SHARING EXPERIENCE IN DESIGN EDUCATION BASED ON RESEARCH AND INDUSTRIAL PRACTICE

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ABSTRACT
We present and share our experience obtained through education in a degree-level course on system design engineering of technical products, in which we successfully integrate engineering design research, education and industrial practice. We focus on and share the experience with the key instruments of this concept, which are education design projects for industry solved by cross-disciplinary student teams. We have identified and present nine key factors that help our students and ourselves to achieve valuable and repeatedly validated long-term results of these projects.

Keywords: Design education, project-based, cross-disciplinary, teamwork, industry collaboration

1 INTRODUCTION
University education faces great challenges in today's world. Universities must educate future professionals, including engineering professionals, who will have to deal with the complexity of all aspects of engineering in the following decades. However, who knows what technical products will be designed in "2050" for instance, and what the conditions of engineering design projects in this future will be? What knowledge, skills and personal characteristics should engineering designers and others possess?
Jean Piaget (*1896 ✝1980), a Swiss developmental psychologist well known for his epistemological studies with children and author of the theory of cognitive development says: *"Our real problem is – what is the goal of education? Are we forming children who are only capable of learning what is already known? Or should we try to develop creative and innovative minds, capable of discovery from the preschool age on, throughout life?"* [1]
Don Norman (*1935), an academic from Northwestern University, the author of many design books and well known speaker on design, in one of his comments on the state of today's engineering design education says: *"The problem with engineering is that it is narrow and deep, because more and more engineering is the specialty. Whichever branch (civil, mechanical, electrical, computer science, etc.) you learn, you have to learn more and more because we are going to end up being specialists. … But in order to apply the knowledge, we do not need narrow and deep, we need a broad kind of education which spans many disciplines so all the narrow and deep is also broad. That is what the designer brings. It is the system approach. … We do not teach engineering, we teach specialty. What we need to do is get people involved in real problems, because real problems cut across disciplines and on the top of that, it is what engineering should all be about. … An engineer of the 21st century has to be a systems thinker."* [2]
These quotations support our beliefs and experience that besides teaching engineering design students deep and in some sense "comprehensive" knowledge (which is of course necessary) from special branches, it is extremely important to provide them with the system of knowledge that helps to integrate this knowledge in order to be applied effectively. It is most useful and very effective to provide students with generally true principles in optimal combination with their applications to real problems.
In this context, we share here our experience obtained through education in a degree-level course *System Design Engineering of Technical Products* (SDE), in which we successfully integrate three key realms of engineering design: (1) research, (2) education and (3) industrial practice. (Figure 1)
The course consists of lectures and tutorials. Lectures aim to provide students with a systematic interpretation of the generalised theoretical and methodical knowledge of Engineering Design Science (EDS) so it can be applied to effective design engineering of any technical product/system. In our lectures we mainly apply the concept [3] of Engineering Design Science knowledge based on the

Theory of Technical Systems (TTS) [4]. We have focused on the theory based concept of EDS knowledge and its applications (AEDS) since the nineties and we have also significantly contributed to its further development [5], [6] and introduced it into several applications, e.g. [7], [8]. It is also being continuously integrated into lectures and study materials so students always have access to the latest findings.

The tutorials involve training in application of design theory and methodology and they are focused on practical activities and consequent experience of the students. Within the scope of the tutorials, they are solving real design problems/projects in cross-disciplinary student teams, which compete with one another. All design problems which are completely new and are solved “from scratch” are assigned by industrial companies.

In this way, the *engineering design education* realm plays a significant role as an interface between the *engineering design research* and the *engineering design practice* realms. The general Engineering Design Science (EDS) knowledge from research is applied (AEDS) to education, and through education further to industrial practice, from which we gain valuable feedback to both previous domains.

In this paper we would like to focus on and share our experience with the above mentioned student design projects that are the key instrument of this concept (Figure 1). We have managed these projects for 7 years and among other things we have found these to be best practice in educating students for future industrial practice in later stages of university education.

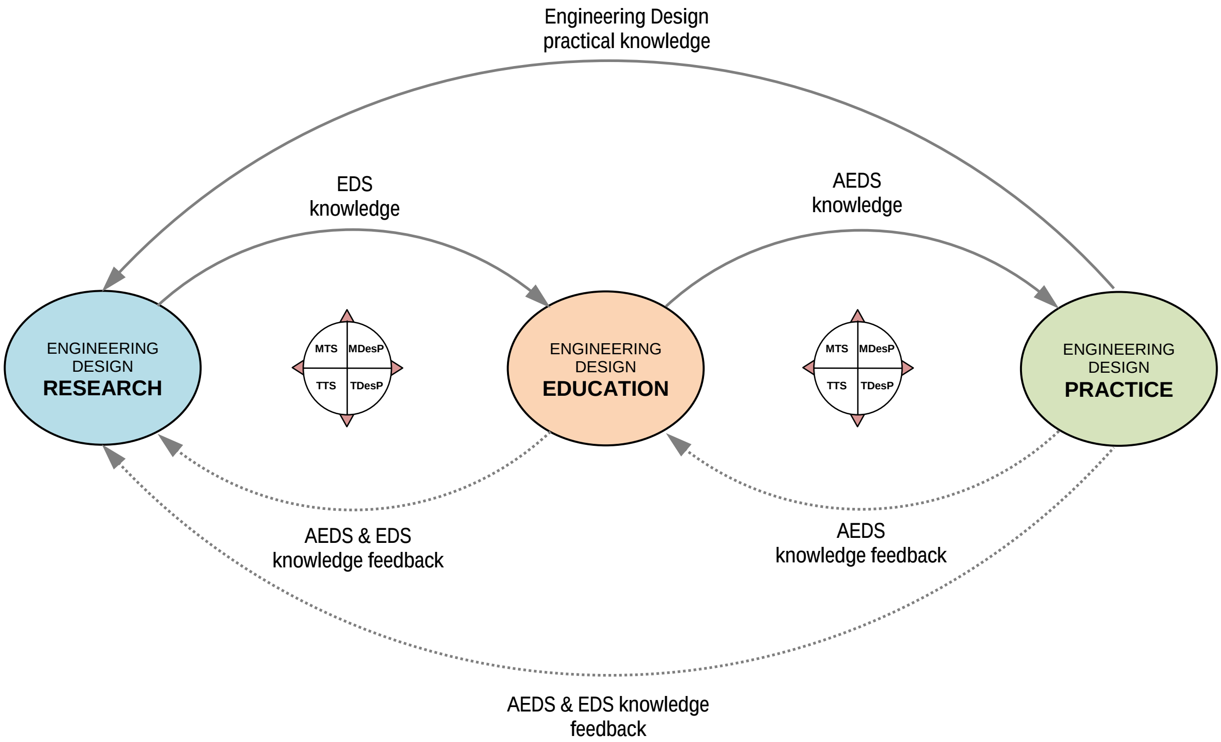

Figure. 1 Concept of Design Education based on research and industrial practice

2 ORGANISATIONAL FRAMEWORK

The course is mainly designed for the engineering design students at the Faculty of Mechanical Engineering (FME) and is obligatory for them, however we have broadened the scope of the course by involving industrial design students from the Institute of Art and Design (IAD) since 2006, and the physiotherapy & ergotherapy students from the Faculty of Heath Care Studies (FHCS) last year (Figure 2). The students from the IAD and the FHCS do not attend lectures, but they participate in design projects, which in this way become cross-disciplinary and cross-faculty. They take the special introductory lesson only, in which we provide them with organisational issues and the systematic theory-based methodological approach, which becomes the fundamental strategy for dealing with the assigned task. We would like to note that this cross-faculty cooperation within this course is not formally integrated into the study programmes of the particular faculties, which means that the students have different individual schedules and participate in the design projects within the framework of three different courses. Of course this brings many challenges, such as coordinating student teams and their meetings, because we have to reflect their schedules, but it is worth it. It still brings great multi-range outcomes that overcome all difficulties in organisation we have to deal with.

The course consists of thirteen lectures and thirteen tutorials and there is 1 lecture (2 teaching hours) and 1 tutorial (2 teaching hours) per week. The lectures are given by a senior university lecturer with industrial experience, whereas tutorials are provided by Ph.D. students with a minimum of industrial experience. There are usually about 60 engineering design students, 15 industrial design students and 40 physiotherapy & ergotherapy students participating in the course.

The engineering design students attend the course in the fourth year of their Master study, while industrial design and physiotherapy & ergotherapy students in the third year of Bachelor study. This implies that they all possess the fundamental specialist knowledge acquired during their previous study and are able to apply this in various cases. For example, engineering design students have engineering knowledge in the field of Machine elements, Mechanics, Material science, Mechatronics, CAD & CAM tools, Design for Manufacturing, etc. After graduation from the course, the students should also be able to:

- understand the essence of technical products/systems (TS)
- look upon TS in the context of their complete life cycle
- understand design engineering as a structured engineering design process
- systematically arrange and use knowledge of TS properties
- combine theory-based, instructive, intuitive and trial & error/success methods during design engineering of TS according to a specific design situation
- systematically analyse, compare and evaluate fulfilment of specified requirements and design competitiveness of the designed or existing TS with other comparable TS
- document and present results and the procedure of the design projects systematically
- work in interdisciplinary teams on integrated design projects and to utilize knowledge, tools and experts from other technical, natural, social and other supporting science and practice fields
- protect their own intellectual property

3 REFLECTIONS ON BEST PRACTICE AT OUR DEPARTMENT

We have identified the following nine key factors/attributes that help our students and ourselves to achieve very good results in the above mentioned education design projects. This is acknowledged not only by the students themselves but also by cooperating industrial partners and our university officials. These factors are presented in the following sub-sections.

3.1 Topics and Assigned Tasks

The selection of a topic for design projects in education has been found to be extremely important in our practice and it should be done carefully. On the one hand, a design problem should not be immensely difficult, as students with limited background knowledge and experience should be able to deal with the problem, but on the other hand it should not be too simple so it would not need much effort. We must achieve a proper balance between these two extremes and come up with a task that students find challenging. If we assign a task that students also find attractive, e.g. belonging to the students' area of interest, it is always beneficial. In both cases, students are more willing to undertake the task and they are much more drawn into the problem and carry out additional self study. Of course, there is a great variety of students with different and very often contradictory attitudes and preferences.

In 2004 we decided to involve an industrial partner for the first time. We approached GRAMMER, Tachov, CZ with a request to provide our students with a design problem that would fulfil the above qualities. Since that time we have acquired 17 design tasks (Table 1) from 13 industrial companies (Figure 2) from the Czech Republic and neighbouring countries. Since 2006 we have always provided students with 3 different topics from the range of master study programmes offered by our department:

- Engineering design of Manufacturing Machines and Equipment
- Engineering design of Transport Vehicles and Handling Machinery
- Engineering design of Medical Technology

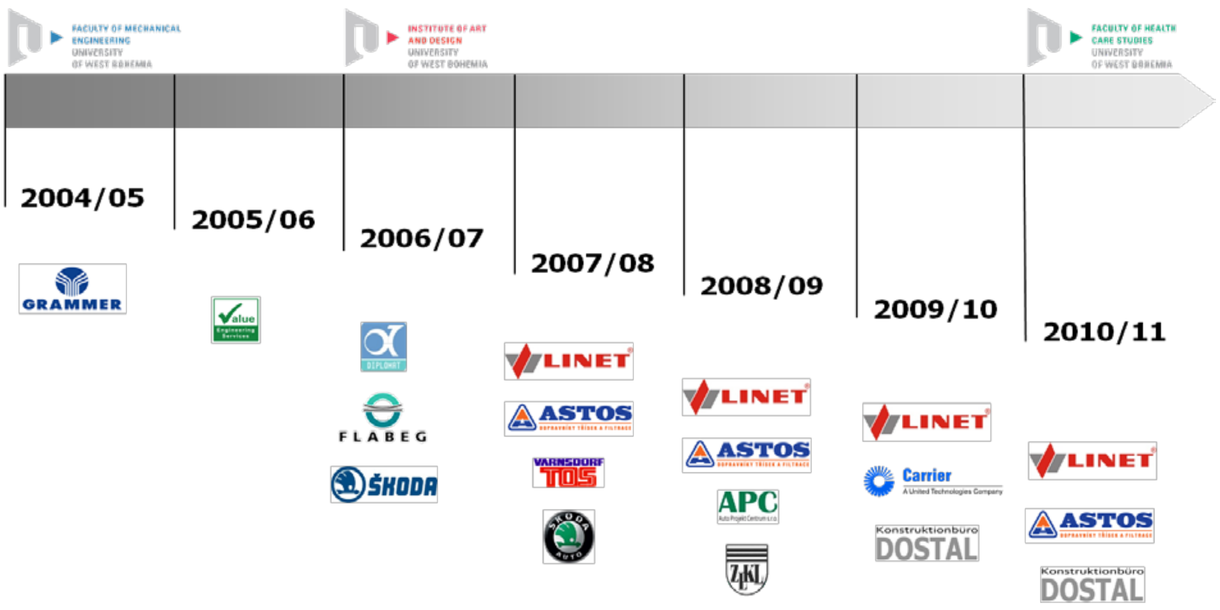

Figure 2. Industrial partners involved in design projects since 2004

Table 1. Summary of topics undertaken for industrial partners

Academic Year	**Topic and Industrial Partner**	**Number of Teams**
2004/2005	Front seat with an active headrest for private cars of a higher class - *GRAMMER, Tachov, CZ, Amberg, D*	16
2005/2006	Locks for a luggage space of private cars of a higher class - *VALUE ENGINEERING, Pilsen, CZ*	14
2006/2007	Dentist's workplace for the 3rd millennium - *CHIRANA DENTAL, Piestany, Slovakia*	6
	Assembly line for gluing hinges on mirror doors for bathroom cabinets - *FLABEG, Domazlice, CZ /D*	4
	Parking facilities for Coupe Vehicles in the project ComplexTrans - *SKODA Transportation, Pilsen, CZ*	3
2007/2008	Hospital bed for very seriously ill patients - *LINET, Slany, CZ*	4
	Covers for workspace of boring and milling machines TOS Vansdorf - *ASTOS, As, CZ; TOS Varnsdorf, CZ*	5
	Luggage space for estate cars - *SKODA Auto, Mlada Boleslav, CZ*	5
2008/2009	Hospital bed for children - *LINET, Slany, CZ*	4
	Semi-automatic robotic workplace for welding of chain chips conveyors - *ASTOS, As, CZ*	4
	Interior of a car for disabled people - *APC - Auto Project Centrum, Pilsen, CZ; ZLKL, Lostice, CZ*	2
2009/2010	Universal transport hospital bed - *LINET, Slany, CZ*	5
	Vehicle with electric drive for disabled and seniors with lower mobility - *Konstruktionsburo DOSTAL, Edstetten, D*	3
	Workplace for semi-automatic packing of refrigerator boxes - *CARRIER Refrigeration Operation CR, Myto, CZ*	3
	Frame and body for a racing car of formula SAE - *UWB, Faculty of Mechanical Engineering, Pilsen, CZ*	1
2010/2011	Hospital transport and rest chair - *LINET, Slany, CZ*	6
	Exterior of a lightweight vehicle with electric drive - *Konstruktionsbüro DOSTAL, Edstetten, D*	4
	Industrial washing machine for machine parts - *ASTOS, As, CZ*	4

3.2 Flexible, systematic, theory based methodological approach

Our research, supported by industrial and academic experience and the feedback gained during cooperation with industry, proves that the generally used approaches to design engineering, which are ‘Trial and Error/Success approach’, ‘Intuitive approach’ and ‘Instruction approach’ [9] are deficient in many aspects for current and future needs. We find that a theory (Theory of Technical Systems) based, integrated, problem solving approach, which we call multilevel Knowledge Integrated Designing (KID) [9], is a very powerful vehicle for treating design engineering and its management. It enables the most appropriate and ‘fully’ consistent use of all the mentioned problem solving approaches, because the theory based engineering design ‘map’ of knowledge spans/covers the other ‘lower’ hierarchical levels (Figure 3). The students manage and solve their projects on the theory based level, which enables them to ‘jump’ to other ‘lower’ levels at any time if efficient and effective, and again to ‘return’ back to follow the planned strategic path. However, Design Specification, Evaluation, and Documentation ought to be almost exclusively systematic. We have experienced and validated that when students are mastering the ‘KID’ concept it is naturally converted into ‘systematic heuristic’ engineering design thinking which can be called ‘Compound Integrated Designing (CID)’. We have also experienced that the ‘KID’ approach also helps to integrate the individual specialists within the cross-disciplinary teams very effectively. [10]

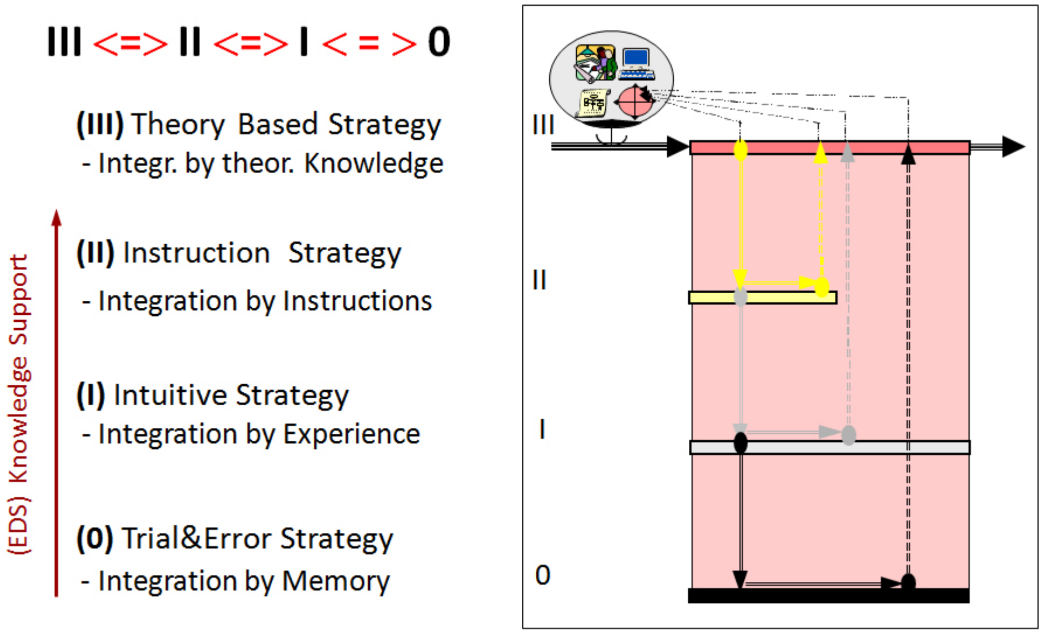

Figure 3. Knowledge Integrated Designing (KID)

3.3 Cross-disciplinary teamwork

Students work in several multiple “competing” teams consisting of engineering and industrial design students. The cooperation of engineering and industrial designers has a very specific feature - both these professions directly affect the constructional structure of a designed technical product. This means the structure, forms and dimensions, materials and means of production, state of surfaces and tolerances of all its elements (elemental design properties according to [4]). However, both these professions have completely opposite priorities when doing it. Engineering designers develop a designed product “from inside to outside”, or in other words “from functions to appearance”, while industrial designers do it in quite the opposite way “from outside inwards”, i.e. metaphorically “from appearance to functions”. The key problem is that this must be done simultaneously. We present a theory based methodology which can be applied to achieve efficient and effective cooperation between these two “competing” professions in [10]. Last year we involved physiotherapy & ergotherapy students as consultants in the teams. They provided the design part of the team with support in health care issues related to the designed products, e.g. they helped in specifying requirements on product properties related to suitability for human health and comfort and in evaluation of their fulfilment.

Each team consists of 3 to 5 engineering designers, 1 or 2 industrial designers and 2 to 4 physiotherapy & ergotherapy consultants. There is always one manager, elected by team members at the beginning of the project, who is responsible for overall team outcomes and for communication with lecturers and industrial partners, if necessary. This extra responsibility brings managers a special benefit in the form of a higher grade if they succeed in this position.

Students' experience in cross-disciplinary design teams (Figure 4) generally helps them to recognize their roles and responsibilities within a design process. Furthermore, it enables students to gain their own experience in cooperation and communication with different professions, which encourages their discussions and provides them with feedback of how they are able to assert their own ideas in a design team and how they are able to accept the thoughts and ideas of other team members and instructions of managers.

Figure 4. Cross-disciplinary teamwork needs effort but brings benefits

3.4 Monitoring and evaluation of students

We use five monitoring and evaluation methods and tools for student/team work assessment:

1. *Continuous monitoring* – during discussions and consultations in tutorials.
2. *Check up tutorials* – there are two check up tutorials in the syllabus, during which we check the fulfilment of the assigned task according to the plan.
3. *Classification of teams* – on the basis of project documentation.
4. *Classification of individual students* – on the basis of a student's activity in tutorials and of the questionnaires. After everything has been done, each student fills in a questionnaire, in which he/she evaluates the contribution of all team members to the overall team's outcomes.
5. *Design contest* – see sub-section 3.6

3.5 Consultations, Excursions and External Lectures

Consultations and excursions are very good tools that help students to better understand the tasks assigned to them. We organise half day group excursions to the industrial partners, where the students have the opportunity to discuss their problems with representatives from various departments, for example R&D, marketing, production, etc. Representatives of industrial partners also visit students and discuss the assigned topics at our university. For example, the representatives of SKODA visited us in 2007 and presented 2 current concepts of luggage space in a hall laboratory at the FME (Figure 5).

We also ask the industrial and institutional partners to give our students external lectures on selected up-to-date topics and they have so far provided our students with the following lecturers:

- *Creativity and Ideation in Engineering and Industrial Design* - Steve Stott, education program manager, Autodesk, UK
- *Project Management"* - Ing. Vladimir Jurka, technical director, Linet, CZ
- *R&D and Innovations in Linet* - Ing. Jiri Kral, head of R&D, Linet, CZ
- *State of the Art in Electric cars* - Ing. Vilem Dostal, Konstruktionsburo DOSTAL, D
- *Management – fundamentals for engineering designers* - Dr.-Ing. Petr Hobl, MBA, executive manager, Schwarzmüller, CZ

Figure 5. Excursions and consultations with industrial partners
(left – SKODA, right – LINET)

3.6 Competitive atmosphere, acknowledgement of the best teams

There have been a lot of discussions on the competitive vs. collaborative atmosphere in class, their positive and negative effects on students, etc., within the education research community and we do not aim to criticize or defend any particular idea.

Our students solve their design projects in cross-disciplinary student teams, which compete against one another in a design contest announced at the beginning of the course, but at the same time they are working in a collaborative environment within their teams. We have found this combination to be optimal. The competitive atmosphere pushes students to do their best and stimulates a 'never-give-up' attitude, while the collaborative environment provides students with feedback on their socio-emotional qualities and stimulates their development.

The design contest for each topic is at the end of the course when students present their results to the committee consisting of representatives from the particular industrial partner, Department of Machine Design and Institute of Art and Design. Members of the best teams are awarded diplomas and a financial reward provided by industrial partners. Each solution is evaluated according to the following set of evaluation criteria:

- applicability in practice,
- quality of engineering design,
- quality of industrial design,
- level of system approach,
- quality of presentation.

Figure 6. Pictures from design contest presentation (left) and the winning design team (right)

3.7 Student-Teacher relationship and Classroom climate

The teacher's attitude and teaching methods are very important and have to be considered in any education course. They should be well adapted to the specialised knowledge of the students, their skills, abilities, attitude, etc. A teacher is someone who significantly determines a student-teacher relationship and a classroom climate, which is important to consider in education.

As mentioned above, the lectures in our course are given by a senior lecturer, whereas tutorials are provided by Ph.D. students. The lecturer acts as an authority and expert in his field, while the Ph.D. students are more like coaches and have a more friendly relationship with students, which is of course affected by the smaller generation gap between them. It has a very good influence on classroom climate, which becomes more relaxed and creative.
Teaching methods should be adapted to the goal to be met at the end of the course. The cultural backgrounds of the students and many other influencing factors also have to be considered. For the course tutorials, we have chosen the following teaching methods as the most appropriate:

- tutorials with discussions and practical applications
- cooperative teaching
- study via problem solving
- student teamwork and self study
- presentation of student work

3.8 Feedback

Any activity which is to be done/managed effectively needs feedback information. Design education is no exception. We identified two kinds of feedback in our practice.
First, the feedback we collect from our students during discussions or via a questionnaire. All students are asked to fill in a short questionnaire about the quality of the course. The eight issues related to lectures and tutorials are judged on a scale of 0 to 6. The students are also encouraged to add their verbal comments to particular issues. We especially encourage them to give us negative feedback with constructive proposals for further improvements. These comments are the most valuable feedback we get. Therefore we should be open to getting negative feedback and reflect on it carefully, because it pushes our boundaries forward.
Here are three examples of anonymous positive feedback on the course:
(1)“The relationship between this course and industrial companies is unique and it was very much beneficial and motivating for me.”
(2) “Thanks to this course, we have acquired a whole range of experience that we would not have acquired except in industrial practice. Teamwork plays a key role in this course. We found out that it is not always easy to agree on a particular subject and to present your own ideas to other team members in way that is clear and easy to understand. The cooperation with industrial design students and alignment of functionality with appearance was a new and very interesting and beneficial experience. This course has opened our eyes and we have realised that design engineering is not a simple activity, but it is very tough and time consuming process, which involves a whole range of difficulties.”
(3)“The course has been very interesting. The project was a peep into real industrial practice. If you only study engineering design theoretically, you never realise what design engineering is all about. Thanks to this course I found this out.”
The students are asked to fill in the questionnaire after completing the course so their either positive or negative assessment could not affect their classification in the course.
Second, casual feedback is provided by the participating industrial and cooperating partners, mostly in the form of acknowledgements. For example, we can cite from an acknowledgement sent by the director of FLABEG, Thomas Frey, its consultant Peter Blohman and Director for Production Jan Sleis to the Dean of Faculty of Mechanical Engineering in January 2007:
“We were very much surprised by the high quality of the solved students’ projects. We can appreciate that the Department of Machine Design leads its students to a much needed broader view of technical tasks. We would like to express our admiration and thanks to those who participated on these projects“.
Stephen Stott, Education Program Manager from the Autodesk, addressed his acknowledgement to the Dean of the Faculty of Mechanical Engineering after visiting the exhibition Design^2 in May 2007:
“I am immensely impressed with this initiative to align the functional aspects of the engineering curriculum with the aesthetic elements of the product design course. … I was able to visit an exhibition of some of the students’ work and found that it is equal to any examples I have seen in premier universities throughout Europe”. University of Cambridge, University of Bristol, University of Strathclyde , University of Wales in Cardiff, Ecole Normale Superieure Paris, Technical University in Munich, etc. were mentioned in the letter.

3.9 Motivation

Motivation is a key issue for successful teaching. The opportunity to solve real design problems, cooperation with industry, cross-faculty cooperation, the design contest and presentation of results to top management representatives of industrial partners, are all very strong motivators which affect most students. In order to further increase the students' motivation we also cooperate with local television, local and national newspapers and technical magazines to increase publicity for these projects, the faculties involved and the university. The results of the projects are presented annually in a university exhibition called Design^2 held in the "Over the Stairs" gallery on the university's Bory campus.

4 EXAMPLES OF STUDENTS' RESULTS

Figure 7. Examples of students' work from cross-disciplinary design projects

5 CONCLUSIONS

We shared our experience obtained through education in a degree-level course on system design engineering of technical systems and associated cross-disciplinary design projects, in which we successfully integrate engineering design research, education and industrial practice. We mainly focused on experience with the projects and we presented nine key factors that help our students and ourselves to achieve results (Figure 7) that are greatly appreciated by the teachers, participating industrial and research partners and our university officials. Several students' outcomes also resulted in utility and industrial models and initiated two significant R&D projects and one educational business project with our industrial and institutional partners.

We have managed these cross-disciplinary projects for 7 years and among other things we have found these to be the best practice in educating students for industrial practice. It has always been our main goal in design education to bring design students closer to industrial practice and provide them with experience which they will need in their future jobs. This is our best practice and we share it in order that you might be inspired and apply some parts of it to your own design education practice, if you find it useful.

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