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DESIGN EDUCATION VIA MULTI-DISCIPLINARY TEAM PROJECTS SUPPORTED BY AN INTERNATIONAL COACHING NETWORK AND DIGITAL LIBRARIES

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1. Introduction

Industry has been demanding for years to see engineering educators "teach the fundamentals" of global enterprise engagement and skilled use of information and communication technology.

The collaboration of universities and industrial partners is a major prerequisite for the realization of an advanced knowledge environment. Therefore a knowledge network has been established, which is an essential part of the overall collaboration framework. Knowledge is built and exchanged by collaboration among users (lecturers, researchers, industrial partners) via various forms of interaction. An essential element of the knowledge pool is a digital library, organized in a database, is the basis of the system, enabling users to compile personalized forms of utilization (online courses, electronic books, portfolios, etc.). This can be achieved by a high level of modularization and structuring of the content.

The collaboration environment promotes the acquisition of knowledge on the basis of users' experience and via shared activities in a collaborative environment, which serves for the working on joint projects. A highly interactive environment with advanced communication tools fosters the realization of virtual innovation projects by project teams. Beside theoretical issues this paper presents the framework of product design projects, which were carried out under the framework.

The environment integrates students and faculty from universities and industry partners in a common effort, to build a knowledge pool and a space for interaction and learning. The learning and collaboration environment is based on a pedagogical model, which encourages individual and social cognition via reflective practice; it is an environment, which offers different learning possibilities and several collaborative instances. The environment considers the currently most-favored pedagogical model for teaching design, which is project-based learning (PBL) [Dym et al. 2005]. The main concept and its features will be discussed.

2. Background

University students are nowadays increasingly challenged within their specific core disciplines; in addition however, they are also supposed to develop skills in order to apply this particular knowledge in practice. This ideally goes hand in hand with a sense of maturity of the individuals' characters vis-à-vis the social, cultural, and economical environment. The practical application of theoretical knowledge can thus only be implemented successfully, if these three basic elements are taken into account.

In addition to university students' disciplinary knowledge, the ability to work efficiently within multicultural environments has become increasingly important. Universities are therefore looking to expand and deepen this particular aspect in order to provide the necessary expertise in this field. This realization has led to universities becoming more proactive with regards to networking and offering joint courses [Holliger 2003].

The collaboration environment sees itself as a learning system cooperating in a network of universities and industry partners. It does so within a reflexive context, taking into account the various cultures involved in order to create new methods of resolution regarding teaching and learning methods. The students are at the core of this concept, and are given the option to develop process-oriented expert knowledge through interdisciplinary teamwork. Simultaneously, they learn to work independently and to deal with current problem cases through the use of modern information and communication tools. In the course of this collaboration activity, it has become apparent that the complementary aspect has gained in importance.

The rapid technological development and the need to cope with an increasing amount of information generate a difficult situation for both: professional courses at universities and industry. University teachers and researchers have to be constantly updating their knowledge on newly available technologies and products. The same happens to professionals working in industry.

The research done in universities increasingly needs the support of industry, not just financially, but also to test ideas in practice. On the other hand, industry can also benefit from having the opportunity to present their products to students, who will be future professional employees and probably work with their products or in development teams in industry. Therefore, the potential which a collaborative networked learning environment could have for both, universities and industry is obvious. Engineering design is a systematic, intelligent process in which designers generate, evaluate, and specific concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints [Dym et al. 2005]. Design problems reflect the fact that the designer has a client (or customer) who, in turn, has in mind a set of users (or customers) for whose benefit the designed artifact is being developed. The design process is itself a complex cognitive process.

There are many informative approaches to characterizing design thinking and the process involved. These characterizations highlight the skills often associated with “good” designers, namely, the ability to:

- tolerate ambiguity that shows up in viewing design as inquiry or as an iterative loop of divergent-convergent thinking;
- maintain sight of the big picture by including systems thinking and systems design;
- handle uncertainty;
- make decisions;
- think as part of a team in a social process; and
- think and communicate in the several languages of design [Dym et al. 2005].

Product innovation, which essentially means the definition, development and production of new products and their successful launching to the market, is the driving factor for a powerful, competitive economy and the prosperity of society. Therefore, the education of professionals at universities and the continuous professional development of engineers in the wide field of product innovation are of central importance. Knowledge about product development and product innovation has both, an enormous width in topic variety and a considerable depth regarding know-how and as well process related knowledge.

3. Pedagogic Model

Aiming to generate a networked collaborative environment, we favour a socio-constructivist approach, where the acquisition of knowledge is based on the users’ experience and collaboration.

The pedagogical backbone is project based learning which is multidisciplinary by nature, and it can be divided into two main themes that seemingly parallel the idea of integrating divergent and convergent thinking [Dym et al. 2005]:

- design-oriented project-organized education deals with know how, the practical problems of constructing and designing on the basis of a synthesis of knowledge from many disciplines; and

- problem-oriented project-organized education deals with know why, the solution of theoretical problems through the use of any relevant knowledge, whatever discipline the knowledge derives from.

Today's engineer must design under-and so understand at a deep level-constraints that include global, cultural, and business contexts. They are part of the new "fundamentals" [Dym et al. 2005]. Thus, educators must look beyond the limits of their own institutions toward a global network for design education. A global network is defined as a network that connects geographically dispersed design teams and (possibly) clients that are connected by appropriate technological means.

Dealing with the education of practitioners represents also a higher demand for the development of critical and reflective abilities. The constant exposition to an increasing amount of information and to technological developments generates new demands on individuals. They need to develop the ability of critically select the most appropriate information and of taking immediate decisions to efficiently respond to the changing scenarios of practice.

Experts and mentors from industry are an essential part of the collaboration structure (Figure 1). Their participation contributes a high degree of practical knowledge to the projects, pointing out the actual 'state of the art'. In this manner, the environment manages to link academic educational and professional practice. The intensive interaction between these three elements guarantees a rapid transfer of technology, while at the same time ensuring that the students involved are motivated to a high degree.

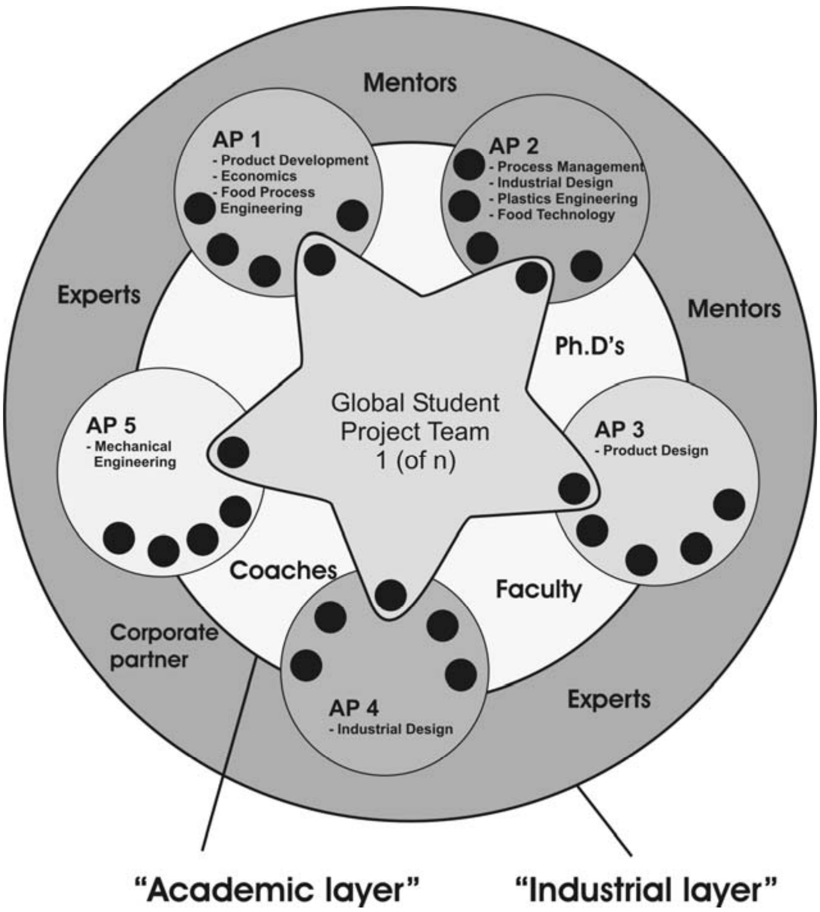

Figure 1. Global team setting: project teams, coaches and mentors (AP= academic partner)

The learning process is mainly structured in three major phases: preparation, application and consolidation. A variety of different learning modes are integrated, from individual to class and team. At the same time an adaptation of teaching technology and teaching modes are necessary. This includes e-learning technology to fill the gaps, where traditional teaching and learning can be supported by complementary measures.
Students work on “real life”, authentic product development tasks, provided by a corporate partner. The courses start with a kick-off week, which will include all participating students and staff from partner universities. At the beginning of the course special notion will be addressed to the team-building process, including the preparation competence profiles of the single team members. Knowledge maps about the teams are crucial elements for the collaboration process. Further topics of the kick-off week will be the definition of roles in the teams with respect to function and discipline, the introduction into the design task (by the corporate partner), training of ICT tools and lectures about effective information retrieval using digital libraries. An instructional short-course about the ICT-tools (especially VC) including a communication exercise demonstrates the relevance of the ICT environment for the project.
The structure of the course is segmented in a seven day kick-off week with physical presence in an old spinnery, part of the University of Applied Sciences Aargau, Switzerland, where all students and faculty come together mainly for the following purposes [Holliger 2003]:

- team formation: it turned out to be extremely important to build a profound social link among the students as the basis for a solid collaboration during the course of the project,
- ICT: the teams could only communicate through ICT during the whole development process after the kick-off. A powerful multi-point video conference system includes all participating sites in one session (Figure 2). This feature is extremely important to allow for almost the same team communication compared to a real meeting in order to keep the sense of belonging to the team on an high level.

Figure 2. Multi-point video conferencing with four sites
(the “speaking site” is automatically shown in the large window)

- lectures on specific topics: several lectures were given to facilitate the start-up for the project with respect to a common nomenclature. Critical aspects of the project were addressed by the lectures, given by faculty and also experts from industry.
- definition of the project’s process outline/ plan: at the end of the kick-off week the teams were in charge to present a project plan including work packages, time line, definition of milestones, resource planning, schedule of further activities, etc.. The presentation of the

project plan to faculty, mentors and experts from industry concluded the kick-off week, dismissing the students to their home universities with comments and recommendations for the further course of the project.

After the kick-off the students return to their home universities from where they could only communicate via ICT. At the same time they formed local teams at the different locations to exchange basic information useful for all project teams (i.e. geometry data of the base version, loading assumptions, list of requirements, specifications, etc.). The planning as well as the manufacturing of the functional prototypes or project documentations were managed over the information platform. The parts and components were then manufactured at different sites, the final integration and assembly was done on the occasion of the final presentation event, which concluded the project by again getting together physically.

The evaluation of the project results are in the duty of a jury, which is formed by one member of each discipline. Each team receives a jury report with an acknowledgement of the contributions according to the following criteria: (1) technical functionality of product, (2) economic efficiency and feasibility, (3) innovation potential of the solution(s), (4) suggested production methods, (5) presentation of the product on web site, (6) fulfilment of given requirements, (7) general impressions.

3.1 Learning targets

The main learning targets addressed in this learning environment are:

- exertion of technical skills and knowledge in multidisciplinary, multi-cultural distributed design projects using a diversity of information resources: analysis of design task, definition of requirements for multidisciplinary design task, concept generation, verification and proof of concepts, documentation and convincing presentation.
- exercise and practise of the English language on the level of negotiation, discourse and critical reflection within the technical domain and in the situation of multi-disciplinary team work,
- gain of experience with respect to product development process while working in distributed, collaborative environments using modern ICT,
- improvement of media competence (collaboration tools, preparation and realization of remote meetings, application of creativity tools within ICT environment: i.e brainstorming over VC, …)
- training and improving of essential soft skills, social competence, practising the role of being member or team leader of multi-cultural teams, managing conflicts, …),
- better understanding of related disciplines of product design in the sense of a holistic approach,
- improvement of information handling literacy (digital information sources, digital libraries),
- creation and management of process related knowledge,
- deeper reflection of the learning process by the students.

4. Project Cases

The courses offered during the past 3 years brought together the disciplines of a) mechanical engineering, plastics engineering, product design, industrial design as well as economics a with students and faculty from University of Applied Sciences Aargau, Aalborg University, ETH Zürich, NTNU Trondheim and Stanford University in the US; the latter with a double involvement as contributor of students as well as in the evaluation and assessment of the courses. The composition of the participating universities was mainly defined by the project subject and may change from one project to the other. The projects were done in tight cooperation of the POLE platform of the UAS Aargau [Holliger, Kündig 2003] and the innoVenture initiative of ETH Zurich [Elspass 2005], thus taking advantage of both competencies and especially infrastructure.

4.1 Project Tasks

With respect to project tasks, the following topics in product design have been worked on so far:

- Design of a novel sports equipment for Snow and Sand

- Design of a novel packaging concept for a food company

5. Digital libraries and team collaboration

In the course of the last academic year, the development of a novel technology, using digital -static as well as dynamic- libraries has been included, a method which is intended to improve teaching and learning. This project combines the idea of creation and use of digital libraries with collaborative interdisciplinary team work. In the future digital libraries with rich content, also addressing all aspects of the development processes (formal and informal knowledge), will play an essential part in higher education as well in professional work. Abundant knowledge is created during the course of a project – but only a small percentage thereof is represented and visible in the final product. Most of the know-how and the decision making does not flow into the documentation and is, therefore, being lost. It is exactly this knowledge, which the digital library is supported to address. Therefore the team video conference sessions for instance are recorded and made available for re-use. Thus the problem of the different time zones can be tackled partly.
ENDIC [Frutiger et al. 2005] is a second generation digital library based on the lessons learned during evaluation of the previous version of a digital library (Figure 3). It features a fundamentally improved user interface based on Macromedia Flash technology as well as a higher level of automation and robustness on all levels but specifically on the content migration side. With respect to what has been pointed out before, the innovative issues of the library part related to formal knowledge can be summarized as follows:

1. realization of new navigational strategies through wide subject fields,
2. simplification of the user interface to visualize and access contents,
3. noticeable reduction of the number of interactions until the required information is available,
4. reuse of content by implementing accepted document exchange standards,
5. free access to reviewed and classified information,
6. facilitation of content input, self-organizing database.

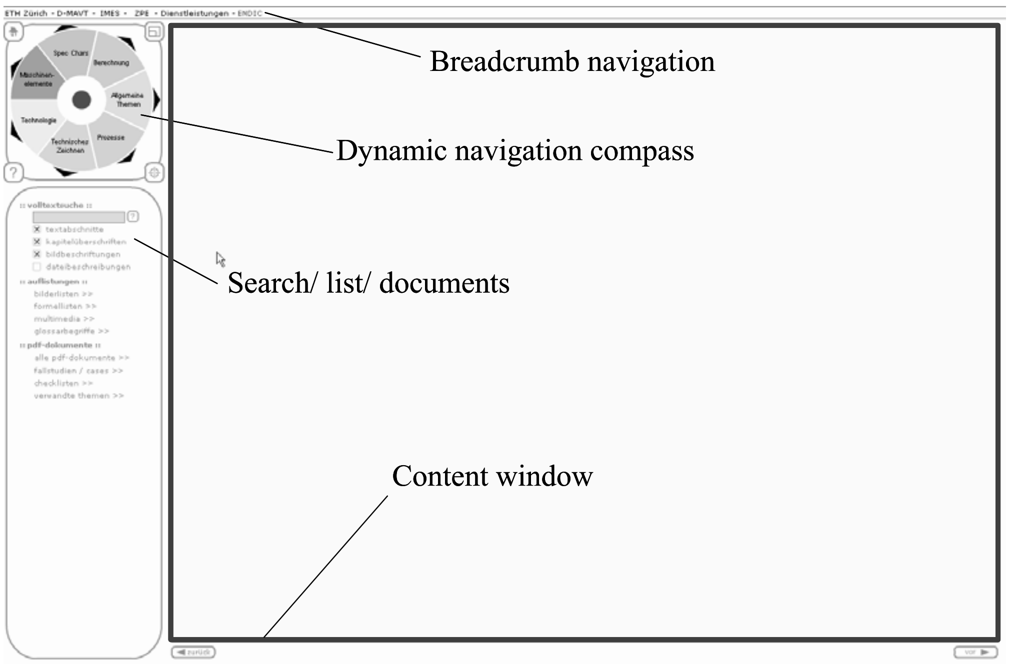

Figure 3. Novel user interface of the ENDIC system (www.ek.ethz.ch)

Special emphasis designing the interface was put on the usability and ease of use. According to ISO 9241-11 Guidance on Usability Standard, usability is defined as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use", where effectiveness measures the accuracy and completeness with which users achieve specified goals, efficiency measures the resources spent, and satisfaction measures the freedom from discomfort, and positive attitudes towards the use of the product. Therefore the navigation compass, a dynamic semantic visualization of the library contents, turned out be a central element of the GUI. Other novel search capabilities include the search for equations or figures.
The students are entitled to learn the

- retrieval of information from digital libraries (containing factual, formal knowledge)
- creation and storage of process related knowledge (informal, tacit knowledge) for later re-use

to serve the needs of their own or of other development teams.
The methodology became possible due to the availability and storability of indexed, annotated digital video sequences. The modern technologies allow the fast and goal-oriented retrieval of both kinds of knowledge.
The documentation of the development process with video sequences capturing process knowledge improves the learning and teaching process, because

- students can reflect about their decisions made during the learning (development) process,
- students get an immediate visual feedback about their performance, contributions,
- the medium "video" captures more process related information,
- future student teams can enrich their learning experience by reviewing video material, prepared by former student teams,
- teachers/ instructors/ coaches will get better and more information about the learning process and can even monitor and analyze the learning progress more flexible and in more detail.

It is anticipated that this project segment will demonstrate how the traditional way of learning and teaching can be enhanced by combining the use and extension of digital libraries with virtual team based co-operation by a) using cutting edge information and collaboration technologies, and b) by recording and documenting the teams' creative process for later re-use.

6. Findings and recommendations

Based on the assessment done on all product development projects so far some general findings have been identified [Eris et al. 2005]:

1. Design teams should be encouraged to take their "vision statements" further and build on them by extracting explicit "design requirements" and negotiating them.
2. The design requirements design teams generate from their vision statements should be discipline specific.
3. The design requirements provided at the beginning of the course should not be static. Students should be able to challenge and negotiate them as they learn more about what they think the product should be.
4. "Critical hardware benchmark reviews" should be held throughout the course, beginning no later than the third week, in order to promote learning by prototyping/doing. Students should be asked to identify critical components of the system they are designing and then crudely prototype those components numerous times in order to learn about their functionality, and how they might or might not work together.
5. Commitment requirements communicated to faculty advisors from different disciplines and institutions should in return be communicated to the students in advance to ensure that they join the class with realistic expectations. Students should earn a similar number of credits.
6. Clearer academic prerequisite guidelines should be established and should be communicated to the students. The suggested categorization scheme is: "Preferred" class standings (4th and 5th year students), "Acceptable" class standing (3rd year students who can provide evidence as to why they would succeed), and "Unacceptable" class standing (1st and 2nd year students).

7. Despite the time constraints, students should be encouraged to spend more time exploring dimensions of the project and the course by doing rather than listening during the kick-off meeting.
8. Rationale for the need to adopt and use ICT should be made explicit. Short distributed collaboration scenarios can be used as simulated exercises in order to promote awareness and discussion.
9. The majority of the ICT system training should be conducted after the kick-off phase, and delivered "just-in-time" through embedded ICT coaches at the local institutions.

Other researchers like Dutta [Dutta 2002] report that students in a global product development course participated in an anonymous, online survey composed of twenty questions. More than 80 percent of the respondents stated that the global team approach "added tremendous value to the course" and that they would participate in a similar course again. Respondents also reported (64 percent) that videoconferencing was "very useful," contrary to the widely held opinion that live video is an unnecessary frill that doesn't improve communication. Notably, all of the students claimed that the course changed the way they saw themselves and/or the world afterward [Dym et al. 2005].

7. Conclusions

The experiences gained from the collaboration projects done so far are very promising. The learning experience of the students is rich with respect to various aspects, among others the multidisciplinary insight, the re-definition of their own profession and an exposure to cultural complexity. Furthermore, the projects involve the development and research issues including the creation of knowledge databases, which will serve as a tool for more rapid evaluation of solutions, the decision-making processes in the future. These efforts are based on the knowledge that a large part of creational, construction, and design processes will be substantially shaped by re-design. The learning environment and its associated methodology allow students to apply their theoretical knowledge in practical cases. Through collaboration in multi-disciplinary teams students are given the opportunity to understand the individual design process involved and acknowledge the relation to the social, economical, and political dimensions.

In the final stage the result of this concept will end up in an integrated learning and teaching environment, which will effectively enhance design learning in global, cooperative, multi-disciplinary team work. Specifically, the approach combines the exciting idea of digital libraries with the development of virtual design studios for team collaboration in an international network. The development of new products for the global market requires the ability of today's students to be able to cooperate by using cutting-edge technologies beyond disciplinary and cultural borders. Modern communication technologies - like virtual platforms, spatially distributed work places, video and audio conferences and email – and in particular digital libraries – will be the backbone in all upcoming courses [Elspass 2003].

In brief, available research suggests that PBL courses appear to improve retention, student satisfaction, diversity, and student learning.

There is a clear need to expand the number of faculty members interested in and capable of teaching design, and to create the facilities-such as design studios and associated shops-needed for modern, project-based design courses. Thus, the most important recommendation is that engineers in academe, both faculty members and administrators, make enhanced design pedagogy their highest priority in future resource allocation decisions.

Finally, design education represents both serious challenges and glorious opportunities. Design is what engineers do, and the intelligent and thoughtful design of the engineering curriculum should be the community's first allegiance.

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This paper is dedicated in memoriam of Prof. Dr. Markus Meier. Markus Meier was Professor of Machine Design, head of the Centre of Product Development and a member of the Department of Mechanical Process and Engineering at the Swiss Federal Institute of Technology from 1996 until 2005.