MULTIDISCIPLINARY WORKSHOPS PREPARING FUTURE ENGINEERS FOR TECHNICAL INNOVATION

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Abstract
This paper focuses on a special field of the engineering profession, namely the breakthrough innovation in technical products and on the education process to prepare young people for this challenging task. Both in the practice of industry and in education, the prerequisite is an adequate technology base, which afterwards is expanded into wider knowledge, know-how and competences. This is symbolized by the T-shape: the vertical part of the T stands for the core technology(ies) and the horizontal bar indicates the later expansion, that can be achieved in hands-on industrial practice or in dedicated education programs. It also links the core technologies of different engineers in a multidisciplinary team.
The paper describes the importance of introducing well-supervised, multidisciplinary lectures, workshops and project weeks for engineering students and illustrates this by means of analysis of two educational approaches – both multi-disciplinary and multi-cultural, namely the development of a master curriculum "Technical Innovation" and the Intensive Program (IP): "A multidisciplinary approach to product innovation". Both programs focus on three main aspects, being essential for success, namely *knowledge transfer, workshop-based implementation on industrial innovation problems* and *guided consult from experienced supervisors.* The IP is an intensive project, acting as an indispensable basic program for engineering students, gaining the competence of 'working in a multidisciplinary and multi-cultural team'. Moreover, this IP is also a teaser for students, who are willing to enlarge the 'horizontal' skills and becoming a full T-shaped engineer through a master curriculum of "Technical innovation".

Keywords: Innovation – multidisciplinary – workshops – engineering students

Introduction

The nature of industrially produced products has changed dramatically in a relatively short period. The increasing global competition, the ever-rising customer requirements and expectations, and the changes in technology "state-of-the art" make the process of developing new technical products more and more differentiated and complex.
In industry - surely in the case of a matured technology based - the design and development of most products follow standard patterns. Procedures and clear responsibilities govern the consecutive steps and (should) safeguard the quality of a new designed product. For all specialists a scope of (CA-) tools and guidelines are available to optimally carry out their

reasonably well-defined tasks. Managers control this process on the inputs and outputs, assigning capacities and funding, by putting targets and setting priorities. Basically they can do that without detailed understanding of the involved – technical or otherwise – disciplines. If the development task is less specified, more complex or less predictable, many interdisciplinary decisions and trade-offs have to be made and unexpected opportunities must be recognized. In those situations a T-shaped manager (deeply knowledgeable in his/her own disciplines and with understanding of the other involved disciplines) is more effective than a pure "bottom-line" one. For the team members – engineers – in such a multidisciplinary project, it is beneficial to have some overlap in the knowledge and understanding of the disciplines (they must be somewhat T-shaped) and of course they should be familiar with project issues. Typically the projects have a phased character with dedicated teams for each phase (Figure 1).

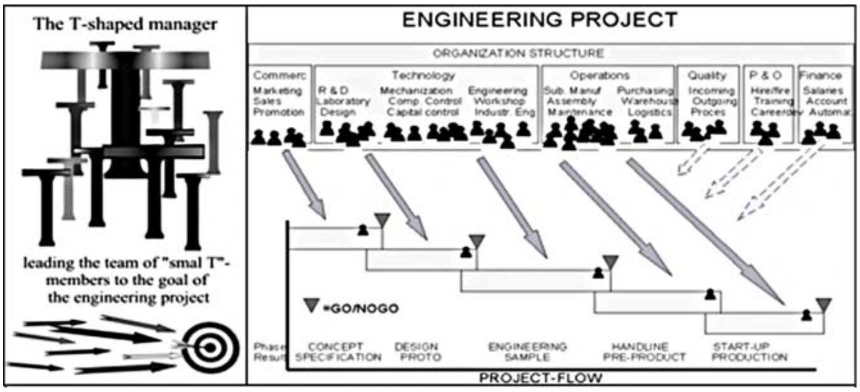

Figure 1. Phase character of “standard” engineering projects

Breakthrough innovation projects, with their high content of uncertainty and with all those open-ended questions, require a lot of idea-triggering exchange, problem-solving and plan and goal change decisions. Typically they will be organized in a more fluent way, in which representatives from all departments and disciplines once in a while are involved: to be consulted, informed and to create a first acceptance of the ideas (Figure 2). This is an environment of strong multi-disciplinary and multi-departmental teams and a very suitable growing soil for essential inventions: all the practical roadblocks trigger out-of-box thinking and spark-off clever break-through solutions that make a new concept finally feasible. Typically a successful innovative product is the result of a lot of technical and non-technical ideas and solutions at a final stage coming together harmoniously working new system. Trevor Baylis’ invention of the clockwork radio would never have been materialized without a score of hidden inventions of the development group that worked on it [1]. (So, who should get the glory?). It took Dyson many years and 100’s of practical creative experiments before his vacuum cleaner was there [2]. When studying the industrial innovation reality, one realizes quickly that it is a misunderstanding that creative thinking and clever experimenting is enough for success. It is essential for successful innovation that there is a solid technology base to be creative with.

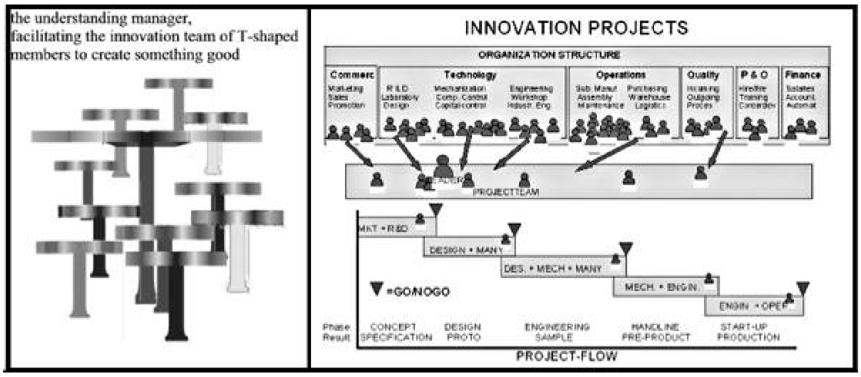

Figure 2. Organization of “breakthrough innovation” projects

Nowadays companies are eagerly looking for innovation managers, product development engineers or industrial design engineers who master a lot more than only technical engineering skills: knowledge of strategic thinking, team play, creativity, problem solving, design methodology, time and project management, market analysis, presentation techniques, ergonomics, intellectual property, innovation management, … are only a few of the necessary skills for engineers, being successful in technical innovation. Most of the successful innovation engineers learned their trade from intensive experience in the field and from dedicated courses, building this wider general knowledge and understanding on top of their specific technical knowledge. Such an engineer was introduced as a “T-shaped engineer” [3] and research, experience and experiments were described for the education of engineering students for a future job as technical innovator in multidisciplinary and active engineering education programs. This “T” is similar to the T-shaped manager [4], with the dual responsibility: contributing and sharing knowledge freely across the organization (horizontal part of the “T”) while remaining fiercely committed to individual business unit performance (the vertical part). For the engineer and manager in innovation projects, the focus is much more on the full integrated understanding of all aspects of the product-to-be, technical, business and human-related, thus enabling to recognize unexpected opportunities, dangers and consequences during the projects. In the T-engineer the vertical stands for the technical core disciplines, the horizontal for the later expansion to business and design skills. In terms of an individual’s skill-set, the vertical stroke comprises specialist skills and knowledge, while the horizontal stroke represents the generalist skills that enable the person to position their specialism in a way that it is useful and desirable for others. This is how T-shaped creativity is described by David Armano in the Marketing Profs blog [5]. In order to make the skills relevant, attractive and useful to others, it is necessary to understand the competences of all members of the multidisciplinary team. As a result, a very important criterion for the success of multidisciplinary workshops is the attitude of respect and appreciation for the way of thinking of team members of other disciplines. Both education programs, intensive program IP and master curriculum of ‘Technical Innovation’ are explained in detail and at the end of the paper conclusions and suggestions are formulated for further discussion in a roundtable session.

Intensive Program (IP): A multidisciplinary approach to product innovation

Concept

European engineering studies are characterized by a high degree of specialization. As a result, different disciplines arise in higher educated students. On the other hand, future engineers will be confronted with product/process innovation. In order to keep innovation in Europe, innovation skills must be taught to our engineering students. This IP project, organized by University College of West-Flanders (HOWEST dept. PIH, Kortrijk, Belgium) aims at developing skills for product innovation through a multidisciplinary approach. Bringing different disciplines and cultures together around an industrial problem case, will result in much more innovative solutions.

The IP brings together engineering students of different countries (Belgium, Spain, Portugal, Italy, Turkey, The Netherlands, Estonia and Finland) and of several disciplines (electronic – mechanic – informatics ICT – human technology – industrial design – product design) and different cultures (south versus north). Through morning seminars about innovation and project management, methodology and product development, communication and presentation techniques, user centered design, intellectual property rights, … the students develop skills for product innovation. In the afternoon workshops, these techniques are implemented on industrial innovation cases (see Figure 3) by means of a multicultural and multidisciplinary team. All professors of the different partners are seated in a multidisciplinary consult board, coaching the students. On several moments feedback is given by the industrial partners.

2007		2008	
Project	Company (B)	Project	Company (B)
Innovative interior solutions for a new high speed/intercity train type (single deck)	BOMBARDIER	Outdoor comfort multifunctional	UMBROSA
Automatic tool change on a press brake	LVD	Idea generation and conceptual workout of an innovative ecodesign product based on solar energy in	ILLUXYS
Innovative solutions for weight reduction of a harness frame	PICANOL	Conceptual design of a self-regulating natural window ventilator	DUCO
Housenumber illumination based on solar energy	ILLUXYS	Ambient Living	PHILIPS INNOVATIVE APPLICATIONS
Facilitate office work in 2012	BURODEP-GISPEN	How to make a nurse's life easier by 2015	TELEVIC
Cooling of electric control boxes in dusty environments	PSI-CONTROL MECHATRONICS	Metal foam applications	BEKAERT
Cable management for flat TV	PHILIPS INNOVATIVE APPLICATIONS	Transport bin for knitted and woven fabrics	DESLEECLAMA
Seamless transition with large plastics	PHILIPS INNOVATIVE APPLICATIONS	Smart pavillions	KORTRIJK EXPO
Development of an innovative and flexible mobile spotlight	CITY OF ROESELARE	Rethinking the functional bedframe	RECTICEL
City guidance signposts using LED	CITY OF KORTRIJK	Development of holder / lifter for portable far infrared dome	AMA WELNESS

Figure 3. List of industrial innovation problems, used during the IP in 2007 and 2008

None of the participating partners have had the opportunity before to set up such multicultural and multidisciplinary teams for a workshop, based on an industrial innovation case. This setup in combination with different lectures, aiming at broadening the horizontal skills, is very innovative. All partners agree that this is very complementary for each existing teaching program. Also the students learn different other skills through the workshop, which cannot be taught during standard education programs. Engineering students experience that design students use a complete different methodology of problem solving. Design and product development students stay much longer in the idea generation phase before getting into the concept development phase. On the contrary, engineering students want to ‘crack an engineering problem’ and go into detail as soon as possible. Those two methodologies often result in stress and friction in the team. Designers feel very comfortable in the initial project stage while engineers wake up at the detailed design and development phase. Translating of knowledge between those two profiles in a team, including language barriers, is an essential katalysator for success. New communication tools must be used such as sketching, mind mapping, mood boards, prototyping, … Dealing with such ‘everyday’ problems is also a very important attitude, which was experienced by the students! The participants of the IP were confronted with different attitudes towards innovation and were cultivated a genuine European approach to innovation. In the follow up program, a European communication network is built as e-innovation platform, in which students of different disciplines and cultures keep on working (distance learning) and improving their innovative solution. Due to the ECTS system, it was very easy for each partner to build this ‘module of 3 or 6 credits’ (without or with follow up) into their program. E.g. some institutions used this project as a replacement of the Bachelor project, before starting with the master program. After the IP project, 3 ECTS credits were awarded, after evaluation of product and process by a jury in combination with peer evaluation by the student team.

An internet site (http://innovation2007.howest.be for IP 2007 and http://innovation.howest.be for IP 2008) is developed which is an ideal tool to share information with the students and professors of all partners. In the e-innovation follow up period, each team keeps on communicating through a digital platform. All partners guided their students in their country and evaluated the final report at the end of the follow up.

IP Program based on a design methodology

The program of the IP is based on the design flow, presented in Figure 4. The design brief (product specification) is made by the company before the IP. Phase 4 (concept development) and 5 (system development) are the main focus during the IP. In these phases a methodology is used, consisting of 4 steps (inform – explore – decide – test), repeated in a loop. Different morning lectures illustrate and train different methods and techniques (function analysis and Methodical design of Kroonenberg, idea generation and brainstorming techniques, TRIZ methodology, decision and validation techniques, rapid prototyping, …), useful in the different steps of this methodology. Through guided consult from experienced supervisors, the different techniques are implemented on the innovation problem during the afternoon workshops. It is proved that ‘hands-on’ implementing of these techniques is the only way for successful learning. Very important for this is the IP-workshop flexible environment, consisting of space-dividers, brainstorming walls, wireless internet, 3D-printers, materialization and testing rooms.

After the IP, detailed design and pilot production is set up by the company. Also different patents were launched.

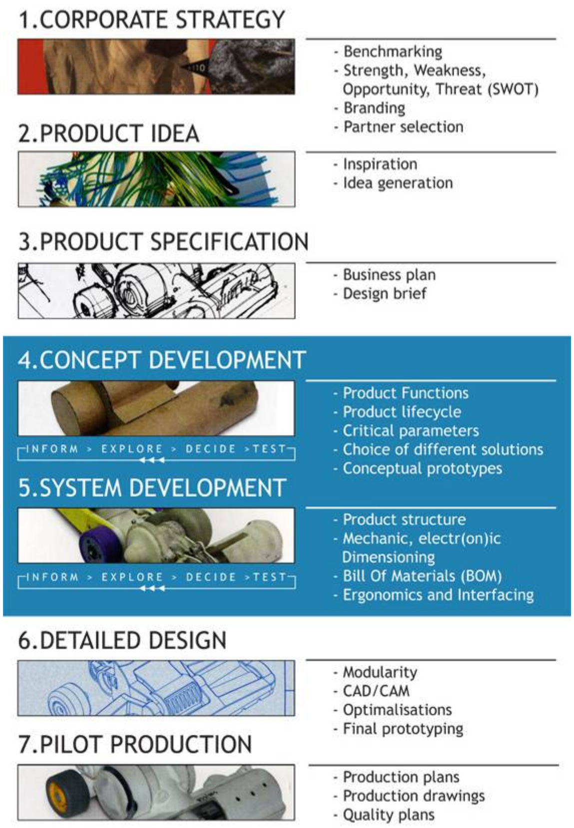

Figure 4. Design flow and different steps of the product development

Output of the IP

The main, however not tangible, output is the attitude and impulse to innovate together with a high respect for other cultures and disciplines! The increased innovation performances of these future engineers is not a direct output but will be of priceless value for the European economy.

In order to monitor if the above objective was reached, an evaluation form was filled in by students, professors and the industrial partners. It was stated very clearly by the students, all professors and the industrial partners that, through this multidisciplinary approach, a higher level of innovation in the result is achieved. All statements, formulated by the industrial partners, can be summarized as follows:

- More ideas are generated in a multidisciplinary team, often ideas out of the standard working environment.
- There is a higher commitment and more creative spirit in a multidisciplinary team.
- The multifunctional approach definitely brings on a broader variety of perspectives on problem-oriented solutions whereas the multidisciplinarity assures an overall approach on technical as well as on design-related level.
- Through the multidisciplinary approach, new combinations are made, new ideas arise, often not possible with the existing specialism in a company.
- There is a higher innovation potential through a multicultural approach, since different cultures think different e.g. on the use of energy

- The biggest added value lies in the speed to develop or the “Time to market” of a brand new idea. Ideas are better and they are qualified (dismissed or accepted) quicker. By putting all the different disciplines “around” the table, there is a win on two dimensions. First of all you are winning in the field of increased creativity caused by the interference of “points of view” of the students. The combination of different skills allows new insights and new approaches. This approach leads undisputedly to better ideas and better results. Secondly you are winning in the field of “speed” or time to market. Often you encounter a designer with a great idea, but when checking with an engineer, the idea proves to be “impossible to produce”. When putting all the people at the table at the same time, you are saving a lot of time, since you immediately get a clear idea of the viability of the product. Briefly said, the interdisciplinary approach has a lot of benefits. It is in fact the only way by which you can create substantial competitive advantage in product development.

This project has resulted in a new European network of Technical Universities who put innovation at the foreground. This pan-European network has triggered all kinds of international projects: from Erasmus student or Teacher mobility projects to joint program development. The University College of West-Flanders has also decided to implement the intensive program as a regular part of its study program (bachelor project). The main intangible spin-off is, as mentioned above, the spirit to approach innovation in a systematic multidisciplinary way. Moreover, the IP pulls attention towards the importance of incorporating “innovation management” in regular curricula for future engineers. It also stresses the importance of bringing together different cultures and disciplines, which is one of the major advantages in Europe and all its exchange programs.
Figure 5 shows a view of the workshop room with 20 teams, working on 10 innovation projects. This means that for each innovation project, 2 independent solutions are worked out. Figure 6 illustrates that different brainstorming and idea generation techniques (e.g. nine windows) are implemented.

Figure 5. The IP consists of 20 teams working on 10 innovation projects

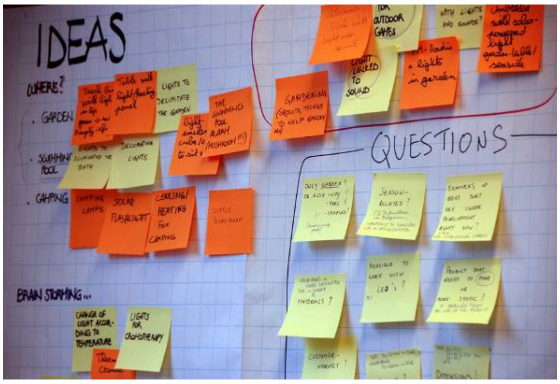

Figure 6. Different brainstorming techniques are used

As a conclusion, the main objective of this IP is reaching higher student innovation potential by working in a multicultural and multidisciplinary team. This program should also be a teaser for T-shape minded students for further developing the “horizontal” skills in an appropriate master program.

Master curriculum “Technical Innovation” aiming at a full T-shaped engineer

History of education in Engineering Design within the European Network

The network ICP-4042 on engineering design was founded in the 90’s and included European academic and industrial partners. It exchanged experiences and carried out the ODD-project: a hands-on research into effective practice of industrial innovation projects with the motto: “It Depends”. Results and implications included new insights and methods to prepare students for the complicated open-ended, result oriented task of technical innovation. These were to a great extend in line with partner Aalborg’s experience on project based, problem oriented learning and the experiments in Groningen’s IPDE-bachelor’s course (Industrial Product Design Engineering) in Groningen and in the workshops of the network. Conclusions were published in many publications [8,9,10,11]. The concept of the T-shaped engineer as a cornerstone of Technical Innovation was introduced in [1]. The education/development for such an engineer was characterized by the metaphor of the “tree”. For best results, establish first a good foundation of basic technical knowledge and skills (the roots), building up the specific engineering and science body of knowledge in an integrated way (the stem) and finally expand into all related disciplines – technical and non-technical as well as the relevant competences (branching out into the tree crown).

One of the main challenges designing a curriculum is arranging the subjects in such a way that the knowledge and competences build up in an effective, useful way. In conventional lecturing, the subjects have already a natural or accepted coherence within the disciplines. Modern combined technical disciplines (call it broadly I-shaped?), like mechatronics, are still looking for the right mix and order of subjects to teach towards integrated knowledge and wide emotional understanding. For T-design engineering this deep, integrated mastering of many technical and non-technical subjects and issues is evenly important. From the experience within the network and from direct feedback of the IPDE-experiments, one can deduct that full integrated understanding, appreciation and learning can be achieved in carefully supervised application situations: assignments, projects, workshops with direct professional feedback: a master apprentice set up with LTC (Love and Tender Care: like when growing a tree?).
Education for innovative engineering must have depth <u>and</u> width, it requires a cleverly set-up package of subjects, projects and workshops, but most of all it requires an active, committed and knowledgeable participating supervision, which might be expensive in time and required expertise, but gives a huge return on investment in the end.

When the Bachelor’s Product Design course (- IPDE) was upgraded into a Master course Technical Innovation, we aimed at educating (suitable) I-shaped engineers into fully creative T-shaped ones, following the tree metaphor of phased, controlled expansion into more disciplines and lateral thinking. We concentrated mostly on the mechanical (bachelors or master) engineers as a starting point. That was partly because of the recognition that generally speaking mechanical engineers typically switch all the time between the virtual world of formulas and graphs and the tangible world of the products they engineer. This switching ability, which might be the very unconscious reason they chose mechanical engineering in the first place, is exactly the important one for the T-shaped education.

But also from the industrial side this choice is valid. Products, innovative or not, have their core functions and attractions, that dictate their market value, based on a wide range of possible technologies and disciplines. However, most of their cost is dictated by Mechanical Engineering issues, the construction, material and assembly and the parts manufacturing, involving investments and cycle times as direct cost factors. Finding clever combinations of a potential market application and a defendable (core competence) production was and is the area of the Mechanical Engineering based IPDE – course. As products tend to have increased electric and electronic content, and the competitive pressure to innovate has increased drastically, the logical step has been to expand the technology base of the IPDE again and take advantage of the acquired above insights on learning. Therefore, in the Master of Technical Innovation we will take in selected BEng and MEng graduates of preferably Mechanical and Electrical Engineering, Informatics and Industrial Design (with technical orientation) background with at least an understanding and interest in Mechanical Engineering. Motivation and talent for out-of-discipline and out-of-the box thinking, as well as analytical competences and talent for design related techniques are as relevant for admission. Engineers from industry, having acquired equivalent skills from practice, are evenly welcome.

The building of a masters course

Following the tree-model, we typically try to build strong multidisciplinary technical core competence set, before expanding into business, design and creative areas. Each phase typically has its own integrating tool: dedicated workshops, assignments and/or project work (the rings in Figure 7). The first phase of the course, about 15-20 ECTS is a kind of deficiency repair, depending on the individual core technical knowledge base, and includes rather detailed manufacturing techniques, functional analysis/ methodical design and design-Taguchi statistics for all. The subjects of individual deficiency repair are to be chosen from the adapted basics of the other than "home" discipline", and range from essentials of mechanical, manufacturing, electrical and control engineering to physics, informatics etc. True to the learned lessons we'll test, integrate and anchor the new knowledge by a multidisciplinary integration project, in which a multi-technology product has to be modified. We typically learned from earlier multidisciplinary projects (the famous Aalborg experiment [12] being the best example), that good supervision and examination on all aspects for all is crucial to achieve the integral learning effect. Lack of doing so results in task distribution within the teams according to previous expertise and willingness to excel. That doesn't build T-shaped engineers, nor does it result in an optimized product.

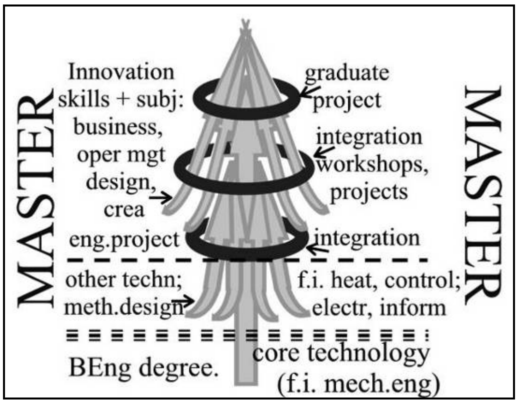

Figure 7. Structure of Master Technical Innovation

The second phase follows again the proven track of IPDE, with even more use of master-apprentice workshops to optimize the learning effects: it contains a further extension of technology and design engineering issues: with overviews of and introductions to new available technologies, materials and components, design methodologies and techniques, simulation, CA-techniques, production time optimizing. Also new trends and laws – patents, safety, environment, outsourcing, open innovation – are integrated in the program. The entrepreneurial and managerial (up to stress management!) and human factors theory, knowledge and know-how, the new angles of business science and industrial design are implemented in dedicated modules, integrated and anchored in workshops and projects under master-apprentice supervision. General assessment of every design task is: will the bottom-line result be beneficial for the intended company? Typical examples of such specially developed modules are, some including anchoring workshops:

- Above indicated presentation techniques and design issues for mechanical engineers, including rendering techniques, model building and perspectives.
- Cultural issues in innovation, in perception, in methodology, in communication-decision making. It has a strong Hofstede component [13].
- Probability and Taguchi statistics for normal people, based on automotive supplier training of Ford, extended to robust design adapted with understandable and easy-to-interpret graphics (Figure 8).
- Patent issues, mainly as part of the defensive barrier theory and design value, in which the strategic consequences of design decisions are discussed, including the risk management.
- Innovation financing and costing in a way even engineer can deal with.

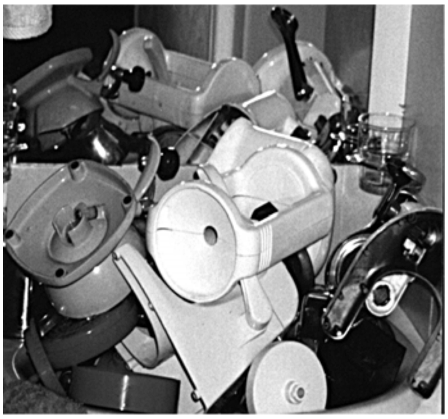

Figure 8. The mess after a clinic, QFD, functional analysis and reverse engineering on citrus presses in Ireland

Workshops as crucial element of "Technical Innovation"-masters

To really integrate a subject into the core knowledge base of a student we found that concentrated workshops of one or 2 weeks intensive, full time supervised exploring and applying of the new elements were an expensive, but worthwhile method. Over the years we developed many different master-apprentice workshops and tested them in the IPDE-course, during guest lecturing and in international joint intensive programs, as well as in industrial in-house training sessions. They all have a high content of hands-on experience of theoretical principles and involved participating of an experienced supervisor. The effectiveness of these workshops is now proven in practice and can very well be explained by the logic of the "full circle" of Kolb [14] and by the effects of "flow" [15]. For the master course Technical Innovation these workshops will be only slightly adapted to the basic disciplines and on the base of the new insights. They will be integrated in a logical order following the pattern of expanding knowledge and know-how, back-to-front: from concrete to abstract and from manufactured product to concepts. Typically they include workshops on functional analysis and design methods, Taguchi-probability and quality in early uncertain stages of a project, practical financial and economical models in innovation, a crash course presentation techniques and industrial design, a dedicated breakthrough concept development for a consumer product – Philips – and an introduction fully integrated T-shaped project (the Nutcracker Suite).

In the Kortrijk-IP, described above, elements of the functional analysis workshop and of finance in innovation (the money game) were included. Therefore we'll go into somewhat more detail on these programs.

Functional analysis and methodical design

The functional analysis workshop is also called the press room, as it deals with orange presses as an fine example. This workshop has been developed in the 90's within the scope of ICP 4021-European Design Engineering Network. Groningen then had in its Mechanical Engineering courses the function- based approach of Methodical Design, but still no further Design methods, like FMEA, DfXXX and VA/VE. For the exchange lecturing in an "Intensive Program" a demonstration on FMEA was given, based on staff's former experience in industry. The demo on the simple product proved to work so well, proven the concept of function based thinking and showing in depth how simple requirements from manufacturing and market work on the design, that the workshop was further developed and used in many joint summer courses, workshops and regular curricula.

Thinking in functions is one of the main elements for good general design, covering products, processes, organisations, systems. For consumer and technical products function based thinking means: what is the product/part supposed to do in main-, sub- and derived functions, in the material, energy and information domain. The information domain must be taken quite widely for the industrial design approach and includes the emotional and ergonomic issues. Almost all of the design methods and techniques are based on this principle of abstraction and it is typically the essential element in our product design courses. Over the years we found in the teaching of this Functional Analysis and the derived methods, including "Methodical Design" on product and process creation, and DfXXX, VA/VE, FMEA, QFD on verification and upgrading, that this structured, logical teaching is only effective if the training is done on real technologies, products and processes in an real industrial setting and supervised by a participating, involved and knowledgeable expert. To prevent superficial application of methods and going-through-the-motions direct detailed feedback on proposed logic is essential, case studies are not enough. This function-training proves to be essential in an effective use of the Cambridge Engineering Selector, the strong computer data based method to optimize constructions against the requirements.

The introduction workshop is done on a simple product: a manual orange press, of which so many examples are available. Some are efficient, some are beautiful, some are dangerous, some are over-killing in strength, some are downright stupid. The choice for such a simple consumer

product as an example is made from the practical educational logic: the obvious and hidden specifications are not too difficult to grasp for the students and the consequences of technical choices on product and performance, production and cost are within reach. Typically, after the introductions, a hands-on experiment is carried out: in this case pressing oranges and other related citrus-fruit on many different presses. Thus the intended, unintended and missing functions are researched and the links and logic to material, manufacturing and cost at one side, and performance, price and market.
Taking this experience into the formal functional analysis, doing systematic reverse engineering (why is there a hole at that spot? why is this material chosen?) then leads to the interlinked design and process FMEA. We found that the detailed participation of the supervisor (the ”master”) at one hand prevented the students to just go through the motions and forced then to follow the “Kolb” circle fully, thus anchoring the methodology. At the other hand, seeing and feeling all these detailed matters and tricks in such a simple product, combined with the fun of playing with food, created “flow”, the concentrated state, in this case of group learning. The effectiveness was observed not only with students, the workshop also worked very well for a group of local SME-entrepreneurs, showing them the value of the methodical approach and FMEA. Mind you they also added vodka to the produced juice, before testing the quality.
In the Kortrijk IP’s we dealt with the subject the first time in the “conventional” way: lecturing and leaving the application to the student’s initiative; the second time we followed the pattern of the masters workshop with guided direct application: this time on analysis and redesign of working principles of a coffee machine- with much better direct results and impact on the overall projects.

Finance for engineers

The workshop “Financial aspects in innovation” is also called: the money game (Figure 9). This workshop, starting with a hands-on execution of a game theory experiment, is extensively discussed in the Casablanca–paper of Pantlin and Gerson [17]. It follows the repeated prisoner's dilemma experiment of Hofstaedter [16] and demonstrates how complex fair trading is, and how unstable pricing arises from negotiating up and down the supply chain. Matters are more complicated than the simple economic curves suggest. In the innovation business world everything has to be recalculated, re-assessed, meaning a different finance and cost price approach.
Typically the workshops are given to groups of about 20-30 international students, and in the money game they play in “national” teams against each other. During the game strategies on dealing and exchange are carried out under experienced supervision, the effects are clearly felt, and feedback is directly appreciated. Interesting is the fact that thus not only the economic trade rules are being disclosed, but also cultural effects.
Introducing the same game to a much larger group – about 100 – made the direct control and feedback less feasible. The economic lessons to be learnt did not come across like it did in the small group, only some of the cultural effects could be observed, but like in the small setting: it was and is a great opener and icebreaker for a workshop.

Figure 9. The money game

Conclusion and issues for round table session

In modern competitive industry, technical innovation is the key factor for survival. Some of the innovations are directly based on new technological breakthroughs, but most have their essence in inventive engineering of already available technologies to new applications and emerging needs. The breakthrough technical innovation projects have a typical multidisciplinary and open-ended character and require far more from the team members than their expertise, like in well-structured and well-planned projects. For industrial companies to be very competitive, it is good to realize that only a small part of their engineering population should have this creative T-shaped skill, most of the engineers should be good at their specific or general engineering. For educational institutes it means that they should not try to develop every student into an creative T-shaped professional. But that is fine: this T-shaping requires a special character and mindset that not all engineers fully possess.

There are a few ways to determine if a person is suitable and inclined for this line of work. That includes of course interviewing by experienced T-shaped professionals. But exposure to open-ended problems in real-life project situations, as presented by the Intensive Program project, gives better feedback to student and selector. For this point of view, multidisciplinary workshops are ideal. They give new insights to students about the multidisciplinary knowledge needs for innovation problems and about their own future role as an innovation manager (T-shaped) or a standard 'I want to crack an engineering nut' problem solver. For the industrial partners, such workshops are very useful as idea-generator and refreshed out-of-box thinking.

Different networks (students – professors – industry), resulting of such international and multidisciplinary partnerships, are also a very important outcome and are of inestimable value in this ever growing innovation culture.

The enthusiasm of students, professors and industrial partners in such multidisciplinary cooperation show the importance and motivation to further continue and develop similar programs and workshops. It is important to conclude that three main aspects are essential for success, namely *knowledge transfer, workshop-based implementation on industrial innovation problems* and *guided consult from experienced supervisors.* This means that a consistent program should be developed with knowledge transfer through lectures and seminars, immediately followed by an implementation in workshop based projects, supervised by experienced consults.

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Philips M. Gerson has the Masters degree in Physics from the Delft University - 1970. During his 25 year industrial career as an Engineering Manager for a score of international companies he built up a rich practical experience on the development of innovative products of (electro-) mechanical, chemical, capital, consumer, automotive and other signature. During the last almost 20 years as lecturer/researcher Technical Innovation in Groningen he developed and led an international course on all aspects of integrated design engineering, founded an international network on practice, theory and education of engineering design. With the network he designed and led many specific innovation related workshops and carried out the 6 year research program "ODD=Open Dynamic Design" on best design practices, leading to the motto: "It Depends". In one of his many publications on the subject, he introduced the concept of the "T-shaped engineer" and the educational implications for this exceptional, but key person in modern industry. Implementation of these principles is done in the development of a master course Technical Innovation, and in his consultancy work of AAA Innovations.

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