Multidisciplinary teamwork as a crucial competence in modern engineering education programs

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Abstract- **The current process of designing and developing new industrial products has become more differentiated and complex. This has resulted in the need for multidisciplinary teams from the initial product development stage. Because engineers are mainly educated in designing typical technical product related aspects, the need for multidisciplinary competences arises. Simulation of real-life industrial innovation cases using multidisciplinary teams must be integrated in engineering education programs in order to develop the necessary competences. This paper describes the importance and implementation of multidisciplinary teamwork in modern engineering education programs as well as the evaluation of the non-technical competences, typically accompanying such project.**

I. 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, the high global pressure on sustainability and the rapid changes in technology "state-of-the art" make the process of designing and developing new industrial products more and more differentiated and complex. "Standard" engineering projects with a typical phased character in time and organization structure are being replaced by innovation projects with a strong need for multidisciplinary teams bringing all the necessary knowledge together from the first idea generation phase. Simple examples of such innovation projects are the Dyson vacuum cleaner using Root Cyclone™ technology that does not lose suction or the Apple iPhone, redefining the mobile phone concept, with strong user-interaction. What used to be a simple electronic telephone device, has now become a new lifestyle. Gerson et al. [1] [2] describe the need for an innovation manager to take the lead in such breakthrough innovation projects. An engineer educated as a 'T-shaped' engineer with extra 'horizontal' skills additional to the 'vertical' business unit specialization can play this management role. Of course, all team members – being mostly engineers – must have the necessary competences to work in such multidisciplinary teams together with designers, user-centered experts, psychologists, ergonomics or simply with other business unit engineers. This explains a high need for multidisciplinary competences in current modern engineering education programs.

II. ENGINEERING COMPETENCES: MORE THAN TECHNOLOGICAL COMPETENCES

A. Bologna reformation process of the European higher education

The first decennium of the 21st century corresponds with a strong reformation process of the European higher education. The Bologna process is a fundamental restructuring of higher education in Europe, of which the introduction of three cycles: bachelor, master and doctorate (PhD) [3]. Its objectives are to increase the employability of European citizens and the competitiveness and attractiveness of European higher education by enhancing the comparability and compatibility of higher education structures and degrees in Europe. Originally signed in 1999, the Bologna Declaration is an agreement to create a "European higher education area" by 2010 and that signatories have agreed to promote quality assurance systems, remove obstacles to the mobility of students, implement a system of easily readable and comparable degrees, and establish a common credit system. In the Bologna process, higher education is confronted with evolutions in Europe, resulting in recommendations and directives to develop modular constitution of education programs. The risk of such 'open' European higher education area lays in the possibility that strong educational countries get stronger due to a brain gain. Weaker educational countries will encounter a brain drain, losing human capital and its industrial innovation potential [4].

Modular education programs are based on clearly defined competences, that must be achieved and evaluated in practice. The most important reasons to introduce modular education is a better matching of education to society, company profiles and labor-oriented market, and a better preparation for lifelong learning. The social relevance of higher education becomes more emphasized e.g. through external quality control towards all stakeholders (government, industry, students, society). Learning becomes a lifelong task, not only realized inside higher education institutes but also during the complete labor cycle. To realize a modular education program, flexibility is essential, both in structure and content of the education program but also in teacher profile. The modular system should give more opportunities for teachers to spend time on research, international mobility, sabbatical, link with industry (internship), … This innovation process in higher education

programs has resulted in a complete quality structure, controlled by the accreditation process.

B. Competences

A key factor in the education quality system is the strong interaction between education and the corresponding industry, resulting in properly defined competences, applied research topics, cooperation in bachelor and master thesis projects, … Additional advantages arise from the combination of both bachelor and master degree programs in one institution, resulting in a wide spectrum from academic research, applied research and professional service to society. Abstract research results or methodologies, often developed in master education programs, get tangible and applied in the bachelor (research) projects. Choosing this way, higher education institutions can create a high innovation potential for any industrial partner. In fact, the industrial partners can be called 'co-creators', due to their strong interaction with the education process, research results or by simply using infrastructure, used for research projects or service to society.

Through these intensive contacts with industrial partners, a list of necessary competences is build and continuously adapted to changing requirements and expectations. The necessary competences for engineering students can be grouped in different competence clusters. For the academic bachelor in engineering sciences, four clusters are detected:

- General competences: applied creativity and general problem solving, thinking and reasoning competences, information gathering, communicating and reporting of problems and solutions, project management, social and economic related competences, …
- General scientific competences: research attitude, being able to apply research methodology and techniques, being able to work in multidisciplinary teams, mastering scientific fundamental knowledge, …
- General engineering competences: solving practical general engineering problems, linking different engineering disciplines to understand technical problems and processes, being able to assimilate, implement and use new technologies, …
- Domain specific competences (distinction between engineering of mechanics, electronics, industrial design, environmental sciences, biochemistry, …)

In a next step, these competences are translated into a coherent curriculum, with different forms of teaching (lectures, exercises, labs, projects, company visits, …). The coherence of the program, in relation to the gradual (Introduction, Advanced, Specialized) competence building, can be checked using a competence matrix (see Table I), cross linking all the competences of the domain specific reference framework with program modules.

Multidisciplinary competences are typical non-technical competences such as being able to work in a multidisciplinary team, having respect for and knowledge of other disciplines, being able to communicate in an international and multicultural team, being able to think and act in a methodic way, project management, presentation skills, … They can be found in the clusters 'General competences' and 'General scientific competences'.

TABLE I
COMPETENCE MATRIX

	Module 1	Module 2	Module 3	Module 4 …
GC 1	I		A	
GC 2 …		I	A	S
GSC 1	I			A
GSC 2 …		I		A
GEC 1	I	A	S	
GEC 2 …		I		A
DSC 1		I	A	S
DSC 2 …			I	

GC: General competence   I: Introduction

GSC: General scientific competence   A: Advanced

GEC: General engineering competence   S: Specialized

DSC: Domain specific competence

III. INNOWIZ: METHODOLOGY FOR INNOVATING USING MULTIDISCIPLINARY TEAMS

The competence of working in multidisciplinary teams cannot be learned without an appropriate methodology and different tools of organizing the different phases in an innovation project. Classical project management tools help a team in time management, responsibility sharing, identification of the stakeholders in a project, … Structuring inspiration and creativity towards innovation with different team member personalities is a difficult challenge.

INNOWIZ (Innovation Wizard) [5] is a research project of University College of West-Flanders (Howest) and funded by the Institute for the Promotion of Innovation by Science and Technology in Flanders [6]. The aims of the project were to stimulate innovation in SME's and to create an online tool to support and maintain this innovation. Two key findings arose in an early research stage.

First, organizations that enroll in an innovation process are in need of inspiration and creative insights. Creativity is typically seen as the basis for innovation, and innovation as the successful implementation of creative ideas within an organization ('applied creativity'). Creativity techniques stimulate this divergent thinking through the use of mechanisms that break pattern thinking. A broad overview of these techniques were classified in the INNOWIZ research project. However, a completely new class of techniques was found on the World Wide Web, more specifically in 'Web 2.0'

applications. The term 'Web 2.0' describes the changing trend in the use of the World Wide Web and web design that aims to enhance creativity, communications, secure information sharing, collaboration and functionality of the web. Some of the web applications were not developed to be specifically applied as a creativity technique, but are built on the same mechanisms and thus break through this pattern thinking.

Second, successful innovation requires a structure or method. Within an industrial engineering context, innovation engineers cannot allow innovation to occur accidentally. Time needs to be taken in account. Innovative products and processes are being developed within ever narrowing time frames. Innovation engineers are assigned simultaneously to several innovation projects with continuous deadlines. To control this complexity of innovation projects, there is a need for an innovation method that allows a shift from innovation towards systematic innovation. An approved method for systematic innovation is TRIZ (Theory for Inventive Problem Solving). TRIZ research began with the hypothesis that there are universal principles of creativity that are the basis for creative innovations that advance technology. If these principles could be identified and codified, they could be taught to people to make the process of creativity more predictable. The short version of this is: Somebody someplace has already solved this problem (or one very similar to it). Creativity is now finding that solution and adapting it to this particular problem [7]. Fig. 1 describes this process graphically. It is a descriptive model with four stationary phases.
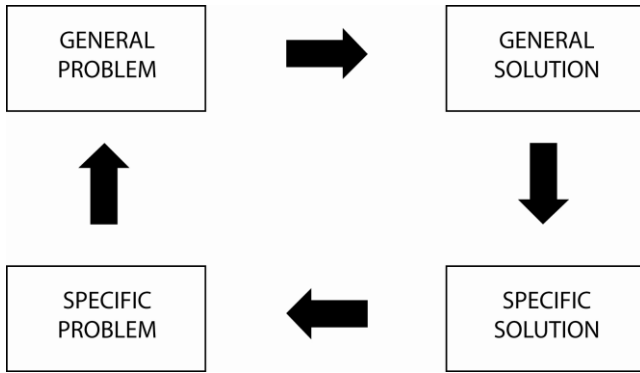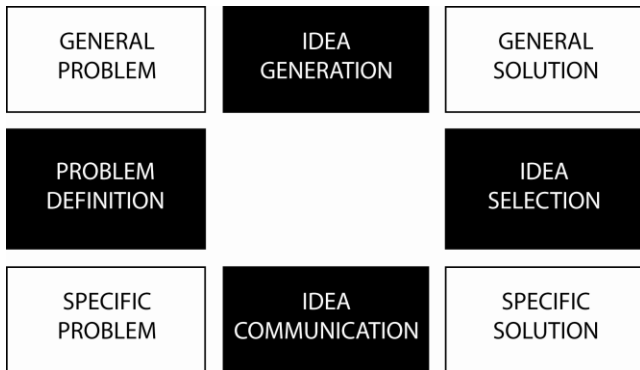
To set up innovation in a multidisciplinary team, a dynamic working model rather than a descriptive model must be developed. The difference between these two ways of thinking was called 'backward thinking' and 'forward thinking' by De Bono [8] or the 'perceptive domain' and the 'operating domain' stated by Moles and Caude [9]. The solution to this problem is in the phase transitions. Fig. 2 shows that this leads to four areas with their own specific attitudes to take in account when confronted with an innovation challenge. The four areas are called 'problem definition', 'idea generation', 'idea selection' and 'idea communication'.

The strength of INNOWIZ is in offering a structured way of dealing with innovation processes, without failing in offering inspiration and creativity. For each of the four areas, specific creativity techniques are available [10]. Within the INNOWIZ webtool, techniques are presented as playing cards with a specific color, depending on the area. This concept is shown in Fig. 3.
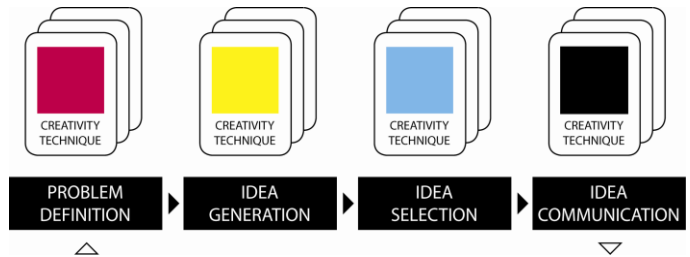

Fig. 3. INNOWIZ.be interface

The main protocol contains sets of different design tools which engineers can use according to their own individual background and skills. Each member of the multidisciplinary team brings in his or her unique insights and thinking preferences. As Howard Gardner would say: "The question is not, how smart am I?" but rather "How am I Smart?". Which methodology is suitable for me and the team at this moment? By guiding teams iteratively through these four phases, engineers apply creativity techniques as part of the whole design process and learn to communicate more efficiently step by step. This is an important methodology being a red wire for breakthrough innovation projects while working with multidisciplinary teams.

IV. MULTIDISCIPLINARY WORKSHOP BASED ON ERASMUS LLP INTENSIVE PROGRAM

A. 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.

Fig. 1. Basic model of TRIZ

Fig. 2. Focus on phase transitions

In order to keep innovation in companies, innovation skills must be taught to our engineering students. This Erasmus Intensive Program project [11], organized by University College of West-Flanders (HOWEST) aims at developing skills for product innovation through a multidisciplinary approach.

B. Workshop in concreto

The 10-day project [12] [13] brings together engineering students of different countries (Belgium, Spain, Portugal, Italy, Turkey, The Netherlands, France, Estonia and Finland) and of several disciplines (electronic – mechanic – informatics ICT – human technology – industrial design – product design – interaction design) and different cultures (south versus north of Europe). Through morning seminars (program see Table II) about innovation and project management, methodology and product development, sustainability, communication and presentation techniques, user centered design, intellectual property rights, … the students develop non-technical skills for product innovation in the modern economy. In the afternoon workshops, these techniques are implemented on industrial innovation cases 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.

The selection of potential innovation projects is done by a jury of experts. Important aspect in the selection is the presence of multidisciplinary features. Some examples of innovation cases:

- New material applications for flat TV (Philips)
- New applications for hybrid textiles (Bekaert)
- New applications for smart PU-foams (Recticel)
- Design of an innovative windtight sunscreen (Renson)
- Re-invent packaging (Unilin – Quickstep)
- How to make a nurse's life easier by 2015 (Televic)
- Facilitate office work in 2012 (Burodep – Gispen)
- Design of a self-regulating natural window ventilator (Duco)
- …

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 (non-technical) 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

TABLE II
INTENSIVE PROGRAM EDITION 2009

	Morning lectures			Afternoon workshop implementation on project	
	Session 1: 9h - 10h30	**Session 2: 11h00 - 12h30**		**Session 3: 13h30 - 15h**	**Session 4: 15h30 - 18h**
Monday 9 Febr. '09	ARRIVAL	ARRIVAL		ARRIVAL	ARRIVAL
Tuesday 10 Febr. '09	Presentation program IP + teamdivision (Frederik D'hulster - HOWEST)	Research of information (Paul Buschman - HOWEST) Innovation Portal (Indie - group)		Research Phase: preparation of questions for company	Team Building Activity Cooperation game (P. Gerson - Hanze NL)
Wednesday 11 Febr. '09	Innovation wizard INNOWIZ (Cies Vanneste - HOWEST)	Innovation wizard INNOWIZ (Cies Vanneste - HOWEST)		Innovation wizard implementation (intro INNOWIZ)	Research phase + briefing with company
Thursday 12 Febr. '09	Creative research techniques (Gerda Jonker & Steven De Boer - Hanze NL)	Creative research techniques (Gerda Jonker & Steven De Boer - Hanze NL)		Creative research techniques (Gerda Jonker & Steven De Boer - Hanze NL)	Creativity method implementation on project
Friday 13 Febr. '09	Industrial Project Management (Norbert Peirs - HOWEST)	User centered design (Johan Bonner - Pars pro toto)		Company visit + ideas screening	Ideas screening by company
Saturday 14 Febr. '09	Visualisation of Ideas - Exposition	Visualisation of Ideas - Exposition	Break	Visualisation of Ideas - Exposition 14h: press moment	Visualisation of Ideas - Exposition
Sunday 15 Febr. '09	free	free	Lunch break	free	free
Monday 16 Febr. '09	Materials Innovation: Solutions waiting for a Problem (Hugo Lievens - Bekaert)	Perceived quality of products and quality of interaction (Anne Guenand - UTC F)		Conceptual phase	Conceptual phase
Tuesday 17 Febr. '09	Validation of concepts (Walter Dejonghe - HOWEST)	Energy scavengers for wearable Electronics (Vladimir Leonov - IMEC)		Concept development phase	Concept development phase
Wednesday 18 Febr. '09	Design driven innovation (Lucia Rampino - POLIMI IT)	High end sheet metal and Tube/Profile Processing (Pedro Vanrijckeghem - VAC Machines)		Concept Validation phase	Concept Validation phase
Thursday 19 Febr. '09	Intellectual Property (Joost Muylle - Gevers & Associates)	A new product communication (Gino Delmotte - Brandspecies)		Presentation phase	Presentation phase
Friday 20 Febr. '09	Presentation and evaluation (jury)	Presentation and evaluation (jury)	Break	Award ceremony Closing session	Closing session

phase before getting into the concept development phase. A typical example is the '5 minute rule' for the time management of product development, consisting of information (1 minute), exploration (2 minutes), selection (1 minute) and communication/materialization (1 minute). 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 catalyst 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, each student individually makes a report of the innovation process, the used methodology and the final results. Due to the ECTS (European Credit Transfer 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.

C. Workshop based on innovation methodology

The program of the IP is based on the general INNOWIZ methodology, presented in Fig. 2. The design brief (product specification) is made by the company before the IP. Different morning lectures illustrate and train different idea generation and brainstorming techniques, decision and validation techniques, communication methods (sketching, 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 (Fig. 4), consisting of space-dividers, brainstorming walls, wireless internet, 3D rapid prototyping printers, materialization and testing rooms.

D. Output of multidisciplinary workshop

This project results in innovation solutions for the industrial partners, a strong network for the international professors and an unforgettable experience for the students.

Fig. 4. IP workshop environment

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 economy worldwide.

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.

In general, 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.

E. Integration of multidisciplinary project in academic bachelor engineering curriculum

This multidisciplinary project is fully integrated as a module of 6 ECTS (workshop + follow up) in the last semester of the Howest academic bachelor program, preparing the students for their master specialization.

F. Future considerations

The edition 2007, 2008 and 2009 of this international project was based on product innovation. The edition 2010, 2011 and 2012 will be focused on sustainability related to product innovation, in which a multidisciplinary team is indispensable. Electronic engineers have competences in energy saving methods, mechanical engineers can choose different production methods or reduce the weight of the product. Industrial designers can analyze the total life cycle of the product. In a multidisciplinary team, an integral innovative solution must be worked out.

V. EVALUATION OF NON-TECHNICAL COMPETENCES

Classical evaluation methods as exams, presentations, reporting, … are no longer appropriate for this new educational approach. Non-technical competences have to be evaluated in another way [14]. The evaluation consists of four parts: 35% of the score evaluates the development process, 35% the innovation potential of the final product, 15% the communication and final presentation, and 15% attitudes an teamwork through peer evaluation.

The "development process" is evaluated by all participating professors in different disciplines. The evaluation process is

based on the INNOWIZ methodology and focuses on non-technical competences.

In the problem definition phase, students are evaluated on how they translate the original project definition towards clear objectives. Research attitudes as information gathering, patent search, insight in available technology, marketing, etc. are combined with synthesis attitudes as definition of target group, project scope, and context of innovation.

In the idea generation phase, students are evaluated on the number of ideas, ordening and structuring of these ideas, creativity and participation. Creative attitudes as openness to new ideas, out-of-the-box lateral thinking, multidisciplinarity, etc. are combined with communication skills.

During idea selection, next to domain specific knowledge, students are evaluated on usability, economic and technical feasibility, development cost, … Research attitudes as synthesis, critical evaluation, interpretation, etc. are combined with documenting and reporting skills.

During idea communication, students are focusing on realization, prototyping, presentation, reporting, … Research attitudes as dealing with uncertainty, critical analysis, integration, creativity, distinction between main points and details, etc. are combined with practical skills, presentation skills, scientific reporting, …

The "innovation potential of the final product" is evaluated by all participating professors (of different disciplines) and project managers of the company. The evaluation process focuses on technical and non-technical competences. Non technical competences are mainly: cost vs. added value, innovation potential in comparison to existing market, functionality, relation between end user and product, working principles and applicability of technology, etc.

"Communication and final presentation" is evaluated by an external jury, composed of professionals from industry. The focus is mainly on the convincing capacities of the team.

"Teamwork, project management competences, motivation, loyalty, …" is obtained through peer evaluation.

VI. CONCLUSION

In order to educate engineers, fitting into this fast growing innovation society, attention must be paid to non-technical competences. This paper shows an example of how these competences can be taught and evaluated using a multidisciplinary workshop. Bringing together different disciplines in a real life industrial innovation project, forces the students to use different methodologies, creative techniques, new communication tools, presentation techniques, project and team management skills, …

Further research must be done to properly guide and consult students, working in multidisciplinary teams, to set up an appropriate digital innovation portal for idea-data management

and to develop new evaluation tools for non-technical competences.

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