

**The Aalborg Experiment**  
**University - Industry Interaction: A Means for Stimulating Engineering**  
**Excellence in Technology and Learning Systems**

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**Abstract:** This article presents what an engineering school at a university may do to stimulate the engineering excellence. The Aalborg University experiment will be used as a case example with its unique use of problem-based education methods in connection with project and group-organised studies – to stimulate the professional learning process by a balancing of teaching/experience, theory/practice, disciplinarily/interdisciplinary and by strengthening the link between research, education and practice. This presentation draws on the author's experience since 1974 with the never ending development and implementation of the Aalborg experiment.

**Introduction: The Aalborg Experiment**

Aalborg University (AAU) was established in 1974 as an innovative experiment in higher education with 900 students from four different schools, now with more than 13,000 students. The innovation was mainly to use the project-based educational approach to overcome some of the problems of the traditional course-based educational system. The curriculum in engineering as well as in the natural science is project-organised from day one till graduation.

There were special conditions for the establishment of AAU. It was established in a region of development with few traditions of higher education. It was also an introduction of a new structure where more local institutions of education were closed down and integrated in the foundation of the new university.

It should also be mentioned that the battle for placing a university in Aalborg was considered as a local national movement.

Especially the local movement element had and still has a very important significance for the new university's relations to the surrounding society with the common goals and task; to strengthen the link between academia and the professional world.

The four main goals of the project-based organisation of studies were and still are:

- Efficiency; to make the study requirements such that most students graduate on schedule without losing professional competence.
- Quality; to increase students' self-confidence, flexibility, creativity, and communication skills as well as their ability to work in teams.
- Flexibility; to solve interdisciplinary problems by improving faculty leadership abilities to supervise students' project teams so that project supervisors become coaches rather than lecturers.
- Innovation; to emphasise integrated problem solving, considering social, economical and political aspects as well as technological aspects.

From 1990 to 1994 The University of Twente [1, 2] planned the innovation from classical to project-led education for the mechanical engineering studies. No other institution had successfully made this changeover when they started in 1994 and this probably remains true in 2004, although some other universities have started developing similar initiatives on a scale which matches their needs and perceptions.

In the following some important elements of the concept will shortly be pointed out, some cases will be given together with experience from interaction between AAU and industry will be presented, followed by summary and conclusion. For more detailed information please see/be referred to [1], [2], [3] and [5].

### Danish Industry

Denmark is characterised by a society with dense underbrush of small and medium size enterprises. In figure 1 only those branches are counted which normally employ graduates from the higher education. Whtrad corresponds to all types of wholesale-trade. Mo+Bs is money and business, included banking but excluded retail-sale. Serv includes all types of private service, consultative, juridical or auditing. The columns show that even in the branch of manufacturing (Manuf), the small and medium size enterprises hold a clear majority.

**Size of Danish enterprises and some branches divided into number of workplaces, independents included.**

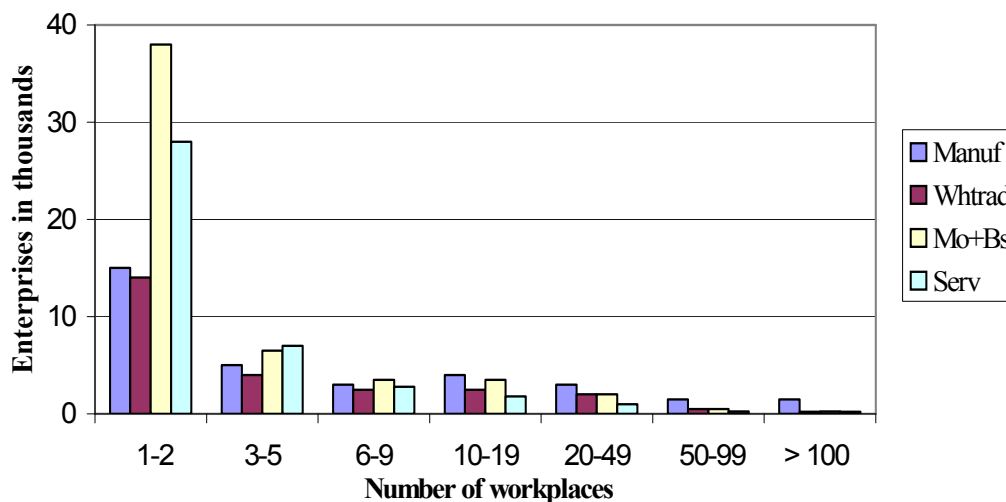


Figure 1. Density of small and medium size enterprises. Manufacturing, wholesale-trade [5].

The Danish home market is by nature small, but it is open. It means that the possibility to live and compete in the market is closely connected to the ability to meet the actual demands of the customers and to do this before the big enterprises have established large-scale production. The expression 'niche-production' is often used because that type of production is typically carried out in small and medium size manufacturing companies.

The small and medium size companies have a common need for a generally higher education level of their employees, and they have a bigger ratio of high-educated persons than the big companies [5].

An immediate solution could be to increase the number of study-lines according to the development. Questionnaires however, among some of the most trend setting Danish enterprises show that they prefer basically well prepared graduates to graduates with less basic knowledge and more specialisation. Further they ask for graduates flexible to changes with the ability to:

- Identify, analyse, formulate, process and solve complex problems.
- Assess technology in a social context in order to solve social problems, fulfil social needs without creating unwanted side effects.
- Acquire and apply new theoretical and practical knowledge as well as up-date old knowledge.
- Be open-minded, co-operative and communicative.

### **The Aalborg concept**

The Aalborg University model of project based learning is comprised 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.

As with more traditional educational systems some of the important questions are:

- How to motivate the students?
- How to determine the elements in a curriculum?
- How to balance the different elements in the curriculum?

Some of the important questions related to the role of the lectures are

- How can we make the lecture-student supervision most efficient?
- How does lecturing task comply with the research task?
- How can we connect different subjects?

The questions listed above are all open-ended.

## The pedagogical concept of the Aalborg Model

The curriculum in engineering [4] as well as in natural science is project-organised from the day the freshman arrives until graduation. In the problem-oriented project work the students deal with some degree of unsolved problems within science and profession in a dynamic interplay among development, applied and pure science, see figure 2.

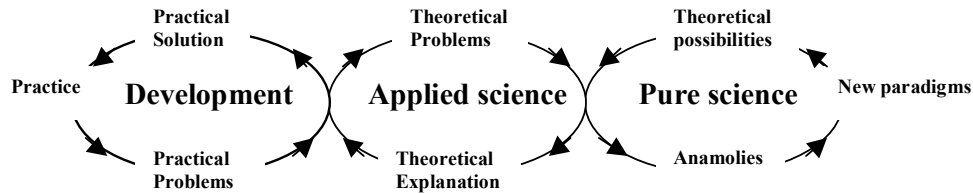


Figure 2. The dynamic interplay among development, Applied and Pure Science [1]

Authors [5] have described the project work as study form in different diagrams and pictures. Figure 3 illustrates an issue specified for the present presentation paper. The figure focuses upon the difficulties to overcome for the students and which the lectures as supervisors have to be aware of to make project work succeed. The area of the boxes in this diagram does not refer to the time volume of each task but to the mental change and effort needed to fulfil a project. The project is often in the beginning only softly and unclearly defined.

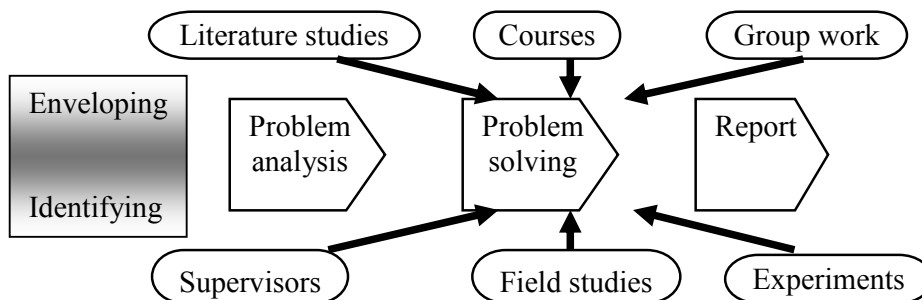


Figure 3. Project work as a study form [4], [5]

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 take place on in an iterative process with scientific methods available and usable for the actual topic. It is like walking up a staircase. Seen from above it seems like walking in circles, but seen from the side, the students' position can be recognised as 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 the phenomenon is not taken into consideration, the students will tend to fall back to the 'Do as Learned Method' and find only conservative solutions.

The project-work is supported by relevant lectures and a great deal of self-training, field studies, supervision and often interaction with companies.

The work is [5]:

- Ability to perceive a complex situation in a systematic way, and from those observations identify and envelope the main elements.
- Ability to identify possibilities and limitations of methods usable to maintain those elements together with their interactions.
- Abilities to handle such methods in a scientific way.
- Ability to look for additional knowledge also outside subjects given in courses.
- Ability to use such knowledge, perhaps assisted by the supervisor.
- Ability to include calculations or evaluations of consequences and find the optimum among the potential solutions.

### **Structure and study curriculum**

The main element of the pedagogical concept is study plans, which for each semester ( 20 weeks) describes courses and prescribes a theme for each semester. Within the semester theme each supervisor together with a student group can choose a project. The project duration is calculated theoretically to cover half of each semester except for the final semester where the project covers the whole term. In practice the students spend more time on their projects. The five years of education for a master degree is divided into 4 phases for gradual individual choice of specialisation. Table 1 shows the phases and the semester themes with examples of semester courses inside the specialty within Industrial Technology.

In the first phase, one-year of basic studies within Technical and Social Science, the studies include course on fundamentals subjects (mathematics, physics, chemistry, computer science etc.) and the basic skills for carrying out problem-oriented project work are trained. After passing the examination after the first year, the students have to choose between several options of programmes, among which are the programme for chartered surveyors.

The second phase has three semesters of common advanced study. Students learn fundamental skills in engineering design based on the interaction of functions, processes, technology and the environment. The project work develops a solid spatial sense and the ability to provide elegant and durable solutions to complex problems through the synergy between systematic analysis, intuitive thinking, creativity and the art of engineering. Therefore this phase is characterised by design.

In the third phase the students can within broad limits choose their the specialisation for obtaining a professional profile e.g. Industrial Technology, Industrial Management, International Technology Management, Design of Machine Systems, Electronic Machine System Design and choose their problems within the themes for obtaining special knowledge. The themes have a more scientific research approach and will provide the necessary theories and knowledge for lecturing within the specific professional areas, and they will provide the methodological skills of problem analysis and applications for training as shown.

The fourth phase, the 9<sup>th</sup> and 10<sup>th</sup> semester is only for preparing a long master dissertation describing a project work dealing with a problem chosen by the students groups themselves. They can also choose to spend 9<sup>th</sup> semester on free studies, often abroad and then make a short 10<sup>th</sup> semester master dissertation thesis.

Phases	Semester	Theme	Courses
Final	10	Master Thesis	None or free choice.
	9	Technology development/ Master Thesis	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 of 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, 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 studies	1 +2	Engineering problems: Model and reality, Models reality	Mathematics, Physics, Computer Science, Technology and society etc.

Table 1. The specialisation in Industrial Technology offers a professional competence in solving complex manufacturing problems in connection with development, design, planning and shop floor control for implementing industrial manufacturing.

The project evaluation is a rather unique process. The students give the project evaluator the report at least two weeks before the project defence. This gives time for the students to prepare for their defence and the project evaluator time to thoroughly review the project. The defence starts with each team member preparing a part of the oral presentation, which takes a total of one hour. After the oral evaluation, the project evaluator gives the project an overall grade while the students take a break. The evaluator goes over the report and the project course materials and asks the students individual questions, and depending upon their responses will raise or lower their grade from the overall project grade. This questioning takes at least two hours and often three to five hours before the evaluator makes his final decision on the individual grades. The students take a break while the evaluator discusses his evaluations with the project advisor. The students come back and the evaluator tells the students their final grade and responds to any comments the students may have.

## University-Industry Interaction

The university-industry interactions have great potential for mutual benefits when keeping in mind that there are two different worlds; industrial enterprises and academia. The benefit of the problem-solving approach contributes to the identification of the core competence of the university and thereby raises new problems to solve. Most of the projects are carried out in groups of students, which allows for practising inter-personal communication skills. Unfortunately, resource constraints at our university often lead to relatively large groups of students.

The use of the problem-based learning approach especially in the engineering education suggests that co-operation with private as well as public enterprises should play an important role for strengthening the link between academia and the professional worlds. Over the years personal and industrial relations have led to a number of different modes of co-operation with mutual benefit which has been reflected in other areas of M.Sc., Ph.D. and research programmes.

Of course, the lecturing of theories, methods and techniques can best be done at the university. But when students are to learn academia and professional skills, all the cycles of Kolb's [6] and Cowan's [7] learning model have to be included. Following the four stages of the Kolb or Cowan learning circle, the engineering problem solution let the students to be involved in e.g.: 1) analysis and diagnosis of industrial issues, 2) development/design of solutions – holistic as well as detailed, 3) planning/implementation and control of solutions 4) a dynamic learning process for innovation, research, methodology, tools and new knowledge, which naturally involves special attention to reflection and awareness of the potential possibilities and resources in connection with human, social and technical dimensions in a necessary interplay between crossover, development, decision and carry out processes.

### A great spectrum of interaction

As Larsen [5] writes:” The risk of a close co-operation between university and enterprises is that the studies and student groups can seem like free consultative partners and with short term solutions only. The risk 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 size 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 size enterprises have only little tradition of doing research work, if any at all. Even rather big enterprises are looking for solutions ready to cook, or at least solutions developed from already existing results of basic research.

That means, if a university is based on enterprise projects alone, the basic research together with the students’ training in fundamental scientific methods will come to starve.”

### Examples of interaction

- Several groups of students work in parallel on industrial, typical 5<sup>th</sup> semester projects
  - Very small enterprise: An inventor- an experienced yachtsman- has produced a lifeline but has not succeeded in turning it into a sales success. 22 groups reengineered the product. It turned out that the groups made 22 different projects in

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terms of both product and production improvement. Furthermore, the product was afterwards commercialised based on suggestions from some of the projects.

- A group of 4 – 7 students works on issues of an industrial enterprise, typical 6<sup>th</sup>, 7<sup>th</sup> and 8<sup>th</sup> semester projects. Cases from the specialisation Industrial Technology:
  - Co-operation with a larger enterprise on 6<sup>th</sup> semester. The starting point is a manufacturing and quality point of view in connection with two automated TIG welding processes was carried out in the laboratory with the 14 critical parameters on which a profound theoretical examination was afterwards based. An advanced mathematical model was developed together with development and programming of a neural network.
  - Co-operation with a small enterprise on 7<sup>th</sup> semester: After profound analyses of the company's order and manufacturing chain the group choose to design a data collection system accounting for illustration of and visualisation of machine data. The physical system was specified, designed and implemented. A data collection program was elaborated in HP VEE to visualise the real time status and possibilities of control for the actual production with the purpose to increase the quality, productivity and efficiency. With the use of JAVA a data treatment program was developed for visualisation and collecting of data from files. The program was developed in modules for more functions in a way so it could in the future be extended.
  - Co-operation with a small enterprise on 8<sup>th</sup> semester: A Danish manufacturer of yarn and net for the fishing industry wants with support of advanced numerical simulation to obtain a better comprehension of the physical characteristics of their products and manufacturing properties with special reference to strengthening position and competition. Throughout the project focus was on finite element modelling of trawl in conventional and in new advanced high strength materials. Likewise, there were focus on development and use of computer assisted simulation tools for design and manufacturing to obtain an efficient order treatment and assessment of proposal for development and designs.
- A master dissertation project (one to three students) can be a 9<sup>th</sup> semester preliminary project and a more focused project on 10<sup>th</sup> semester.
  - Co-operation with a small or medium enterprise on 9<sup>th</sup> semester and 10<sup>th</sup> semester. Integrated product development. The focus was on development, design and order treatment of systems (mechatronic) for palletising. The interim project (concept development) was carried out at Sydney University, Australia. The students also followed courses in electronics, programming and methods of optimisation. On the 10<sup>th</sup> semester the concepts undergo further development and the design process began together with the use and development of methods and computer added tools. Focus was furthermore on development and design of computer control systems, which could be adapted to the customers planning control systems for manufacturing.
- An industrial PhD. project engages in a broad development project in an industrial enterprise.
  - Project in co-operation with medium enterprise. How can industrial companies relate to, introduce and absorb new technology, with the objective to strengthen and improve the company's ability to innovate and thereby improve its business.
- A post graduated student following a part-time master program initiates a development process in his own company.

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- Research and development programmes.
  - Industrial case studies.
  - Medium/Larger enterprise. Going program: Centre for Industrial Production. Mission: Through basic and applied research to develop new knowledge and innovative solutions of value for Danish Industry [8].
  - National co-operation among universities and industries
  - EU co-operation among universities and industries from different countries
  - --

### **Experience and implications**

The curriculum in Engineering as well as in the natural science is project-organised from the day the freshman arrives until graduation.

The projects on which the students work how different they may seem have some common characteristics with the professional world's projects [9]:

- they are complex – in the outline to take complicated systems connections and the interplay between people and technique into consideration,
- they are characterised by development – in the outline of finding new solutions and try new ways,
- they demand a interdisciplinary effort, where students and supervisors with different professional knowledge have to be involved in the solution of the project,
- they demand an interorganised effort from different departments and orders in the outline of resource contribution, acceptance etc.,
- they are subject to a multi-organised interest , i. e. that more departments, institutions, groups of employees take interest in the project and the solution,
- they have a considerable extent according to human resource, expenses and economic results,
- they are guided to a result of essential extent and importance – in the light of relations to a number of people who will be affected, and to the result's functionality (lifetime) and economic influence.

The above characteristics naturally involve special attention to reflection and awareness of the potential possibilities and resources in connection with human, social and technical dimensions in a necessary interplay between innovations, development, decision and executing processes.

The graduates achieve great experience in interdisciplinary teamwork and they will normally possess 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.

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 by 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 have been able to

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identify phenomena described at a higher level of abstraction that is commonly used. And they have been able to develop a radically new solution, partly because as newcomers they were unbiased and could 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 a 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 crucially; 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.

Ries [8] 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 pre-planned in advance. To 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 their 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, many times the teacher has to agree 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.

### **Summery and conclusions**

At Aalborg University very good experience is obtained by using the problem-orientated and project-organised study method in a project co-operation with enterprises. The concept contents some difficulties and some risks. They are, however, to be handled without attacking the academic independence.

By establishing good relations to the employment of graduates 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 engineering excellence of technology and the learning systems.

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

I am convinced that the project-based education model can contribute to stimulating and strengthening engineering excellence in the academia and professional world, but "one best way" will never be found because of cultural differences, Creese [3], Boer [10] and Hofstede [11].

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