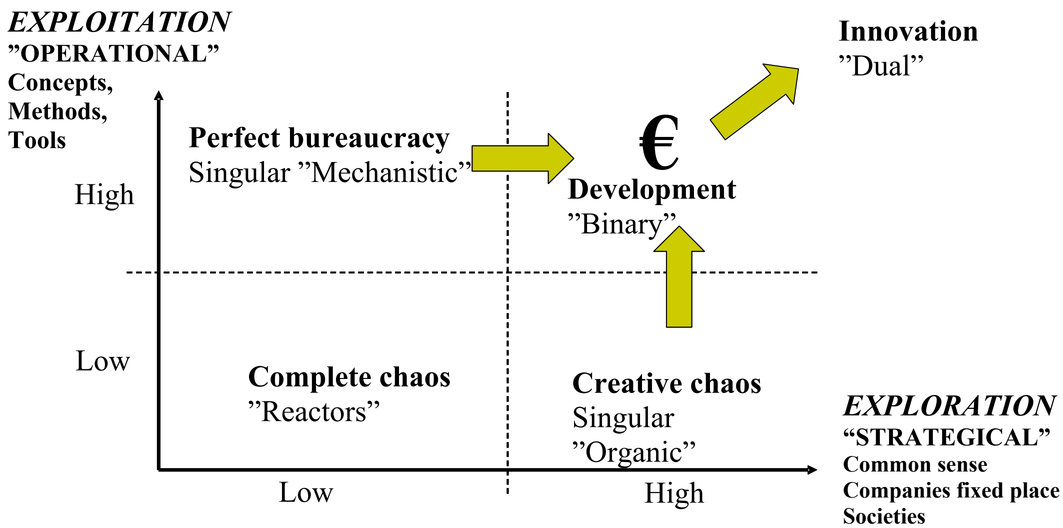

Figure 1: Innovative development as a combination of theories and common sense.

Operational effectiveness requires excellent exploitation capabilities and strategic flexibility requires excellent exploration capabilities.

Project- problem based learning, an innovation experiment in higher education

As an experiment in higher education Aalborg University was established in 1974 starting with 900 students from four different schools – today with more than 13,000 students. Experience with project-organised and problem-oriented studies since then has proved to be an important innovation in higher education, Kjersdam [2]. The curriculum in engineering as well as in the natural science is project-organised from the day the freshman arrives until graduation. In design-oriented project work the students deal with some degree of know-how problems which involve a great part of theories and knowledge acquired from lectures.

There were special conditions for establishing Aalborg University. It was situated in a region of development with few traditions of higher education. A new thing was also that more local institutions of education should be closed down and the programmes integrated on a new foundation in the university. It should also be mentioned that the battle for placing a university in Aalborg was seen as a local national movement which had and still has a very important meaning for the relations to the surrounding society with the common goals and task: To strength the link between the academic and professional worlds.

The four main university goals of the project-based systems are:

- EFFICIENCY**:** To make the program requirement such that most students graduate on schedule without loosing professional competence:
- QUALITY: To increase student's self-confidence, flexibility, creativity, and communication skills as well as to increase their ability to work in teams.
- FLEXIBILITY: To solve interdisciplinary problems by improving faculty leadership abilities to direct students project teams so that project advisors become coaches rather than lecturers
- INNOVATION: To emphasise integrated problem solving, considering social, economical and political aspects as well as the technological aspects.

The Aalborg University model of project based learning comprises of the concepts of problem based learning and project work including:

- Problem orientation
- Experience-based learning
- Interdisciplinary learning/projects/lectures/courses
- Gradual specialisation
- Project work in groups.

To emphasise learning instead of lecturing is the main idea behind both project work and problem based learning. Learning is the active process of investigation and creation based on the learner's interest, curiosity and experience, and it should result in expanded insight and knowledge skills.

The main element of the pedagogical concept is study plans, which for each semester (½ year) describes courses and prescribes a theme for each term. Within the semester theme each supervisor together with a student group can choose a project. The project time is calculated theoretically to cover half of each semester except at the final where the project can cover from one to two semesters. The five-year's education for a master degree is divided into 4 phases – for flexible individual choice of competence. Table 1 shows the phases and the semester themes of the current Industrial Technology curriculum with examples of semester courses. Table 2 shows the phases and the semester themes of the current Architecture and Design curriculum with examples of semester courses

The speciality in Industrial Technology offer a professional competence in solving complex manufacturing problems as development, design and manufacturing of products from an industrial point of view, consequently the aluminium luggage trolley project could fit to a final master project covering 9^{th} and 10^{th} semester, maybe a 7^{th} semester bachelor dissertation project or an integration of 7th and a 9^{th} semester projects.

On the other hand the new (at that time) speciality in Industrial Design offer almost the same professional competence as Industrial Technology, but more from the user point of view, consequently the aluminium luggage trolley project could also fit into 8^{th}, 9^{th} or 10^{th} semester projects.

As lecturer and supervisor within both programmes, I could recommend the project starting up in the frame of the Industrial Technology programme.

Phases	Semester	Theme	Courses
Final	10	Master dissertation	Free choice (from 0 -~5)
	9	Technology development	Outsourcing, Investment and decision theory, Laws/rules for companies, Strategy planning
Specialisation	8	Design/planning and manufacturing	Product data and product modelling, Generation of data for manufacturing. Methods of optimising, Systems identification, Elementary methods, Marketing, Advanced materials and processes, Development of information systems.
	7	Carry through manufacturing	State-space modelling, Systems theory, Methods of elements, Production control, Structural programming, Assembly methodology, Simulation, Constitutive modelling
	6	Manufacturing processes	Dynamics, Partial differential equations, Theory of plasticity, Manufacturing processes, Experimental methods for engineers, Welded designs, Finite element methods, Modelling of processes, Metrology.
Common ground	5	Production Preparation	Production planning, Human factors, Physics, Organisation theory, Quality control, Probability theory
	4	Production process Realisation	Mathematics, Mechanics, Plastic forming, Control systems, Metal cutting, Foundry
	3	Engineering design	Mathematics, Geometry, Materials, Mechanics, Strength analysis, Engineering design
Basis	1 + 2	Engineering problems: Model and reality, Models reality	Mathematics, Physics, Computer science, Technology and society

Table 1. Phases, semester themes and courses of the M.Sc. Programme in Industrial Technology.

Speciality		Urban design	Architecture	Industrial design	Digital design
Phases	**Semester**	Theme	Theme	Theme	Theme
Final	10	The dissertation project	The dissertation project	The dissertation project	The dissertation project
	9	Values and methods of urban design	Values and methods of architecture	Values and methods of industrial design	Values and methods of industrial design
Specialisation	8	Urban design in practice	Architecture in practice	Industrial design in practice	Digital design in practice
	7	Urban restructuring	Large buildings	System design	Augmented reality
	6	Urban development	Architecture and ecology	Integrated design	The digital space, virtual reality
			Courses		
Common ground	5	Product design	Design methodology, Ergonomic, Mechanics, Strength analysis, Engineering design and mechatronic, Manufacturing, Choice of materials		
	4	Settlement and urban planning	Consumption of energy and temperature conditions in buildings, Architecture, Town plan and history of design, Planning, Cad2		

	3	The urban building	City-house, Static and construction of buildings, Materials, Loss of heat and energy consumption, Light, Form and colour, Cad1
Basis	2	Implementing a design	The body-anatomic adventure exploration, Shape and colour, Techtronic, Croquis, Mathematics
	1	Assessing a design	Space, Human and context, Co-operation, Learning and management of projects, Architecture and designs, Information technology, Design

Table 2. Phases, semester themes and (some) courses of the M.Sc. programme in Architecture and Design

The project work-study form – as a dynamic concept.

The project based education [3] fit to the four dynamic concepts: Contingency, Problem solving, Knowledge and Learning, which are closely related. Gaps in knowledge lead to novel contingencies. Contingencies create the need and opportunity for problem solving. If problems are solved well, this will lead to learning and new knowledge about how to detect, respond to, prevent or exploit contingencies. Knowledge, which is effectively exploited, alters the whole production environment and system.

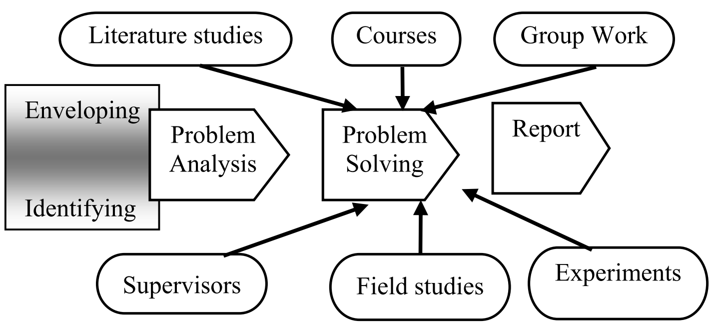

Figure 2. Project Work as a Study Form

Authors have described the project work as study form in different diagrams and pictures. Figure 1 gives an issue specified for the present paper. The figure focuses upon the difficulties to maintain for the students and to be aware of for the teachers as supervisors if project work shall succeed. The area of the boxes in this diagram does not indicate the time used on each task but to the mental change and effort needed to fulfil a project.

The project itself from the very beginning is often only soft and unclear defined. A big and demanding part of the work, therefore, is to envelope, identify and analyse that part of the total whole which is to be solved through the project. This enveloping, identifying and analysing must go on in an iterative process with scientific methods available and usable for the actual topic. It is like walking in a staircase. Seen from above it can look like walking in circles, but seen from the side, the students' position, one can recognise a constantly increasing level.

The supervisors of project-organised education need to be aware of that and not press the project group too hard in the first part of the project period. If that phenomenon is not taken in consideration, the students will tend to fall back to the 'Do as Learned Method' and find only conservative solutions.

Process-based model for contingency - a dynamic approach

The core of the model is a balance between attention to and reflection on the potential opportunities and resources in connecting human, social and technical dimensions the characteristics of the process e.g. the people involved in the process and the organisation of the process.

Recognising that contingency is essentially a consciousness-raising learning process; the process can be modelled based on Kolb's [4] and Cowan's [5] four stages experiential learning model as follows. Triggered by the recognition of a need or an opportunity to innovate, Boer [1], the innovation problem is defined or redefined, ideas for possible solutions are generated, information is collected, analysed and evaluated during (1) the *creative stage (experience)*. Next, during (2) the *selection stage (reflect)*, sufficiently promising ideas are selected for further elaboration. Alternative solutions are specified, priorities and evaluation criteria are set and, based on that, the alternatives are evaluated and selected. During (3) the *design stage (generalise)*, concrete possibilities are elaborated, principle solutions designed, and operational specifications determined. Finally, during (4) the *application stage (test)*, the innovation is tested in practice or with the help of a model and then implemented, or implemented without any testing.

Product development and design of the luggage trolley.

Product development and design called total design is [6] seen as a broadly based business activity in which specialists collaborate in the investigation of a market, the selection of a project, the conception and manufacture of a product, and in the provision of various kinds of user support.

Total design incorporate an understanding of creativity, innovation and design, the design of organisations, open systems theory, the effects of environments, design as a collective decision making, stages in design, stages in the contexts of innovation, the business design boundary, models of small group performance etc.

Over the years five groups of students have been involved in the total design project. They have all been attached to the project more and less according to figure 1 from the exploitation and the exploration point of view.

From the exploitation point of view they have used the so-called Stage–gate model (IPD model) [7], [8], as concept, the methods from the product synthesis model [9], a FEM model [10] and the tools of the general problem solving model are illustrated in figure 3.

From the exploration point of view they have used the “learning” model are illustrated in figure 4

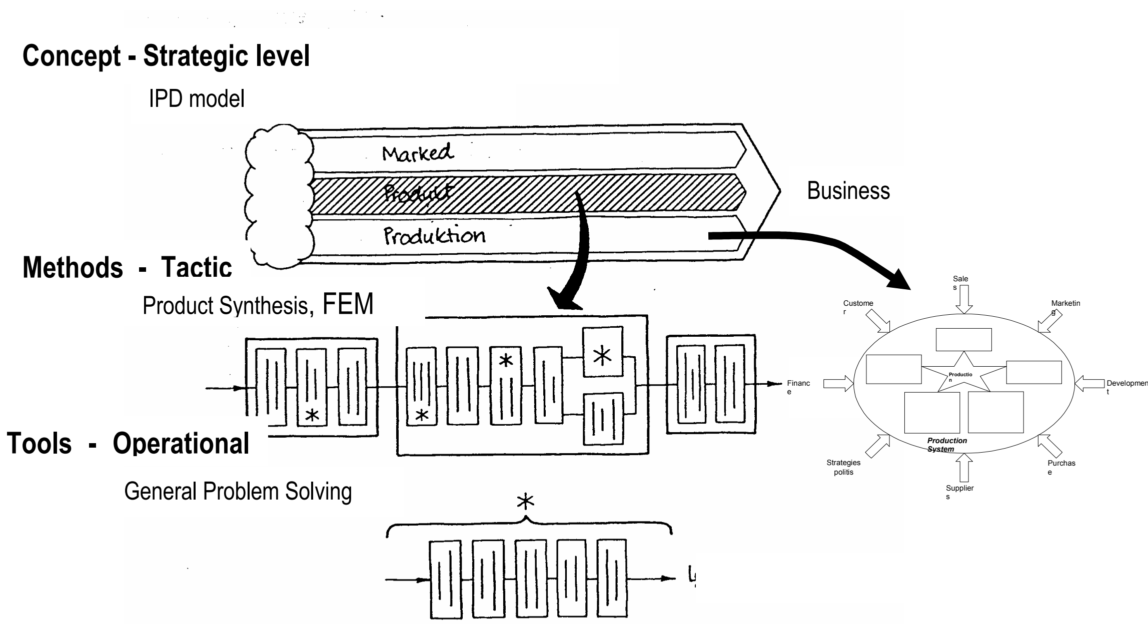

Figure 3. Exploitation: concepts, methods and tools

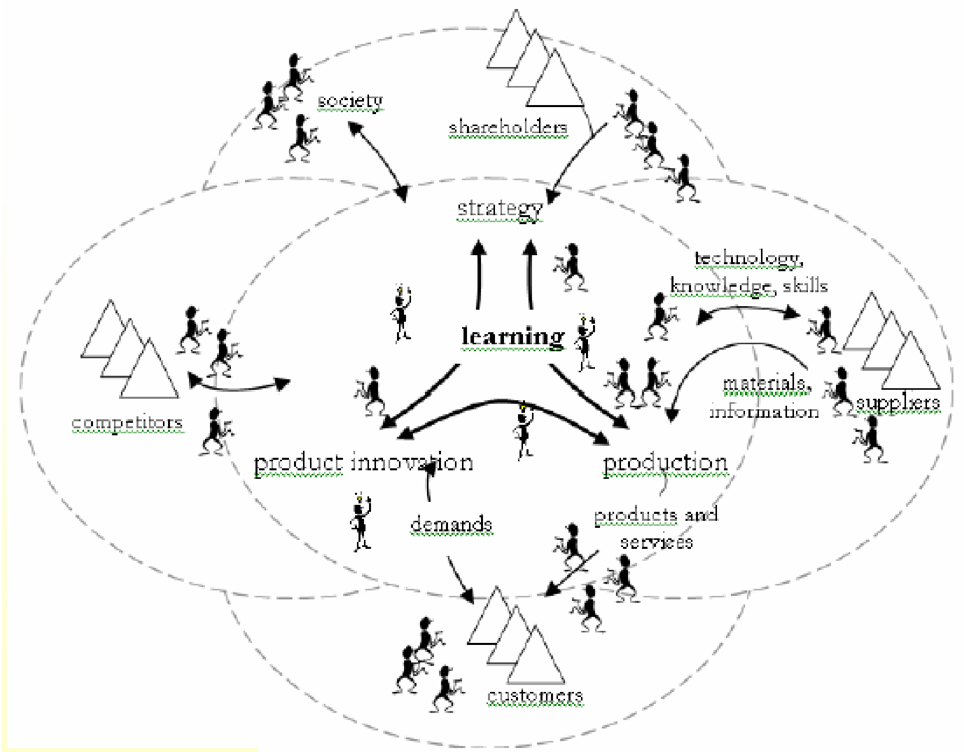

Figure 4. Exploration: The learning process [11]

A group of 4 students within the Industrial Technology programme, two 9th semester student and two 7th semester (bachelor dissertation) students ended op with a design concept see figure 5 grounded on a comprehensive analyse and diagnose of the companies operationally and strategically opportunities.

The group of two students now 10th semester continued the projects and ended up with the final prototype see figure 6. For that project they got a reward for one of the best engineering project in Denmark this year.

Then the design of the test equipment and test see figure 6 was handed over to a 7th semester student (bachelor dissertation, Industrial Technology).

We knew some much about the project at that moment, as a result we decided to let:

An 8th semester group of 5 students from the Industrial Design programme make a redesign. Among a lot of design concepts figure 7and figure 8 was chosen and was handed overtaken over to:

A group of two 7th semester students (bachelor dissertation, Industrial Technology) for testing figure 9, redesign see figure 10 and primarily production preparation.

The final test and production planning was then handed over to the company.

The projects had created so much attention, as a result two 9th semester students within the Industrial Design programme as a part of their project wrote a book (in Danish and free of charge on the internet) about aluminium to benefit for students as well as for industries.

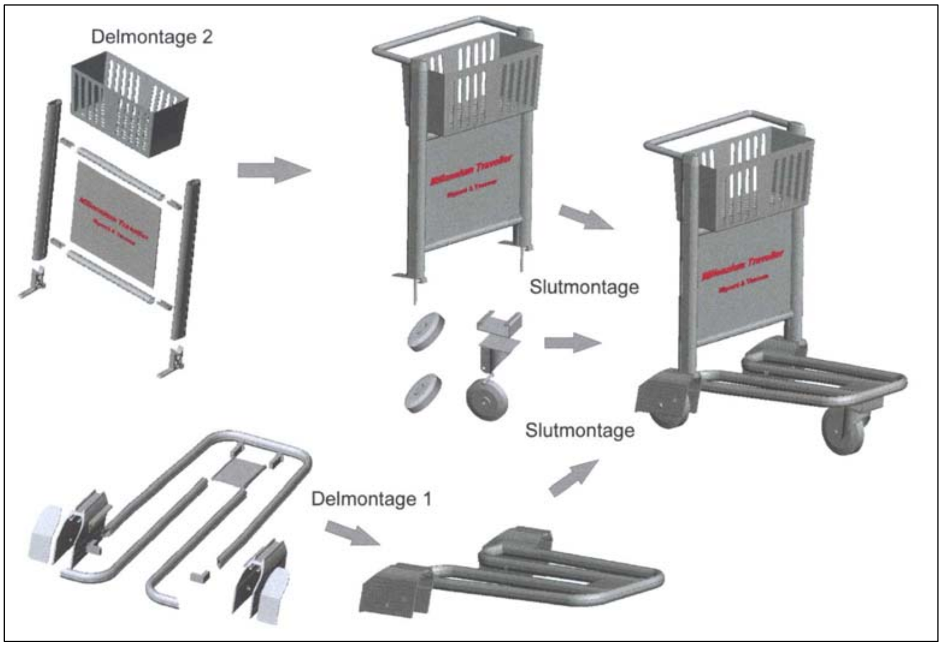

Figure 5. The first design concept (delmontage ~ part assembly, slutmontage ~final assembly)

Figure 6. The test equipment and the first prototype

Figure 7. The new design concept

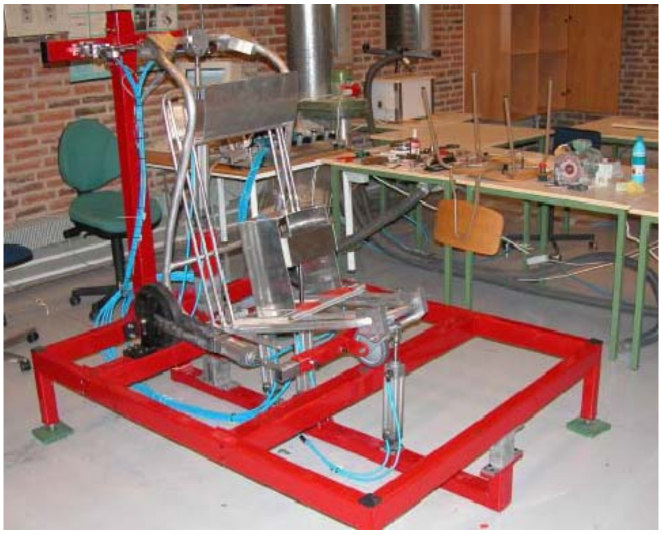

Figure 9. Test of the new prototype.

Figure 8. Exploded view of new prototype.

Figure 10. Final design for production planning and testing

Some experiences of learning objectives into students competencies.

In their progress through the program, the students develop a range of competencies built up in a logical sequence see table 1 and table 2. As a result ('the deliverables') the aluminum projects have all contributed to the students development and demonstrating the following groups of competencies:

Engineering competencies at academic level: an ability to apply knowledge of mathematics, science and engineering, an ability to design and conduct experiments, to develop (computer-aided) models and simulations, and to analyse and interpret data, an ability to identify, formulate and solve engineering problems, an ability to integrate theory and practice from a range of disciplines, an ability to use the techniques, skills and modern (computational) engineering tools necessary for engineering practice and an ability to design a system, component or process to meet desired needs.

Social and business competencies: an ability to work in multidisciplinary teams, an ability to communicate effectively about their own work and the work of others, an insight into the complex working of modern industrial organizations, an understanding of the impact of engineering solutions in a global and societal context and an ability to take decisions and an understanding of professional and ethical responsibility.

Self-development competencies: a knowledge of contemporary issues, an ability to collect and use information in an independent manner and recognition of the need for and a development of the ability to keep up-to-date at academic level as a preparation for life-long learning.

The competencies are the objective basis for assessing and improving the quality of the program.

Some experience from lecturing and tutoring aspects.

Plan what you want the students to be able to do by the end of a given project. Set up intermediate check points, and get the students to report (with short talks) how well they are meeting the checkpoints. If not why not - get them to tell you.

Set the standards and keep to them: the students need to know what they have to do to succeed.

Running project groups can be fun, but it is hard work and challenging: the unexpected is always just round the corner. Good preparation is essential.

Recognise that running project groups is not always easy: you may have to adapt on the spot; students may ask questions to which you don't know the answer. In general you have more experience than they do of solving engineering problems. But you have to build up experience of running group projects - it is also a learning experience for you!

In developing a project, consider the benefits of involving a partner from a related branch of engineering industry.

Don't be afraid of the students: they also wish to succeed. They can help you to succeed with your teaching and research. Treat them fairly and they will treat you fairly.

Use the students to help you. Ask them for feedback. Ask them what they like about the project or the lectures, what they find difficult, where the blockages are.... Talk to them as adults and they will respond positively - you lose no authority, and you can only gain from it.

Get members of the group to work together to solve their own problems - try and suggest approaches to solving the problem in hand, rather than telling the students the answer. Can another student provide an answer to one student's problem - they always like to show they know (if they do). Staff also likes to show what they know, but are strongly advised to hold back.

Share your experiences of group work with your colleagues: you can learn a lot from each other.

Learning to learn is more important than lecturing alone: ensure that the student knowledge is and remains active.

Some experience and results from university –industry interaction

The risk of a close co-operation between a university and the enterprises is that the studies and student groups can appear to be something like free consultative partners and with short terms solutions only. The real risk of that would be a lower scientific but more pragmatic level of the studies.

In general the enterprises have a considerably shorter strategic perspective than that necessary at a university or other higher educations. Many small and medium sized enterprises have a high degree of product development and product adaptation. Here, the expression 'product' is used in a very broad meaning which includes also service-products.

However, by nature such small and medium sized enterprises have only little tradition for research work, if any at all. Even rather big enterprises are looking for solutions ready to use, or at least solutions developed from already existing results of basic research.

That means, if a university leans against enterprise projects alone, the basic research together with the students training in fundamental scientific methods will come to starve.

As mentioned above, we are dealing with two different worlds, the life in an industrial enterprise and in academia with different goals, criteria and success and reward systems. But, there is potential synergy in using industry as laboratories for lecturing, projects and research.

A traditional contribution is a set of proposed decisions that represent an appropriate solution to a well-defined problem. However, an equally significant contribution may be structuring a complex issue and the pointing out of appropriate options available, leaving it to the company to decide for themselves. Also, because of their academic training, students are able to identify phenomena described at a higher level of abstraction. And they are able to develop a radically new solution, partly because they as newcomers are unbiased and can use their theoretical principles and good practices of other companies.

Hence, the benefit to a company from having students and action researchers working on development projects should be viewed in broader terms than merely the potential savings; for example in form of a greater awareness and understanding of the mutual interplay of current practice, identification of areas for further attention, new directions and opportunities for the company implied in proposed idealised solutions, and transfer of knowledge from students and faculty advisors to industry employees and managers.

However, a continuous act of balancing focus, time and effort is crucial; for example, the students are often too eager to engage in company problems, and there is a spectrum of solutions – from repair to radical innovations.

Challenges to the engineering faculty - Some experience.

Ries [12] writes: The engineering problem-solving approach represents in many ways a different mode of learning than the traditional lecturing methods. We have observed that this has given rise to two challenges to the engineering faculty:

- New teaching roles and qualifications are implied in the engineering problem-solving approach. Good lectures will always be appreciated, but the role of a teacher will change from that of a lecture to that of a coach. Facilitation of a student project group requires that the teacher be prepared to discuss open-ended issues and the application of methods and solutions on hand. Interaction with students thus follows a non-linear process that can be planned in advance. On the contrary, on the basis of a broad knowledge of issues, theoretical perspectives and models of awareness of a broad spectrum of practical solutions, the teacher should be able to combine planning and improvising.
- Engineering faculty members are also supposed to do research and to publish their results. To accomplish this faculty members are encouraged to focus their research on rather specific topics to increase the chances of having their papers accepted in international journals. Few journals accept papers that adopt a multi-perspective view and address complex issues of industrial companies.

As a consequence, there are several forces at play in an engineering school that makes it difficult and even risky to apply an engineering problem-solving approach. In addition, often the lecturer has to sign an agreement of confidentiality so that article and other publications are impossible. Nevertheless, the issue is vital for any engineering school and challenges it to find a balanced solution.

Conclusion and summary.

At Aalborg University very good experience is obtained by using the problem-orientated and project-organized study method in a project cooperation with enterprises, private as well as civil enterprises. The concept contents some difficulties and some risks of a lower scientific but more pragmatic level of the studies. They are, however, to be maintained without attacking the academic independence.

By establishing good relations to the purchases of graduates and research results, a valuable and inspiring, actual feed back is obtained. Interesting student projects are carried out and often continued in real and actual research projects as a means for stimulating manufacturing excellence in larger as well as small and smaller industrial enterprises.

The university – industry relationship plays an important role offering potential opportunities and benefits for both parties. However, attention should be paid to ensuring transparency in objectives in a continuous strive to balance scope, conflicting interests and effort.

The results and experience of the research which is carried out at the university is easily incorporated in the lecturing programmes because of their close relationship to problem-solving, and because of their direct integration with the educational systems and its programmes.

The graduates achieve great experience in interdisciplinary teamwork and they will normally posses the latest scientific and methodological knowledge, which is thus spread quickly and free of charge to both public bodies and industry, due to the employment of new graduates.

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