

**AC 2007-1582: FROM CAPSTONE COURSES TO CORNERSTONE PROJECTS:  
TRANSFERRING EXPERIENCES FROM DESIGN ENGINEERING FINAL YEAR  
STUDENTS TO FIRST YEAR STUDENTS**

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# **From Capstone Courses to Cornerstone Projects: Transferring Experiences from Design Engineering Final Year Students to First Year Students**

## **Abstract**

At KTH, the Royal Institute of Technology in Stockholm, Sweden, large capstone courses have been the base of higher engineering programs in product development during the last 20 years. The capstone courses has since the establishment been expanded to cover the most part of the students' final year and also constitutes the main competitive mean of attracting new students to the area of engineering design.

This paper presents results from an attempt to introduce a similar concept into the students' first year of studies, in the form of cornerstone projects. The intention was to build on the extensive experience from the many capstone courses and projects, and to bridge the gap between the first year and the final year, with the purpose of giving a perspective and a broad overview of the entire curriculum and the following courses.

In conclusion, a number of mechanisms are presented for the exchange of experiences and knowledge between the students of the first and final years of studies. This has proved to be highly advantageous for especially the first year students to get a better understanding of the final years of their education and their future professional roles as design engineers.

## **Introduction**

In recent evaluations, students regard the capstone course as the most valuable course in their curriculum and their choice of specialization is often based on the reputation of the various capstone courses. This has been the case at KTH, the Royal Institute of Technology for quite some time, and with increased competition between specializations most departments have introduced capstone courses according to the internationally established setting where focus is on the utilization and application of knowledge and skills gained in previous courses and projects<sup>1</sup>.

Beginning in 2003, in an effort to adapt the engineering programs at KTH toward the Bologna process, based on a B.Sc. cycle followed by a M.Sc. cycle KTH chose to introduce the concept of cornerstone courses in a number of programs. These courses should give students "a perspective of the subject, the curriculum and of higher education in general"<sup>2, 3, 4</sup>.

Where the capstone projects attempt to utilize knowledge and skills from previous courses the cornerstone projects should build on knowledge and skills gained in courses taken in parallel together with prior education and life experience. And, where the capstone projects attract students to specializations, the cornerstone projects could attract students to the entire program.

## **The subject of Design Engineering in Sweden**

In recent years the concept of design has been introduced in an engineering context in Sweden in the form of new engineering programs such as the Design and product realization program. The aim of these new programs is primarily to make a move from more traditional analytical programs such as mechanical engineering towards the area of product development, however often within the sphere of mechanical engineering. Similar programs are offered at other technical universities in Sweden. Examples of programs in this sphere are “Innovation and product design”, Mälardalen University, “Industrial design engineering”, Chalmers University of technology, “Mechanical engineering and industrial design”, Lund Institute of Technology and “Product innovation” at Luleå University of Technology<sup>5, 6, 7, 8</sup>.

When the program of design and product realization was introduced at KTH the ambition was to further establish the area of “Design engineering”, to stress the difference with “Engineering design”, and thereby to also distance further from the established programs of mechanical engineering which sometimes were (often mistakenly) defined as engineering design programs.

Design engineering represents a multi-disciplinary subject that involves areas both in traditional academic subjects such as mechanical engineering and electrical engineering, as well as in areas traditionally defined as non-technical, subjects such as project management, communication and visualization. In a previous attempt to describe the introduction and establishment of the concept of design engineering in Sweden<sup>9, 6</sup>, the identity of design engineering is defined according to the concept of synergy; the purpose of design engineering can be seen as finding the synergy between form and function, between choice of materials and functionality and between choice of a mechanical solution and usability, ergonomics, attractiveness etc. The identity of design engineering therefore points toward the ability to make use of knowledge and skills in disparate subjects, as well as to combine this knowledge and skills into synergistic, or attractive, products.

## **The program of Design and product realization at KTH**

In this article, the focus is on one of the new programs introduced in 2003, Design and product realization (the DnP-program), a five year combination of a three year B.Sc. and a two year M.Sc. program. This program attracts approximately 100 students every year and the course studied has since then been performed with the total number of 400 students divided into a large number of teams and projects. During the first three years of the engineering program, extensive courses in design engineering are given, starting with the cornerstone courses with the purpose of giving a perspective of the program, the concept of design engineering and the future professional role as design engineer, and continuing with the aim of teaching design engineering in a setting characterized by project-organizations, cross-discipline and student motivation.

Figure 1 shows the structure of the DnP-program, which in essence follows all engineering programs in Sweden as well as the European two cycle programs according to the Bologna declaration. As shown in the figure, two cornerstone courses constitute a part of the first year, in total 30% of the curriculum of the first year. The capstone course in the fifth year typically constitutes between 30% and 50% of the curriculum of the fifth year varying with the different elective specializations.

The basic idea of the cornerstone courses is to create a bridge between starting and finishing university. The students of the cornerstone and the capstone courses are therefore also integrated; the cornerstone students share facilities with the capstone students who also provide guidance and supervision. While the capstone students however spend the majority of their time during the final year on the course and project, the cornerstone students also focus on courses in mathematics, physics etc, and spend approximately two days per week on the cornerstone courses. In both courses, approximately half of this time is spent on the cornerstone projects. The cornerstone courses have been described in detail in previous publications<sup>10, 2</sup>. Typical capstone projects have also been described previously<sup>11, 1</sup>.

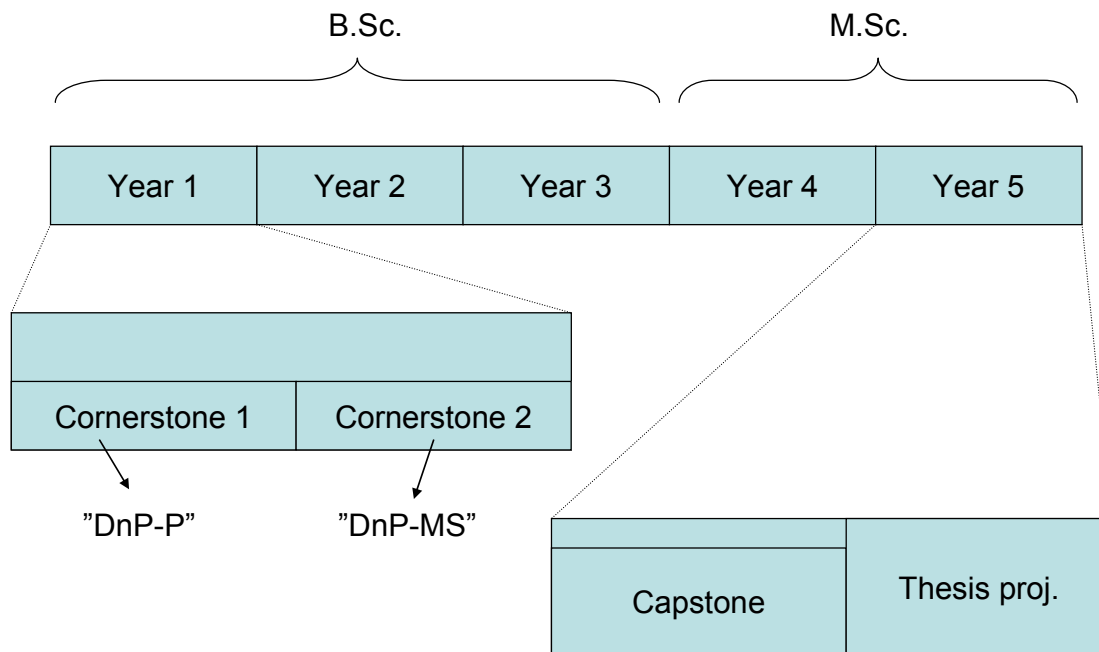


Figure 1. The structure of the DnP curriculum.

### The cornerstone courses

The cornerstone courses are divided into two courses each covering one semester. The first, Perspective on design and product realization (DnP-P) aims at introducing the subject and giving the students a broad perspective of the subject and the program. The second, Design and product realization, modeling and simulation (DnP-MS) aims at introducing more advanced methods in mainly product realization by use of tools for modeling and simulation.

The structure of the first cornerstone course, DnP-P, consists of the following five elements:

1. Sketching and visual thinking: The course begins with an intensive module involving drawing from live nude models, study of anatomy, rapid sketching, portrait work, and sculpting in Styrofoam, plaster, etc.

2. Analysis project: In the analysis project, the students are divided into teams of three. Each team is assigned a company and a product or system to analyze. Each team undertakes an intensive study of their product/system and visits the assigned company to analyze its design process. This project takes one month to complete.
3. CAD: Students are introduced to computer-aided design using Solid Edge, with which the students practice 3D modeling, assembly, animation, and rendering.
4. Matlab: An introduction to Matlab is a required component of all introductory courses within the same school.
5. Cornerstone project 1: This creative project constitutes half of the course and the other modules in the introductory course are seen as supporting this project, which takes two months to complete.

The second cornerstone course, DnP-MS, is structured according to the following:

1. Modeling and simulation theory: Approximately one sixth of the course introduces methods and tools for analysis of mechanical structures, balance equations, mechanisms, motors and gearboxes etc, all with the purpose of enabling the students to create own products using these tools and elements.
2. Modeling and simulation exercises: Approximately one sixth of the course is spent by the students performing smaller exercises dimensioning gearboxes, calculating stresses in existing structures, choosing materials etc.
3. Design methodology: Approximately one sixth of the course focuses on the use of a design methodology in design and product realization.
4. Cornerstone project 2: The project constitutes half the course and takes two months to complete.

Both cornerstone projects are characterized by open ended industrially oriented projects. The students are working in large teams, in the first project with up to seven or eight students, with a formalized team management organization with student responsibility, and in the second project with three students. The faculty provides supervision and guidance, coordinates between teams and projects and provides resources. Of high importance is the focus on social skills, teamwork- and team management skills which in itself can be seen as a preparation for future courses and projects.

### **The cornerstone projects**

The purpose of the cornerstone projects is to introduce the students to their future professional role as design engineers. The project spans two months, corresponding to 15% of the entire curriculum during the first semester. The primary aim is to teach design methodology and to enable the students to practice and improve teamwork skills. The total number of 100 students are divided into three classes, which are each divided into teams. Each class is assigned one faculty member. In the first project the students are assigned individual roles such as project leader, student responsible for external contacts, student responsible for documentation, etc. Each team is assigned the task of designing an innovative product that satisfied a particular need specified by the faculty. The projects are divided into three main phases:

Phase 1 – Kick-off, information gathering and brainstorming: The first project is introduced to the students with a 36-hour kick-off activity. Each class travels by bus to the town of Falun 225 km away. There the students visit industries and forms project teams. Each team is assigned a project and team-building activities are conducted. During the rest of this phase, the students perform brainstorming activities, information searches, background studies, etc. The team spaces are also organized, with each team being assigned a workplace in one of four labs. In the second project the students also perform industrial visits and interviews.

Phase 2 – Concept and detailed design: During the second phase, the students work simultaneously on up to three different concepts, each derived from the brainstorming sessions. Each concept is designed in detail, taking into account both shape and functionality. At the end of this phase, the three concepts are presented in the form of sketches, drawings, Styrofoam models, and functional prototypes in wood, metal, paper, and the like. Each team presents three concepts to the other teams and the faculty member, who assists in the selection of one final concept.

Phase 3 – Final design, documentation, and presentation: In the third phase, the students simultaneously produce the final design of the chosen concept, create a functional prototype, models the solution in a 3D-CAD tool and creates detailed drawings, specifies the manufacturing process, and prepares the final presentation in the form of a written report, a presentation, a poster, and a display to be placed in an exhibition hall.

Each individual student is at some point responsible for the team or for a sub-team. All responsibilities are assigned by the faculty member.

### **Typical cornerstone projects**

In the first project, the teams of six to seven students are assigned one project each from the faculty. The projects are specified as a problem, a need or an area where improvement is possible. Examples are: ergonomic bicycle holders for cars, solutions for compact living, portable washing machines and sleeping aides for bus seats. The students typically design a new product and present a prototype together with documentation. In the second project all teams of three students are given one area for product development where the students define their own problem, product or idea. Typical areas are: water management in third world countries and aides for heavy labor in the health sector. Typical projects, as conceived by the student teams, are equipment for the changing of sheets in hospital beds, aids for getting in and out of wheelchairs etc.

More detailed examples of cornerstone projects are shown in Figure 2 and Figure 3. In the first picture, a CAD drawing of an innovative closet is shown. This closet was developed in course DnP-P by a team of six students. The students were assigned to the theme “Compact Living”. Besides a CAD model a smaller scale closet were manufactured and all functions were demonstrated. Figure 3 shows an automatic dishwasher developed in the same course, by another six students. This team was assigned with the task of designing an automated system for the washing of dishes in smaller homes, typically student housings, without space for regular

dishwashers. In both figures, CAD drawings are showed for clarity, but it's important to note that functional prototypes also were manufactured in all cases.

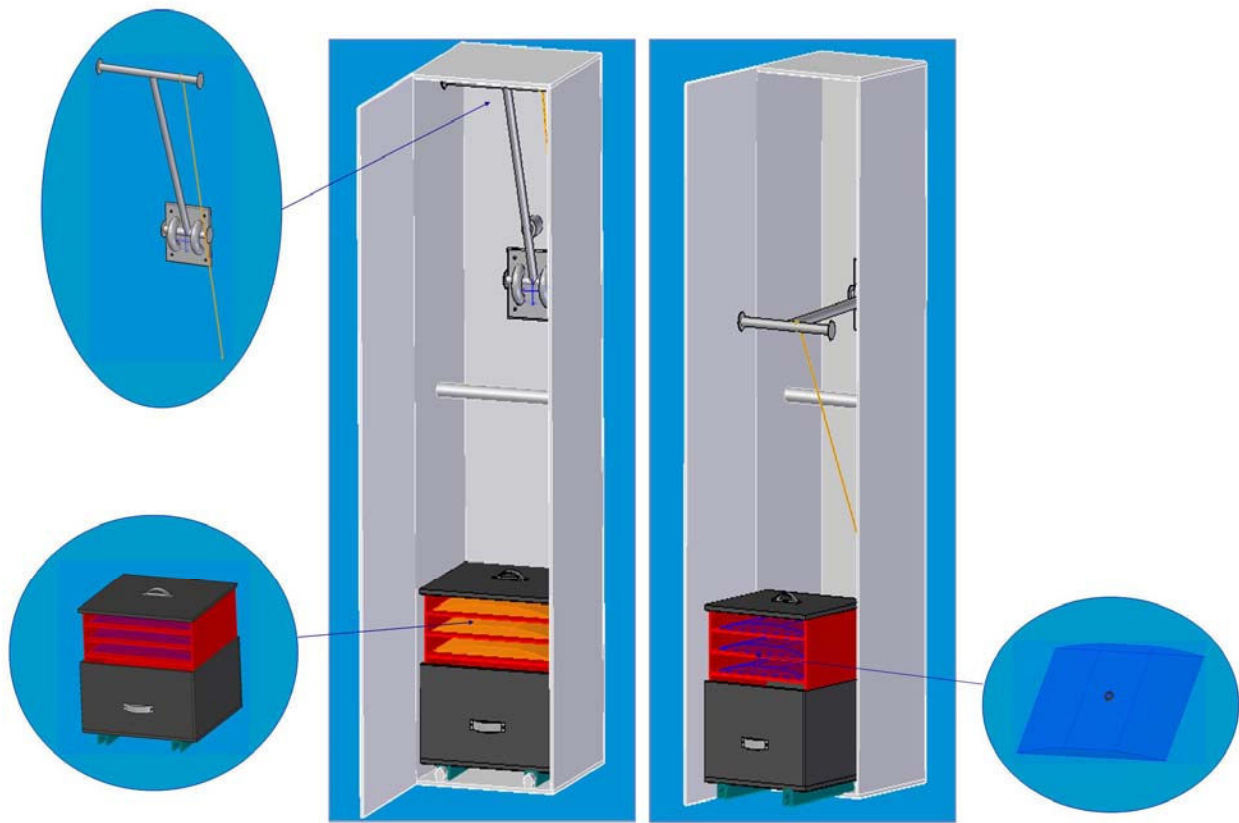


Figure 2. A closet developed as a cornerstone project. The closet is designed for apartments with exceptionally high ceilings and is equipped with an automatic lowering mechanism for the upper clothes rack. The dark grey box contains a vacuum system for compacting seasonal clothes, i.e. winter clothes during the Swedish summer.



Figure 3. An automatic dishwasher for use in regular sinks. The pipe is manually connected to the tap and draws energy from the water pressure in the existing water pipes.

### **The capstone courses and projects**

Students of the DnP-program choose one of fifteen different specializations, among which four are program characteristic specializations and eleven are specializations originally developed for other programs. These characteristic specializations are:

1. Industrial design
2. Integrated product development
3. Mechatronics
4. Machine Design

The specializations attract between 20 and 50 students each, including students from other programs. The four specializations vary in length and scope, but all share a common denominator in that all are based on a large capstone project. This project typically spans at least one semester and are done in unison with an industrial sponsor. Typical projects are organized, performed and managed by students and supervised by the faculty. Typically, one project equals one student team, which consists of between six and fifteen students. Every team has different industrial sponsors. Usually every specialization is responsible for between two and five projects that are divided according to technological focus. The organization and educational structure vary according to project, specialization and industrial sponsor. As an example a typical project within the specialization of Mechatronics is described further:

This project is divided into four phases; phase one to phase four. Each phase ends with a presentation where the results are presented in the form of a written report and in the form of a seminar for all people related to the project. In the end of the final phase a prototype is typically delivered to the industrial sponsor.

**Phase One – Defining the problem and conceiving the product:** In this first phase, the faculty focuses on teambuilding and conceptual understanding of the projects. The students are divided into sub-teams with different responsibilities and tasks. Examples of these are:

1. Project management and organization.
2. Problem formulation and product definition.
3. Pre-study. Defining needs of competence etc.
4. Resources and facilities. Workshop, economy etc.

**Phase Two – Designing the product:** This next phase focuses on the design of the project. In the end of phase one the product is defined, and the project where this product will be designed and implemented is established. Based on the results of this definition new sub-teams are formed. In this phase typically a matrix-like organization is used where each student is given a particular responsibility of either product related or project related areas.

**Phase Three – Implementing the product:** This third phase focuses on the implementation of the product. As in earlier phases the team is divided into new sub-teams, and each student is given a particular responsibility.

**Phase Four – Operating the product:** The last phase is a brief period of time where basically the product, or prototype, is delivered to the corporate sponsor. During this phase all material is gathered and condensed into deliverable documentation.

### **Typical capstone projects**

A typical capstone project can consist of up to the equivalent of five man-years of product development time and most projects are developed quite far in terms of knowledge, skills and technology. A typical mechatronics capstone project integrates technologies such as microcontrollers and distributed control systems, advanced control algorithms as well as mechanics and electronics. Products such as robots and autonomous systems are common. More specific examples are the development of an autonomous lawn mower, a balance prosthesis for use in research of the human balance and an active mechatronic knee prosthesis.

Two examples are shown in Figure 4 and Figure 5. In the first figure, the overall structure of the balance prosthesis is shown. The balance prosthesis consists of a network of sensors for measuring tilt and sway in the vicinity of center of mass on a human body when walking or running together with sensors for measuring the center of pressure underneath the feet. The sensor network is processed in a number of microprocessors which controls around 80 vibrators placed on the upper torso and used to provide feedback to the user. The entire system is wirelessly monitored and supported by researchers and technicians<sup>12</sup>. In Figure 5 an early design of a system for controlling adaptive airbags is shown. In this case, a number of arrays of radio

receivers are mounted in the seats and detects waves from a central transmitter, or rather the energy that is dissipated by a human placed in a seat. Algorithms detect the size of the person sitting in the seat and adapt the airbags functionality accordingly. Even if concept sketches are shown, functional prototypes are manufactured in all cases.

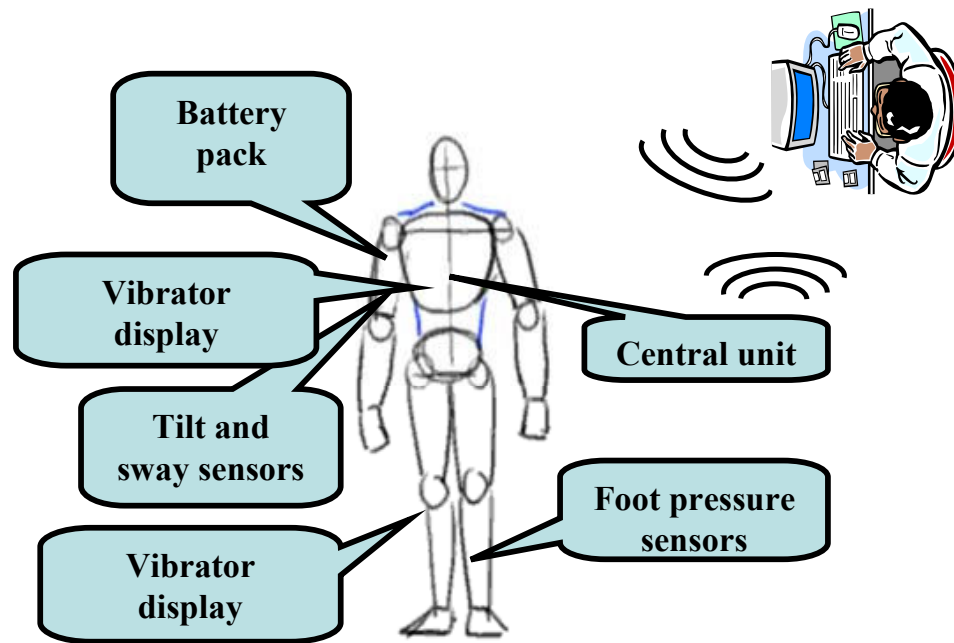


Figure 4. A system view of the balance prosthesis as developed in a capstone project.



Figure 5. An illustration of the adaptive airbag system as developed in the capstone project.

### **Integration between cornerstone and capstone projects**

Both cornerstone courses/projects and capstone courses/projects are common in higher engineering education. The uniqueness of the courses and projects described in this article is the synergy between the cornerstone course and the capstone course. This synergy is based on the following combinations:

First, the two courses are given by the same department, which is uncommon. Four years of studies separates the two courses but since the department recently has been given the responsibility of the full program, the DnP-program, this is possible. Some faculty members are engaged in both courses which also provide continuity. Secondly, the two courses share facilities. The facilities consist of 25 office space modules in varying sizes, suitable for between five and fifteen students. Typically each capstone project is assigned one module and a number of cornerstone projects share one module. The modules are assigned randomly which means that the cornerstone projects are mixed with the capstone projects. All student teams also share social spaces, meeting rooms, coffee spaces etc. Thirdly, students of the capstone courses are engaged as coaches for the cornerstone projects and thereby feeding back their own experiences.

The basic idea with this setup is to create unofficial and spontaneous meeting places between cornerstone and capstone students. The intention is therefore to create awareness with the first year students of the capstone projects, thereby creating an awareness of the specializations, the

projects and also the subjects taught to the final year students. The setup provides a bridge between the first and final year of studies which often is difficult to achieve otherwise.

## Conclusions

Capstone courses and projects have been given at KTH during the last 20 years and proved to be highly successful and appreciated by both the students and the hiring industry. In an attempt to overcome the difficulties for first year students to grasp the scope of their education and their future professional role the experiences from the capstone courses have been transformed into new cornerstone courses and projects. To draw further advantages of these courses a setup is created where synergy between the capstone and cornerstone courses are utilized. It might be as simple as having students share a coffee machine, but also by having capstone students coaching and mentoring cornerstone students or having cornerstone projects as a subproject of a larger capstone project. All these mechanisms creates an exchange of experiences and knowledge between the junior and the more senior students which has proved advantageous for the junior students to better understand their future professional roles.

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