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DESIGN COMPETENCE DEVELOPMENT IN AN ACADEMIC VIRTUAL ENTERPRISE

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ABSTRACT

Development of competence has been one of the major issues and goals of modern academic design and engineering education. Nevertheless, our literature study revealed that we are still far from a common interpretation of design competence. There are different views on it which we called reductionist and holistic. In the reductionist view, design competence is considered to be not else than a set of low level competencies such as drawing skills, spatial vision, specialized knowledge, intuitiveness and creativity, verbal communication, and technical writing, which have been typically addressed disjointedly. In the holistic view, design competence is a synergetic construct of some generic capacities. We followed this latter view in our work. We studied the implementation opportunities and manifestation of holistic design competence at the development and conduct of our recent European Global Product Realization course. Based on our past experiences and the information from the literature, we assumed that holistic design competence is a construct of five generic capacities: capabilities, attitude, knowledge, skills, and experiences, and can be efficiently developed by concurrently focusing on each of these, respectively. The professional content and didactic approach of the course were designed accordingly. An academic virtual enterprise was formed with the involvement of an industrial company and universities of five countries. The course included two instructional streams, which have been called professional navigation and industrial project. This paper presents our interpretation of holistic design competence, the didactic aspects of developing the underpinning generic capacities, and their manifestation in the European Global Product Realization course. A qualitative research has been completed with the involvement of 46 students to make out how our approach contributed to the development of the elementary design competencies. The conclusion has been that our approach equally well supports the development of both the holistic design competence and the elementary design competencies that are needed by product designers to be able to successfully operate in geographically dispersed virtual enterprises. The students' opinion has been that the course was challenging but rewarding from the point of view of their future carrier as product designers.

KEYWORDS:

Borderless education, academic virtual enterprise, virtual team work, design competencies, competence development

1. INTRODUCTION

In this paper we concentrate on the development of holistic design competence that enables future product designers to work efficiently in geographically dislocated collaborative design environments. The need for this kind of competence has been recognized many years ago, but it is not yet developed routinely in current design courses. Various efforts have been made to convert conventional design courses to competence training practices. The most of the efforts were concentrated on active learning, and a variety of pedagogical designs have been employed and tested such as problem-oriented instruction, project-based learning, and integral product development projects.

These efforts however could not always lead to the expected results. As far as we can see, the major reasons were: (i) superficial awareness of the theoretical issues of competence development in the context of product design, and (ii) underestimation of the importance of effective pedagogical (methodological) frameworks. One of the most important theoretical issues is that we are still far from a common interpretation of design competence. Another issue is that most of the prevailing definitions disregard those constituents of design competence, which are needed for future product designers in order to be able to efficiently and successfully operate in virtual design studios and dislocated product development enterprises. As far as the pedagogical frameworks are concerned, the major issues are: (i) which course designs offers the most intensive learning environment, (ii) which course designs can be applied with success in more than one field of product design, and (iii) how the latest information and communication technologies can be employed to facilitate multi-disciplinary design collaboration.

The above mentioned theoretical issues as well as many other practical ones have been addressed in our international product development course, called European Global Product Realization (E-GPR). Global product realization plays a specific role due to (i) the rapid globalization of the industrial and marketing operations towards new business opportunities such as the markets of the bottom of pyramid (BoP), (ii) the new possibilities offered by the current and emerging communication and collaboration technologies for world-wide operation, (iii) the growing need of and insistence on user centeredness and cultural sensitivity, (iv) the indispensability of developing rigorous, verifiable methods for product development, and (v) the growing emphasis on placing design at the center of product development processes. This video-conferencing-based course is a result of the cooperation of five European universities and various industrial companies over years.

Being the fifth in the series of courses, the last course, organized in the spring semester of 2005, concentrated on the development of holistic design competence. In the preparation phase of this international product development course, our assumption was that in the future the work of designers will be characterized by (i) the strong need for exploration, aggregation, and verification of design information, (ii) extensive integration of physical, technological, environmental, economic, cognitive, social, cultural, and human factors (iii) intensive multi-disciplinary cooperation, (iv) web-hosted remote collaboration in virtual and physical prototyping (VPP), and (v) application of advanced product, interface and knowledge technologies. Based on this assumption, the educational goal of the E-GPR course was to equip the students with the capabilities needed to take most of the known challenges of their future operation as product designers. However, not only the conventional elements of design competence have been considered, but also those which are essential to the future professional practice in virtual enterprises (e.g. effective application of advanced design support systems, familiarity of information and collaboration systems, knowledge asset management, etc).

Table 1 Participants and foci of the various E-GPR courses

Year	University participants	Core company	Educational focus	Research focus
2002	UoL, EPFL, and DUT	LIV Postojna, Slovenia De Vlamboog, BV, the Netherlands	Redesigning and prototyping of consumer durables for global market	Dislocated cooperation in academic virtual enterprise
2003	DUT, UoL, and EPFL	De Vlamboog, BV, the Netherlands	Conceptualization and prototyping future product for the core company	Project oriented learning in virtual environment
2004	EPFL, UoL, UoZ, and DUT	De Vlamboog, BV, the Netherlands	Combining operational research and product conceptualization	Navigation of active learning
2005	EPFL, UoL, UoZ, CUoL, and DUT	AVIDOR, Switzerland	Human- and environment-centered product development	Development of holistic design competence
Abbreviations: EPFL - Ecole Polytechnique Federale Lausanne, Switzerland, UoL - University of Ljubljana, Slovenia, UoZ - University of Zagreb, Croatia, DUT - Delft University of Technology, the Netherlands, and CUoL – City University of London, England				

The basic pedagogical concepts, educational constructs, organizational framework, course contents, achieved results of, and early experiences with the previous E-GPR courses have been reported on in our former publications (Horváth, I. et al., 2003) (Horváth, I. et al., 2004a). The list of universities and companies who took part in the courses as participants, and the educational and research goals are summarized in Table 1. It has to be mentioned that the E-GPR courses are not only practice-oriented design courses for interested design and engineering students, but also research cases for the course organizers. Actually, each course is accompanied by a staff research with a particular focus. The educational and research foci of the particular courses are given in Table 1. Obviously, the objectives of research have been selected with a view to the educational objectives of the various courses. Interested readers are advised to refer to papers and articles such as (Tavcar, J. et al., 2003), (Horváth, I. et al., 2004b), and (Bufardi, A. et al., 2005) for specific details about our experiences with the educational goals and the insights gained by our previous research.

As mentioned earlier, the European Global Product Realization course has been brought to existence as an answer to the concept of borderless education as well as to the major trends in digitally-supported design such as (i) design across value chains (globalization of product development, realization and marketing), (ii) design across multiple domains (growing importance of integrated multi-disciplinary design), and (iii) designing across life cycle processes (from conceptualization, through production and utilization, to recycling. These are indicating the multiplicity of the aspects to be dealt with, the multi-faceted nature of the knowledge the students need to learn, and the complexity of the problem from educational point of view.

This paper gives an overview of our concepts, work and conclusions concerning the issues of systematic development of holistic design competence. It also deals with the reflections of competence development on the side of students. The content is structured as follows. Section 2 summarizes and critically analyses the literature to conclude about the concepts and achievements in the field of competence-centered engineering design education. Section 3 presents our understanding of holistic design competence and systematic competence development. Sections 4-8 explain how the specific capacities underpinning holistic design competence have been addressed in the last E-GPR course. Finally, Section 9 concludes about the scientific and practical contribution of the course.

2. PROGRESS IN THE FIELD OF COMPETENCE-CENTERED ENGINEERING DESIGN EDUCATION

It has been discussed by various authors that there is a need for, and has been a gradual shift from learning design content to building up design competencies in various contexts (Bourgeois, E., 2002). In the past the emphasis was put on the body of knowledge that a designer should posses and employ. Students have been equipped with competencies that helped them pass the exams, rather than solve real life design problems with success. However, over the last two decades, design problem solving capabilities have been given growing attention and various aspects of design competence have been investigated. The major issues have been: (i) what design competence is, (ii) what competencies professionals in the field of product design are expected to have/master, and (iii) how to develop design competencies by university-based engineering design courses. Obviously, knowledge remained important, but it is now considered as element of design competence, rather than as the only goal of design education.

Many studies are focusing on the interpretation of design competence. Munch, B. and Jakobsen, A., 2005, identified the three most important characteristics of competence: (i) contextual (it is a perspective on personal performance in a specific context), (ii) behavioral (it involves attitudes, motives, intuition, skill, will power, drive, etc.), and (iii) problem oriented (it relates to solving problems of an authentic practice). There seems to be an agreement that there is no universal design competence, but only design competence which is developed according to certain needs by scholarly activities. This can be explained by the fact that design appears in several forms, with different goals, and in various contexts. However, the presence of competence can generally be observed in terms of its operation to enable design problem solving.

Important question is whether ‘competencies in designing’ can be defined across fields of design practice and associated domain knowledge areas, and if so, how? Various authors claim that there exists a set of application independent design competencies. For instance, Crain, R.W. et al, 1995, defined categories of these design competencies, such as (i) teamwork, (ii) information gathering, (iii) problem definition, (iv) idea generation, (v) evaluation and decision making, (vi) implementation, and (vii) communication. They claim that these need to be developed by introductory design courses. They found that other competencies are to be addressed in higher design courses in order to suit specific disciplines.

There are also studies about the manifestation of design competence. Many authors reported on addressing specific knowledge, skills, and methods. At the same time, many authors, for instance the above mentioned ones, consider design competence as a complex totality. In other words, many authors believe that design competence is actually an integral of design competencies. We called these two approaches reductionist and holistic. Reductionism assumes that all complex systems can be completely understood in terms of their components. In the reductionist view, design competence is considered to be not else than a set of low level competencies such as drawing skills, spatial vision, specialized knowledge, intuitiveness and creativity, verbal communication, and technical writing, which have been typically addressed disjointedly. In the holistic view, design competence is a synergetic construct of some generic elements (human capacities) rather than being added up by low level competencies. It follows from the holistic interpretation that no element of design competence can exist apart from the whole and that the individual elements are determined by their relations to all other elements. We followed this latter view in our work.

Researchers found that construction of knowledge and competence is not only personal, but also social. We can talk about competence in connection with individuals and organizations, and thus differentiate personal competence, which is related to individual professionals, and communal competence, which is related to a team or a community of professionals. Creativity, communication, integrative thinking, project work, problem solving, and learning from examples are usually mentioned as typical personal competencies necessary for industrial design engineering. Multi-disciplinary collaboration, dislocated communication, balanced comprehension, and resource sharing are mentioned as typical communal competencies. As a matter of fact, communal competences are of the same importance in the current industrial practice as personal competencies. Berge, N. et al., 2002, presented a survey of the competencies that are needed from training and development professionals. The conclusion of this survey is that communal competencies are becoming more and more important for a successful operation nowadays, when the conventional (hierarchically organized) companies are converted to self-directed, cross-functional, process-oriented, and knowledge-based companies.

Not being a unique characteristic, competence may manifests in multiple forms and levels. Typically, the word ‘level’ is used to express the stage of development of competence. In this respect, higher levels of competence imply more specific problem solving capability and knowledge. One way of classifying the levels of competence is matching it to design tasks. This way, we can differentiate basic, routine, innovative and creative design competencies, which are respectively related to elementary design, parametric redesign, innovative redesign, and new design tasks. Interestingly, the same word (level) is also often used to express the generality or specialty of competence. In this context, high level design competencies are for global problem solving, while low level competencies are for solving special design problems.

Certain researchers defined design competence as a complex ability to act based on effectively mobilizing and using a set of resources (Ledsome, C., 1994). The motivation behind this argumentation is that, in practice, engineering competencies form an indivisible whole. This is true even for interpersonal and intrapersonal competencies. Many people differentiate between conventional design competencies and modern competencies, with the goal to distinguish design problem solving capacities from design process management capacities.

Overbeeke, K. et al., 2004, identified nine competencies that are requested to be developed by industrial design engineering education. They sorted them as core competencies and meta-competencies. The core competencies are: (i) ideas and concepts (developing visions and innovative concepts by using creativity techniques, experimentation and operative research), (ii) integrating technology (awareness of technologies and combining technologies for products and realization), (iii) user focus and perspective (observing, analyzing, and interpreting user needs), (iv) social and cultural awareness (observing and analyzing social behaviors and cultural contexts), (v) market orientation (exploring strategic marketing opportunities and consumer oriented positioning of products), and (vi) visual language (connecting thoughts to function and form by visual means). The meta-competencies are: (multi-disciplinary teamwork (performing in international multidisciplinary teams), (ii) design and research process (mastering design and operative design research processes), and (iii) self-directed and continuous learning (personal development by defining new learning goals and approaches). It has to be mentioned that these competencies are practically the same what the organizers found important for the E-GPR course.

As a conclusion we can claim that two major conceptual paradigms are apparently reflected by the papers and documents we have studied. Part of the researchers follows the reductionism paradigm, and builds their research on the assumption that design competence is a large set of elementary competencies such as hand drawing, verbal communication, spatial viewing, critical analysis, creative ingenuity, and manual dexterity. Another part of researchers thinks that design competence is holistic in nature, and as such, integrates multiple constituents which are difficult to separate since mutually interacting. While the first community puts the emphasis on the identification of particular competencies that are needed in a particular design practice or by a design task, the other community is thinking about the capacities embraced by design competence and investigates how they can be amplified by each other in an integral way. We followed this latter view in our work.

3. OUR UNDERSTANDING OF COMPETENCE DEVELOPMENT IN DESIGN EDUCATION

The word ‘competence’ expresses the comprehensive capability to do something in an effective and successful way, but it also refers to a purposeful set of behaviors that enable achieving goals. Competence enables problem solving not only in known situations, but also in unpredicted situations. As an outcome of our forerunning explorative research, which included the study of the related literature, experimenting in earlier educational courses, and consultations with educational experts, our understanding has been that competence is a complex whole. In the context of design problem solving, competence is a combination of capacities complementing one another. If only one of these capacities is missing, or significantly weaker than the others, we cannot speak about fully featured design competence. This is a simple explanation why design competence may be addressed from multiple aspects and can be decomposed to a large number of elementary competencies.

We studied the implementation opportunities and manifestation of holistic design competence at the development and conduct of our recent European Global Product Realization course. Based on our past experiences and the information from the literature, our assumption has been that design competence is a combination of five capacities. These constituents are (i) capabilities, (ii) attitude, (iii) knowledge, (iv) skills, and (v) experiences (Figure 1). They are epistemologically and methodologically strongly connected. In other words, they jointly provide the intelligence, knowledge basis, and the

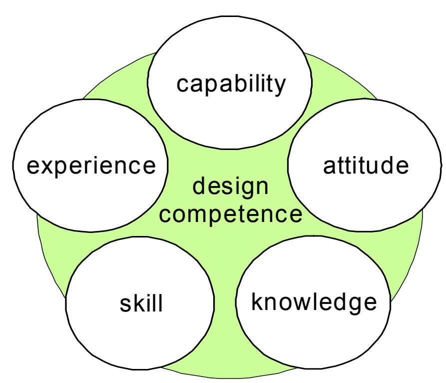

Figure 1 Interacting constituents of design competence

problem solving resources for design competence. Design capabilities are mental and/or physical potentials and qualities to perform a function. Design attitude is a way of thinking, acting and behaving related to design problem solving. Design thinking is reasoning in a constructive rather than just in a purely analytical way. Design knowledge is whatever we are aware of right now related to and/or independent from a problem at hand. Design knowledge or skill results from experiences. Design skills are learned abilities to perform a design action or execute a process. Finally, design experiences are actual observations of or practical acquaintance with solving practical problems. If we want to develop design competences for future designers, all the five capacities should receive equal emphasis in the educational programs, in particular in design courses.

4. DEVELOPING DESIGN CAPABILITIES

Design capabilities are natural capacities which enable us to act as designers. They manifest in various forms such as intelligence, imagination, creativeness, inventiveness, artfulness, technicality, pragmatism, and productiveness. The existence, strength and balance of these capacities determine how good someone can be in design. Design capabilities can be developed likewise any other innate physical and mental human capabilities. This development of this kind of capabilities typically requires many years of focused learning and practicing, and is usually challenging due to the abstract nature. Furthermore, they are complex and difficult to address directly. The possibility of development is higher if the level of the innate capabilities is reasonable high.

From the point of view of the E-GPR course it was of importance that all students had a remarkable suite of design capabilities, but they were varying and focused differently per individuals. They all had a degree of familiarity with design processes, but they were involved in different branches of design (industrial design engineering, electronic design, mechanical engineering design, design for sustainability, and computer aided design/engineering) and learned different methodological approaches. The course instructors observed remarkable difference also in terms of the way of handling design tasks. Students with industrial design engineering background preferred to do widely-based information gathering first and to generate multiple concepts then. Students with mechanical engineering background preferred starting out from existing solution paradigms and synthesizing novel solutions on this basis.

It has to be mentioned that the students teamed up according to their wishes. The only expectation was that each country should be represented in each team. This way the working teams were not only multi-disciplinary, but also very heterogeneous in terms of initial knowledge assets and design capabilities. The instructors also observed very large differences between students. Part of them wanted to rely on some familiar methodological framework; part of them concentrated on the general problem and tried to find candidate solutions in a pragmatic way. Part of them was ready to build pilot functional implementations based on intuitions; part of them had difficulties with making meaningful decisions and coming up with technically feasible concepts.

For the reason mentioned above, only two goals could be formulated: (i) optimal exploitation of the already available capacities, and (ii) harmonization of the various problem solving approaches and process organization/management capacities of the students. Related to the former goal, the instructors tried to explore the strong points as well as the weak points of the students, and to help the students to share the tasks at hand accordingly. With regard to the latter issue the instructors played a kind of moderator role by making efforts to find the optimal workflow according to the requirements of the problem at hand. During the project review meetings the students became aware of the way of thinking and working of the others, received feedback about the correctness of their approach, could compare the values of their concepts with what was expected by the company representatives and the instructors, and could see the best practices of the others.

Obviously, design capabilities are difficult to measure and capture due to their abstract nature. For instance, how can it be measured if students managed to sufficiently develop their systematic thinking, creativity or balanced comprehension? These are reflected and can only be implicitly judged based on the results of the course. This is the reason why virtual, physical, and augmented prototyping were put in a central position within the course and the academic virtual enterprise. We believe that further research is needed to investigate how design capabilities can be expressed and assessed with a view to some principles such as consistency, independence, timeliness, correctness and appropriateness.

5. DEVELOPMENT OF DESIGNERLY ATTITUDE

In its widest meaning, the word attitude means relationships between student and design profession. This relationship involves the way students regard the intellectual and social values of design profession, and how they habitually do things related to design. One of the goals of attitude forming is the development of a kind of designerly way of seeing, thinking and doing. Actually, a designerly attitude starts with some general elements such as behavior of the students towards systematic working, applying computer based tools, inclination to address concrete issues, and system oriented creative thinking. It is also expressed by being analytical and integrative at the same time, being critical about the outcome of decisions, and consideration of a wide range of aspects and issues related to real life problems. The designerly attitude also has other elements that are more specific to design. These are, for instance, such as (i) the way of thinking about practical creativeness, (ii) the motivation and inspiration of creating useful things, (iii) the enjoyment of inventing artifacts, and (iv) the mind set related to materialization and realization. Working in virtual environments points at other specific element of the designerly attitude, e.g., (vi) liking problem solving with multi-disciplinary flavor, (vii) openness to sharing problems, knowledge and resources, (viii) feeling responsibility towards others, and (ix) being accustomed to working in a multi-cultural environment.

It has to be noted that, development of the elements of the designerly attitude, likewise of capabilities, is challenging not only because they are numerous and interrelated, and some of them are even innate, but also because development needs time. It means attitude development should be a concern for the design education program as a whole, rather than just for specific courses. Nevertheless, even one design course can make remarkable contribution to the development of the specific elements of the designerly attitude, especially if the innate elements are present up to a level. This is actually our conclusion related to the recent E-GPR course.

There have been four things considered as means of developing specific elements of attitude: (i) increasing the curiosity of the students towards the designing, (ii) creating a stimulating environment for working, and (iii) facilitating achieving positive results and satisfaction, and (iv) being recognized for good results. The course organizers were aware that the students worked typically on educational problems so far, and they always felt that these were created only for educational purposes. We assumed based on former experiences that working on a tempting, open ended, real life problem will change their attitude. Hence, the design task for the course was selected from the daily design problems of the core company of the academic virtual enterprise. The company was a Switzerland-based medium sized company producing viticulture equipment. The task of the student was to develop a new concept of spraying equipment for insecticides in vineyards. More specifically, the company expectation was to design and prototype a human and environment friendly spraying equipment for small- and medium-sized vineyards.

The concept of academic virtual enterprise (AVE) has been invented with the aim to establish a stimulating learning and working environment for the students. The AVE is project-oriented educational arrangement, which is based on a volatile alliance of industrial and academic partners for mutual advantages. The AVE has a specific organization framework as well as an arsenal of tools to support video-conferencing, and collaborative design and engineering. Students are supposed to master the use of this CMU- and CSCW-based communication and collaboration infrastructure. This infrastructure made it possible for the students to move from the desktop video conferencing (DVC) to working in a true collaborative virtual prototyping environment (CVPE). Professional communication was supported by multiple channels and media forms, as it is typical in a shared multi-media environment (SMME).

Students were motivated by (i) working on a concrete industrial problem, (ii) being in daily contact with company designers and engineers, (iii) using videoconferencing for sessions, and (iv) even by being instructed by the company how to consider its goals, interests, and opportunities in conceptualization of the new product. The last issue, namely facilitation of satisfaction, was addressed by (i) careful monitoring of the progress of students, (ii) providing professional guidance and organizational support, (iii) offering the opportunity to prototyping and testing the designs, and (iv) making possible to report on the work done in a symposium and to make the tangible results of the work visible in an exhibition to the interested public. The students thought that the extreme large number of visitors was the largest recognition of their work, contrary to the high marks they typically received.

6. DEVELOPMENT OF DESIGN KNOWLEDGE

Industrial product design and development is characterized by synthesis of technological, business, social and human aspects. Without this multi-disciplinary knowledge integration and application of the learned scholarly and creative capabilities it is impossible to create competitive products.

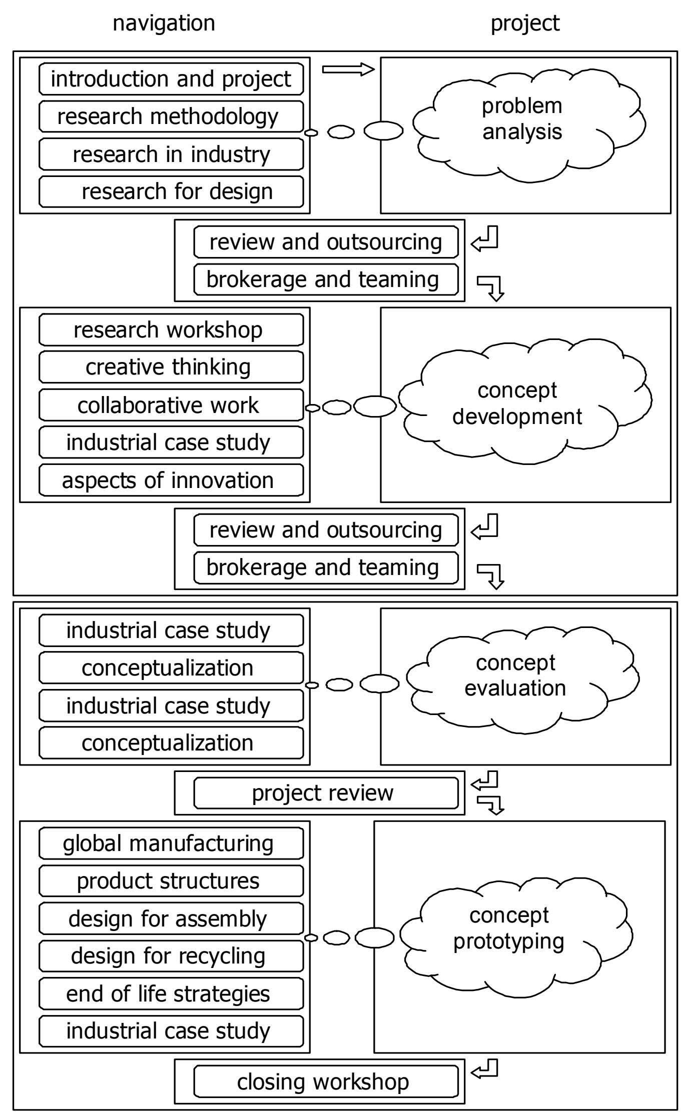

Figure 2 The interplay between technical presentations and problem solving

Design students have to be aware of a body of specific knowledge relevant and necessary for the particular field of design they are studying. Design knowledge is multi-faceted and it has both understanding and information elements. Understanding is of general nature, i.e., it goes beyond concrete design cases, while information is specific, i.e., associated with concrete design cases. The understanding part of design knowledge involves both formal (codified) design knowledge (originating in science and engineering) and informal (tacit) design knowledge (stemming from intuitions, experiences, and educated guesses).

Knowledge appears in four contexts in design education: obtaining, exploration, management, and application. In the E-GPR course the students have been put into the position of young professionals who are purposefully and systematically construct their knowledge in the academic virtual enterprise environment. The following sources have been considered for the students to acquire knowledge from: (i) academic lectures, which are thematically arranged according the knowledge needs of the design project (Figure 2), (ii) industrial case studies and best practice analysis lectures, (iii) explorative research related to trends technologies, users, markets, competitors, products, legislations, and design tools and methods, (iv) web-based literature search and information gathering, (v) brainstorm sessions, consultation and interviews with experts related to various sub-problems of the project, (vi) learning from each other in multidisciplinary students teams, and (vii) company visits and field experimentation, and (viii) self-management

From the many objectives of dealing with design knowledge in the E-GPR course, here we emphasize the following ones: (i) equip the spontaneously formed teams of design/engineering students with the theoretical and practical knowledge of international collaboration, (ii) cast light on the important role that operative design research plays in increasing the intelligence of designing by exploring new knowledge and by placing design decisions onto scientifically validated pieces of knowledge and information, and (iii) present the necessity of multi-disciplinary knowledge integration to enable solving complex real life product innovation problems.

A remarkable achievement of the E-GPR course is that a knowledge network has been established, which is an essential part of the overall collaboration framework. Knowledge is built and exchanged by communication and collaboration of the various participants (students, company experts, instructors, lecturers, researchers, industrial partners, and users) via various forms of interaction.

7. DEVELOPMENT OF DESIGN SKILLS

Design skills are various abilities that enable students to do design actions well. Skillfulness largely increases the potential of solving complex and challenging design tasks. Development of skills assumes special practical training which involves (i) correct application of design methods, (ii) effective use of design tools, (iii) creation and expression of dexterity with creating virtual and physical objects. As practiced abilities, design skills are closely related to experiences, so much that building experiences is inseparable from building skills in the educational practice. Skills in designing lend themselves to the efficiency and quality of designing. Obviously, the basic cognitive skills such as memorize, understand, and apply are indispensable for product design, but they should be complemented by more dedicated general design skills such as analyzing, synthesizing and evaluating skills.

In the literature, on the one hand, micro-, meso-, and macro-level skills have been distinguished, and, on the other hand, they have been classified, as perceptive, cognitive, and motor skills. Theoretically, five categories of macro-level design skills have been identified, namely: (i) design knowledge inquiry, (ii) situation diagnosis and problem analysis, (iii) artifact synthesis and prototyping, (iv) remote collaboration, and (v) project management capabilities. In the past, various problem and project oriented learning approaches have been applied to intensify the development of problem solving skills and obtaining experiences with solving real life problems.

From the extremely wide range of perceptive, cognitive and motor skills, the E-GPR course put the emphasis on the following macro-level skills: (i) exploration, aggregation, filtering and verification of information by using a diversity of information resources, (ii) multi-disciplinary design task analysis, discourse and critical reflection within the technical domain, (iii) application of various operative research methods together with structured design methods, (iv) effective communication and exchange of technical information in quasi-industrial circumstances by means of media application, (v) professional use of video-conferencing equipment and CSCW tools, (vi) decomposition of complex design problems and allocating the related tasks to experts, (vii) combining creative

Figure 3 Factory testing of the various prototype designs

Figure 4 Preparation of spraying equipment for field test

(artistic and craft) capacities with system development (mathematical modeling, analysis, synthesis, and digital simulation) capacities, (viii) self-responsible project organization, management, and allocation of resources, (ix) virtual, physical and augmented concept prototyping and testing, and (x) practicing of the English language on the level of business and professional negotiation.

The objective of the E-GPR course was to achieve a parallel development of intellectual skills and practical skills. The latter was achieved through building functional physical prototypes (Figure 3), that gave the opportunity for the students to test the operation, manufacturability, assemblability, and usability of the designs. Building these physical prototypes requested the students (i) to combine their background knowledge into a multi-disciplinary body of knowledge, (ii) to operationalize all of their professional skills, and (iii) to make the best out from their system oriented thinking.

8. DEVELOPMENT OF DESIGN EXPERIENCES

Design experience means the familiarity gained from seeing and doing things in the course of acting as designer. The goal of gaining experiences replaced the emphasis to the practical side of education, and placed the multi-disciplinary collaboration in the semester-long design project into the focus. By working in an academic virtual enterprise, the students could get experience with (i) using videoconferencing equipment, synchronous communication software, and collaboration support tools, (ii) integration of knowledge assets from multiple human and formal sources, (iii) harmonization of the concepts as well as the way of thinking and working of international partners, (iv) thinking and working according to the business interests, technical conditions, and best practice of an international company, (v) considering a wide range of feasibility aspects in concept development and design, (vi) implementation of rather complex functional models and physical prototypes, and (vii) testing the physical prototypes in real life experiments. This latter was considered an important goal, and actually has been successfully realized during the course. Having finished prototyping and factory testing (Figure 4), the students prepared their equipment for field tests, and tested them under field conditions. Various measurements were made by the company's specialists to check the spraying efficiency, fulfillment of the environmental regulations, and the comfort of using the equipment (Figure 5). The members of the six student teams could compare the performance of their equipment with the other teams and learn from it.

Experience also means the feelings and reflections obtained in relation to designing and designs. Experiences may affect the attitude of the students positively or negatively. This was also a question for our research what influence this

Figure 5 Field test of the spaying equipment

complex course has on the feelings of the students. It was observed that taking successfully all challenges that came along from the complex industrial problem and from working in an academic virtual, gave satisfaction to the students and increased their self confidence. Nevertheless, they made some critical comments on the difficulties of organizational communication which has in many time adversely affected their cooperation.

A qualitative research has been completed with the involvement of 46 students to make out how our approach contributed to the development of the elementary design competencies. Not surprisingly, the students' response indicated that they found the process management and infrastructure utilization capacities more important elements of the design competence of the future product designers, than the conventional design capacities. It has to be noted that experience has a time factor, i.e., it needs time to be built up through repeated trials. Unfortunately, this aspect could not be considered in the E-GPR course due to the fix timeframe. Nevertheless, the AVE framework proved to be an original concept to supporting active learning. The industrial partner provided full professional and financial support for the course, in particular for the design project. The students received immediate feedback on the proper application of the acquired knowledge and the practical value of their proposed solutions.

CONCLUSIONS

The goal of the European Global Product Realization courses is to enable students to develop capabilities that are needed (i) to solve complex, real life new product development problem, (ii) to collaborate over geographical, professional and cultural boundaries, (iii) to generate product ideas and forward them to the status of testable product prototype, and (iv) to organize and manage their knowledge inquiry and skill development. The recent course concentrated on the issues related to comprehensive design competence development that was, on the one hand, the educational goal, and, on the other hand, was the focus of the accompanying staff research. Our assumption was that design competence is actually a composition of capabilities, attitudes, knowledge, skills and experiences, and should be developed by giving balanced attentions these generic constituents, rather than by focusing on a specific set of elementary design competencies.

Our experiences show that the educational concepts applied in the E-GPR course are relevant to, and useful for a comprehensive development of design competence. These concepts are: (i) cooperating with industrial company and other international academic partners in an academic virtual enterprise, (ii) project oriented leaning on the basis of solving a real life industrial design problem, (iii) interaction of the disciplinary specializations of the students, (iv) working in multi-disciplinary and multi-cultural student teams, and (v) professional use of communication and collaboration support tools and methods. As a conclusion we can assert that the interaction of these major educational concepts is the major factor in the development of a comprehensive design competence. Another conclusion has been that our approach equally well supports the development of both the holistic design competence and the elementary design competencies. The students' opinion has been that the course was challenging but rewarding from the point of view of their future carrier as product designers. They indicated that they receive a lot from what they need to be able to successfully operate in geographically dispersed virtual enterprises.

Another interesting conclusion is that our constructive approach is appreciated by the students not only because of its novelty, but also for the reason that it puts design education and building design competence in a social context. This way the take away of the students is magnified and the experiences can have more influence on their professional carrier. This was confirmed by the reflections of the students. Their assessment shows that the E-GPR course made it possible for them to develop not only those competencies that are required to pass a written exam (e.g. memorizing lexical data and reasoning based on content), but also those which are needed for solving concrete problems, or, in a more general sense, for their future professional life.

Our last conclusion is that our investigations were in fact very limited in scope and actually many more things should be investigated in order to have a validated theory of comprehensive design competence development. In our study we could not deal with the comparison of educational design of various courses from the aspects of efficiency, trade-offs, and results. We were not able to analyze the situation of design competence development in association with students as individuals. Likewise, investigation of the relationships between the generic constituents of design competence (capabilities, attitudes, knowledge, skills and experiences) and the specific needs of various design tasks remains for future research.

NOMENCLATURE

The following acronyms are used in the text:

AVE	Academic Virtual Enterprise
CSCW	Computer Supported Cooperative Work
CVPE	Collaborative Virtual Prototyping Environment
DVC	Desktop Video Conferencing
E-GPR	European Global Product Realization
SMME	Shared Multi-Media Environments
VDS	Virtual Design Studio
VPP	Virtual and Physical Prototyping

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