INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'09
24 - 27 AUGUST 2009, STANFORD UNIVERSITY, STANFORD, CA, USA

EXPERIENCES WITH COMBINING PEDAGOGIC THEORIES IN THE EUROPEAN GLOBAL PRODUCT REALIZATION COURSES

Imre Horváth, Niels C.C.M. Moes
Delft University of Technology

ABSTRACT
The European Global Product Realization courses are organized for design and engineering students based on the partnership of five European universities and volatile industrial companies. They focus on new product conceptualization for global realization and use. Four major goals were formulated: (a) exploring and aggregating knowledge for successful innovation, (b) finding proper solutions for the real life conceptualization problem, (c) realizing the solution concepts in functional and testable prototypes, and (d) mastering the use of media-enriched telecommunication in remote cooperation. In order to enable the students to cope with the challenges and achieve optimum output, a specific course design is applied. It has three major learning components, namely: (i) synthesizing disciplinary background knowledge, (ii) exploring and scrutinizing product- and stakeholder-specific information, and (iii) conceptualization and prototyping of artifacts and services. These components have been underpinned by different pedagogical theories and methodologies, such as instructive, explorative and constructivist. The mixed use of these principles enabled us to increase the efficiency of the whole course and achieve remarkable results.

Keywords: Pedagogic theories, instructive learning, explorative learning, constructive learning, mixed theory approach, European Global Product Realization courses

1 INTRODUCTION
The European Global Product Realization (E-GPR) courses have been organized based on the partnership of five European universities from different countries (Table 1). The courses are driven by four major goals: (a) exploring and synthesizing knowledge for successful innovation of products with global character, (b) finding proper solutions for the real life product conceptualization problem, (c) realizing solution concepts in functional and testable prototypes, and (d) mastering the use of media-enriched telecommunication in remote cooperation. Offered for design and engineering students, the E-GPR courses are committed to a collaborative ideation and a multidisciplinary conceptualization of novel products, which fulfill the specific needs of the concerned problem-owner companies and their stakeholders. While the academic partners have been the same over the years, a new company is invited for a volatile partnership in every year. The formation represented by the collaborating academic institutions and industrial companies has been called academic virtual enterprise (AVE). The course has been the subject of educational research done by the involved staff (professors and instructors) with the help of the participating students. The major achievements, findings, and experiences with many of the previous courses have been published in various papers [1], [2], [3], [4] and [5].

1.1 Challenges for the students
Regularly 45-50 students in total take the course in the spring semester of each academic year. Typically 5-6 mixed teams are formed, with 8-9 international students in each, who work on different product concepts. The background knowledge of the students originates from various fields, such as industrial design engineering, mechanical engineering, electrical engineering, engineering design, and manufacturing technologies. The students are put into the position of self-organizing and self-responsible evolving young professionals, and they perform both as knowledge producers (researchers) and as knowledge consumers (designers) at the same time. They work together using

Table 1. Participants and objectives of the various E-GPR courses

Year	University participants	Core company	Topic of semester project	Educational objective	Staff research's objective
2001 - 2002	UoL, EPFL, and DUT	LIV Postojna, Slovenia De Vlamboog, BV, the Netherlands	Adaptive vacuum cleaner Respiratory protection device	Redesigning and prototyping consumer durables for global market	Dislocated cooperation in academic virtual enterprise
2002 - 2003	DUT, UoL, and EPFL	De Vlamboog, BV, the Netherlands	Integrated welder protection solution	Conceptualization and prototyping future product for the core company	Project oriented learning in virtual environment
2003 - 2004	EPFL, UoL, UoZ, and DUT	De Vlamboog, BV, the Netherlands	Advanced visualization based welding mask	Combining operational research and product conceptualization	Navigation of active learning
2004 - 2005	EPFL, UoL, UoZ, CUoL, and DUT	AVIDOR, Switzerland	Sustainably sprayer for vineyards	Practicing human- and environment-centered product development	Development of holistic design competence
2005 - 2006	EPFL, UoL, UoZ, CUoL, and DUT	Kesslers International, Ltd., England	Novel displays for male grooming products	Consideration of human experiences in product conceptualization	Videoconferencing as a means of design collaboration
2006 - 2007	EPFL, UoL, UoZ, CUoL, and DUT	Niko, d.d., Slovenia	Stairs climber	Innovation through reusing standard engineering solutions	Attitude development in academic virtual enterprise
2007 - 2008	EPFL, UoL, UoZ, CUoL, and DUT	TEHNIX, d.o.o. Croatia	Portable ecological house	Awareness of the principles of ecologically and socially sustainable design	Multi-disciplinary knowledge integration
Abbreviations: CUoL - City University of London, England; DUT - Delft University of Technology, the Netherlands; EPFL - Ecole Polytechnique Federale Lausanne, Switzerland; UoL - University of Ljubljana, Slovenia, and UoZ - University of Zagreb, Croatia					

video-communication throughout the semester, and meet in person only during the one-week long closing workshop at the end of the project.

The students need to cope with multiple challenges that are raised by the necessity of (i) teaming up and cooperating with previously unknown foreign students of different mindsets and cultural backgrounds, (ii) acquiring and aggregating knowledge from multiple disciplinary fields, (iii) taking the responsibility of organizing their own actions and processes within the international teams, (iv) managing the complexity of the real-life design problem, (v) working together with industry experts remotely, as well as by the (vi) the high expectations for the quality and practical usefulness of the product concepts, and (vii) the required strong commitment and persistence. The students need to split their attention amongst three domains of activities: (i) synthesizing different bodies of background disciplinary knowledge, (ii) exploring and scrutinizing product- and stakeholder-specific information, and (iii) conceptualization and prototyping of artifacts and services. Indisputably, this totality was difficult for the students to tackle within a one semester course, at least in the first years of running the E-GPR course.

1.2 Challenges for the course developers

At the beginning, the E-GPR courses have been offered to students as a project-based active learning exercise with a focus on product design for global markets. In case of active learning, learners are supposed to take a greater responsibility over their own inquiry and learning, and over the organization of what has to be learned or what they prefer to learn. That is, the tasks of self-management, self-motivation and self-critique were delegated to the learners. However, soon after launching, the issues of coping with the above described complexity, intensification of the work towards tangible outcomes, and providing inspiring learning experience for the students have popped up. This called the attention of the course organizers to the fact that there was a need for a better pedagogical structuring of the course. At that time, it was based on the theory and principles of constructive learning, in particular, on those of project-based learning.

Our research explored that, alone, none of the known and tested educational theories are able to provide sufficient underpinning for each of the abovementioned three domains of activities of students. The reason is that the educational theories make specific assumptions on (i) the basic mechanisms of learning, (ii) the links between the learners and the subjects matter to be learned, and (iii) the relationship of the learners and the educators. In a sense, they explain only part of the total picture and from some particular aspects. Furthermore, they all have their own pros and cons. Consequently, it has been hypothesized that learning components should be identified within the course and that they should be underpinned by different learning theories. Assuming that the individual learning theories go well together and, when integrated, lend themselves to an efficient solution not only on learning component level, but also on course level, a decision has been made to work out and introduce a mixed theory-based course design. We will further elaborate on these issues and the related reasoning in the next Sections.

It should be noted that his paper does not concentrate on one particular course, but on the developments in terms of the pedagogical framing of the courses over the last four-five years. In the next Section, we survey and analyze the major education theories and methodological approaches adopted in the recent European Global Product Realization courses, and the involvement of learners in the related forms of education. In Section 3, we explain how instructive, explorative and constructivist theories have been combined and embedded in the program of the E-GPR course. Finally, in Section 4, we will discuss our observations and major findings, and propose some conclusions.

2 OVERVIEW OF THE MAJOR LEARNING THEORIES AND THEIR IMPLICATIONS TO THE PRACTICE

2.1 Instructive learning theory

Instructionism is a kind of educational application of objectivism and a typical methodological approach of in-school learning, involving lecture halls, class rooms, laboratories, practice rooms and study/library rooms. Instructionism is also an education strategy which presumes that learning entails knowledge transfer and submission of learners [6]. As a methodological approach, instructional education focuses on the knowledge flow from educator to learner, and describes not only what is to be learned, but also how it is to be done. Instructive learning typically involves lectures and demonstrations in which the students play a passive and dependent role. Traditionally, instructional courses have been designed as systematic processes to achieve desired educational goals and results, but by reasoning backwards, that is, starting from the goals and setting up strategies, using supportive methods, and passive learning materials to achieve them. The instructive approaches have been found more useful for teaching theories and other knowledge constructs than for developing competence and experiences [7]. The goal of instructional methodology is to improve instruction and comprehension. To this end, it employs teaching methods, processes, and study materials that support the instructors to intensify the transfer of knowledge as well as the learners in absorbing knowledge.

One way of this intensification is to use computers in education. Instructional technology means integration of computer and network technologies into the curriculum and instruction. Actually, in some approaches, computers do the instruction, which leads into the whole idea of computer-aided instruction and computer-based instructional systems [8]. Having many advantages, learning through hypermedia has become a popular form of instructional education. For the time being, successful navigation in hypermedia systems needs the orientation and explanation of the instructor, or else it might lead to disorientation and confusion [9].

Although instructional education is proliferating due to the push of computer-based technologies, cognitive and developmental psychologists criticize it for imposing constraints on the dynamic interaction of the learners with the real world while they are constructing their own knowledge. It is also criticized for the inherent constraints and for the dependence on the school facilities. In addition, it has been found that instructional education does not support learning in complex domains and socialized knowledge creation sufficiently. One part of the trouble with instructive learning is that its goal remains to communicate knowledge by teachers in the most objective and efficient manner [10]. Other part of the trouble is that it is not easy to include interactive learning strategies that facilitate the active and interdependent involvement of students on the basis of the underpinning educational theories and infrastructure [11]. This explains why many researchers propose to combine acquisition strategies and participation strategies instead [12].

2.2 Explorative learning theory

The main assumption of the explorative learning theory is that learning decomposes into two main process elements: *exploration* (searching for and unearthing) of knowledge and *explanation* (interpretation) of the knowledge in context. Explorative approaches of learning stimulate intentional searching for information and knowledge, and support aggregation of domain knowledge based on the development of, or elaboration on hypotheses and theories [13]. That is, they go beyond posing questions and seeking answers. It has been observed that exploration embedded in real work context increases the authenticity of the learning tasks and increases the motivation of the learner [14]. In general, what learners do is experimenting, research, discovery, or a combination of these. Methods of empirical and qualitative research have been considered the most effective facilitators for explorative learning, in particular, in university level engineering education. The cognitive interaction between the learners and collaborative groups work has been also activating [15].

Explorative learning can be further articulated according to the way of implementation, or, in other words, the methods of exploration [16]. There are three typical representatives of this methodology, namely: (i) learning by experiments, (ii) learning through research, and (iii) learning by discovery. In the case of *learning by experiments*, the learners create simplified models of parts of the world, design their own experimental environments, observe and analyze experimental results, and regenerate alternative hypotheses. This approach assumes that students learn how to design experiments and how to accomplish them in a controlled manner. That is, designing experiments should be embedded in the program of the accompanying courses, or preferably in the forerunning courses.

Learning through research is a structured inquiry-based learning, helping the learners formulate research questions and generate knowledge with sufficient rigor. Typically, a structured process is involved proceeding with identification of the problem, forming hypotheses and theories, collecting and analyzing data, and verification and conclusion. Learning through research requires the students to be aware of the basic principles of scientific research, to know which qualitative and quantitative methods to choose and how to apply them, and how to interpret and generalize research data and findings. This typically needs preliminary studies and skill development. *Learning by discovery* combines experimenting and doing research, requires development of search strategies, investigation of cases, analogies and patterns. Like instructive learning theory, explorative learning theory also enforces a kind of analytic view and approach.

2.3 Constructive learning theory

The theory of constructivist education explains that learning is a process of construction and confrontation of meaning rather than exploration and memorization of facts. In addition to the making of meaning, it emphasizes the social aspects of learning, interactions with the environment, distributed cognition, and the endeavor of completion [17]. Constructivism holds that it brings an advantage for the learners if they acquire knowledge by building it from innate capabilities by solving problems in an organized process and in interaction with the environment [18]. It assumes the learners constructing knowledge for themselves by creative activities such as planning and design. The *cognitive constructivists* give priority to sensory-motor and conceptual activities of individual learners [19]. The *social constructivists* prefer building knowledge by a group of learners in social context [20]. The philosophy of social constructivism, through use of collaborative discussion and a digital story telling-based learning styles theory, established the basis for Shih's mobile learning model [21].

Constructive learning represents a learner-centered form of education and manifests in a broad diffusion of approaches of *stimulated active learning*. In the fields of design and engineering, constructive learning involves creative action, and targets both individuals and groups. Form a didactic point of view, the learners involved in stimulated active learning can follow individual learning paths, can act in different functions, but they may also collaborate (or compete) with each other in teams and with other teams. This latter gives the floor to more social interaction and prepares the learners for the challenges posed by working together with unfamiliar individuals, solving complex tasks based on remote cooperation, and other real life situations. They can integrate new knowledge in various ways according to their own mental schema and get immediate confirmation on the appropriateness of the use of this knowledge. This way, they can constantly check the validity of their mental models in the course of inquiry and problem solving. It has been recognized that the constructive methods are working well with learners who have reached the formal operation level of development.

Constructive learning also applies *co-operative learning strategies*, and places emphasis on the development of cohesion, communication, and endeavor. When oriented to a group of learners, it forwards group learning to group functioning [22]. Supported by web technology, collaborative learning enables interaction with distance partners and repositories of data [23]. In an ultimate case it creates active learning communities based on virtual communication and course programs developed for multi-cultural study groups [4]. There are three major forms of constructive learning (i) case-based learning, (ii) problem-based learning, and (iii) project-based learning. The objective of *case-based learning* is to place the learners in direct contact with the subject matter through practical (real-life) cases, and to facilitate finding information through critical analysis and social communication.

Problem-based learning concentrates on (i) better understanding and solving recognized problems, and (ii) motivating learners to achieve better performance [24]. It emphasizes learner-centered learning activities that are interdisciplinary and integrated with real world concerns and approaches [26]. As Schmidt, H. G. analyzed, problem-based learning stimulates learning through a number of cognitive areas, e.g., (i) activation of learners' prior knowledge, (ii) elaboration of prior knowledge through cooperative discussions, (iii) restructuring of knowledge to fit the problem presented, (iv) construction of an appropriate semantic network through internal discourse, (v) learning in the scaffolding context of a real-world problem, and (vi) emergence of epistemic curiosity due to relevance of problem [27].

Project-based learning gives priorities to learning activities that are for long-term, multidisciplinary, and connected to real world issues and practices [25]. Various approaches have been developed and investigated [28]. Obvious advantages of project-based learning are (i) the opportunity of collaborating productively in teams, (ii) identifying someone's own strengths and weaknesses, (iii) preparation for problem solving in unfamiliar situations, (iv) enforcing a holistic approach and thinking, (v) reasoning critically and creatively, and (vi) committing oneself to lifelong learning. In the field of product design and engineering, project-based learning is either an artifact synthesis process, or an artifact analysis process. Project-based learning is an adequate pedagogical methodology for design and engineering education since it allows a group of learners to collect, analyze and synthesize information, develop alternative problem solving strategies, and improve their skills and capabilities [29].

2.4 Involvement of learners

Operationalization of the learning theories involves not only methodological frameworks and approaches, but also the targeted learners and their participation in achieving the goals of learning, Obviously, learning can be organized for an individual (one person), a group (team, class, year) and a public (communities, segment of population). The philosophy of individual oriented approaches is that learners with different background, interests and capabilities may follow different learning paths adapted to their personal needs. The philosophy of group oriented approaches puts dynamic interactions and collaboration of multiple learners into the center and pursues methodologies for a full scale exploitation of the social elements [30]. Finally, community oriented learning methodologies try to satisfy the learning needs of large segments of the population relying on various public media [31]. By combining the methodological approaches with the targeted learners, we can define a kind of topography of the conventional learning approaches. This is presented graphically in Figure 1. We can observe the scarceness of explorative and constructive methodological approaches for direct public education and learning, whereas several methodologies are available for individual and group learning. A further aspect of discussing educational methodologies is the form of participation of learners in the learning process. From this aspect we can sort the methodological approaches into the categories of passive and active learning. *Passive learning* methodologies are directed to absorption and imprinting, and establish a short term, educator-centered, and isolated educational practice. Conventional lecture hall and class room presentations are representatives of passive learning set-ups. *Active learning* reflects the principles and assumptions of the cognitive and constructivist philosophies. Its typical goals are: (a) substitution of absorption of information with more intensive forms of thinking, (b) engaging the learners in a fast-paced and intuitive learning process and environment, (c) improvement of creative skills, capabilities and competencies, (d) enhancement of experiences and sharing know-how. To achieve the above goals, active learning methodologies applied in design and engineering embed various facilitators such as (i) problem-solving, (ii) systematic inquiry, (iii) task, context and semantics analysis, (iv) creative synthesis, (v) application of equipment, tools and computer programs,

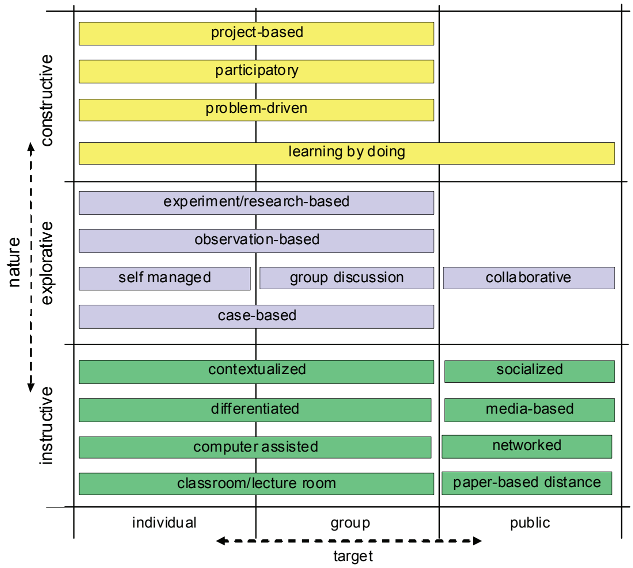

Figure 1. Learning methods to connect learning theories and target learners

(vi) artifact evaluations and experimentation (vii) literature studies and operative research, and (viii) discussion forum and workshop.
The fundamental didactic approach of active learning is *learning by doing*. It has several manifestations, which have been described by various, often synonymous, terms such as, self-managed learning, problem-driven learning, project-based learning, networked collaborative learning, and so forth. Learners are, to a large extent, their own educator, and this improves the skills and capabilities needed to extend the existing knowledge, and to apply what they have learnt. The supporting technologies can be categorized as conventional and advanced ones [32].
Active learning can involve a single learner or a community of learners with homogeneous or heterogeneous interests in the mind. Active learning of a single learner may manifest in a variety of forms, such as collaboration with the educator, multi-media study, and carrying out a personal project. The typical forms of active learning of teams are cooperative problem analysis, team and multi-team projects, or taking part in real life undertakings. Active learning seems to offer better opportunities for learning in the emerging knowledge society, where the dynamics of knowledge is high, and the amount of knowledge is rapidly growing Due to the increasing need for new knowledge, there is a need for flexible life-long learning (LLL). Preparation for LLL involves the development of the attitude and mentality of being interested in new knowledge, and the capabilities to generate innovative ideas and to make founded decisions, as well as the skills needed to cooperate with other professionals and to solve complex multidisciplinary problems [33].

3 COMBINING AND EMBEDDING LEARNING APPROACHES IN THE E-GPR COURSE

3.1 Main considerations and course design

From the beginning, various course programs and pedagogical frameworks were constructed and made operational in the E-GPR courses. As noted earlier, since the primary goal of the course was to facilitate and stimulate learning by doing, we based the course exclusively on the principles proposed by the constructive learning theories. In our practice it meant that the course was organized as a project-driven course, focusing on problems-implied learning, creative problem solving and socialized multi-disciplinary cooperation. However, we observed many important things. For instance, the complexity of the semester projects and the need for intense cooperation was overwhelming for the student teams. Without orientation, students often spent much more time on acquiring project related, but text book level knowledge, than was desired and useful. Furthermore, the students who had not heard about the methods of design research had difficulties with conducting exploratory and confirmative research, and produced results of limited value. These limitations in the research skills also had a negative impact on the learning of these students. They could not arrive at sufficient and proper in-sights and a correct understanding of the boundary conditions and the relationships between the main influential factors of the product innovation tasks at hand. Therefore the final outcome was suboptimal in terms of both the project deliverables, and the students' learning by inquiry.

These called our attention to the fact that, though popular in the context of design education, a constructive learning theory-based approach alone is not capable to achieve optimal results. Based on our multi-year experimentation with various course programs and structures, we assumed that this situation can be resolved, or alleviated by considering

- the instructive learning theory as an instrument for transferring the necessary disciplinary knowledge, professional know how, best practices and experiences,
- the explorative learning theory to enable attaining and scrutinizing product and stakeholder specific information and knowledge, and
- the constructive learning theory to enable conceptualization and prototyping of artifacts and services and learning from these in social context.

The instructive learning theory considers learning as achieving understanding, and places it in a cognitive perspective. The explorative learning theory explains learning as an explorative activity, and places it in an empiricist (and associationist) perspective. The constructive learning theory interprets learning as a creative social practice, and puts it in a situative perspective. Hence, the considered theories allowed us to address concurrently multiple aspects of active learning. On the other hand, they implied the necessity of combining different learning approaches which manifested in three learning components in the pedagogical framework of the E-GPR courses (Figure 2). Actually, this course design was adapted four years ago to give floor to specific *learning components*, which have been called 'navigation', 'exploration' and 'innovation'. Our objective was to achieve a strong interaction among the learning components in order to intensify the learning of the students and to provide positive experiences. From a methodological point of view, the introduced pedagogical framework enabled multi-methods learning, which proved to be more efficient in our practice-oriented design education than the traditional mono-method (i.e. project-based) learning approach. The course design is graphically shown in Figure 3.

The learning component called 'navigation' was organized according to the principles of instructive learning. It consisted of a series of videoconferencing-based lectures, which provided the students with specific professional and procedural knowledge, as well as factual information that they could use or benefit from in solving their product conceptualization problem. Actually, these lectures included oral presentations on the set up, content and conduct of the course, the objectives, the product innovation strategy to be followed, various bodies of disciplinary engineering knowledge, the characteristics and application of research methods, specific product and process technologies, principles of product innovation in global context, human and business factors, and the principles of ecologically and socially sustainable design. In addition, presentations about the company and its clients, product demonstrations and/or company visits were also included. This navigation and provision of project-

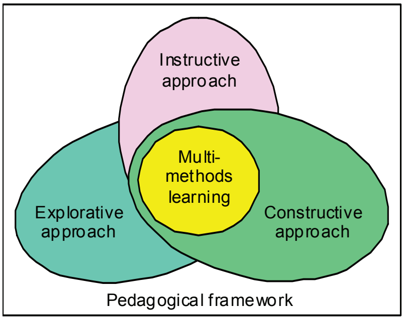

Figure 2. Concept of multi-methods learning

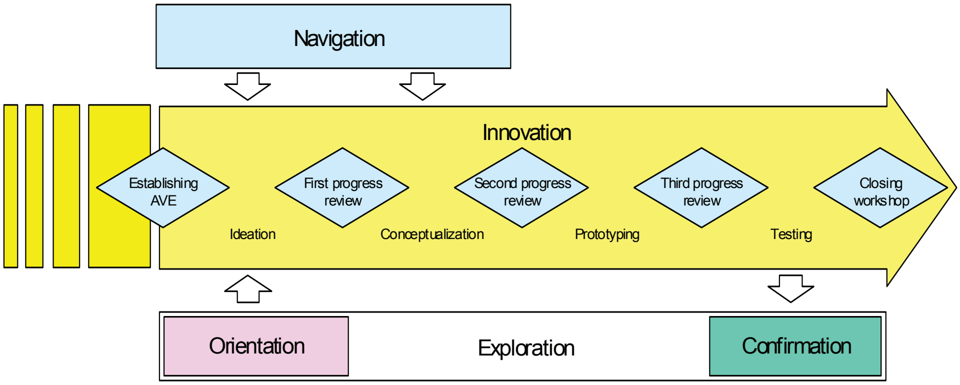

Figure 3. The course design

specific knowledge was important from the aspect of creating a common intellectual (thinking) platform for the students, who featured different specialization and background knowledge. As these considerations show, our intension was to equip the students with the necessary problem solving knowledge and information, rather than with just lexical ones.

The 'exploration' learning component was based on operative research and associated with both the ideation and the testing phase of the project. Hence, it served a dual goal: (i) prospective orientation, concerning the current state of the art, and the opportunities and possible directions of innovation, and (2) a retrospective confirmation, concerning the validation of the used methods and the project's outcomes, in the contexts of product functionality, usability and experience. Typically, the student teams conducted literature studies and keyword constructs-based searches on the Internet, completed market and user studies, did observational research, organized workshops and brainstorming sessions with industrial and academic experts, and investigated products and technologies experimentally in the prospective orientation part of operative research. The confirmative part of research involved experimental testing of prototypes, user-product interaction studies, user experience studies, and environmental impact studies.

The 'innovation' learning component was a project-based and design problems-driven vehicle in the past E-GPR courses. This involved ideation (analysis), conceptualization (synthesis), prototyping (detailing) and testing (experimentation) actions. From a didactical point of view, the goal of this learning component was twofold: (a) facilitating active learning and design competence development of the students related to the company-specified innovation task, and (b) enabling the students to find real life solutions for real life problems, while purposefully and systematically constructing their knowledge. Innovation of new global products for the problem-owner company comprised (i) generating ideas for the new solutions (product and service combinations), (ii) searching for new design concepts and analyzing them from system integration point of view, (iii) virtual and physical prototyping of alternative solution concepts, (iv) multi-aspect functional simulation and life cycle analysis of the solution concepts, and (v), experimental testing of human interaction with the solution concepts and assessment of usability. Shown in Figure 4 are some randomly selected examples of the physical prototypes that have been developed by the students in the past years. Pursuing their own genuine solutions, the international student teams always ended up with very different physical prototypes.

3.2 Discussion of the observations and experiences

As argued in [5], the educational and professional objectives of the various E-GPR courses were to enable students to develop design competences that are needed to (i) solve complex, real life, new product innovation problem, (ii) collaborate over geographical, professional and cultural boundaries, (iii) generate product ideas and further develop them to the status of testable product prototype, and (iv) organize and manage their knowledge inquiry and skill development. The subsequent courses reflected a growth of complexity that was the consequence of (i) the increasing sophistication of the industry proposed innovation projects, (ii) the growing number of students and the differences of the

a. E-GPR 2002/2003 b. E-GPR 2003/2004 c. E-GPR 2004/2005

d. E-GPR 2005/2006 e. E-GPR 2006/2007 f. E-GPR 2007/2008

Figure 4. Examples of physical prototypes produced by the student teams in the past years

background knowledge, (iii) the video-conferencing-based conduct of the courses, (iv) the extent of autonomy and self-organization of the student teams, (v) the amount of information needed to successfully complete the projects, and (vi) the relatively short time (one semester). Actually, our most important observation was that the E-GPR courses needed much more organizational efforts and time investment from the students than the regular design courses. Students had to spend unnecessarily large amount of time on searching for project (company, product, and trends) related information, familiarizing themselves with the needed research methods and tools, and mastering self-organization and remote (ad hoc) multi-personal communication.

This gave the inspiration for the course organizers to start thinking about an effective pedagogical framework, which would reduce the 'wasted' time, rationalize the inquiry of the students, and intensify their learning in comparison with conventional project-based learning. The learning theories discussed in this paper provided empirically-based accounts of the variables which influence the learning process, and explained the ways in which that influence occurs. The proponents of the various learning theories prescribed the broad principles through which the concerned theories could be applied in the learning and teaching practice. However, they did not clarify how the complementary nature of the theories could be exploited at organizing practical product innovation courses, and how they could be combined towards optimum results. Considering the elements and principles of the instructive, exploratory and constructive learning theories, we constructed a specific pedagogical framework that enabled a multi-method approach to the project work.

It is difficult to find quantitative measures to objectively express the influence of the applied pedagogical framework. However, the tension caused by the growing complexity of the semester project was decreased, and the professionalism of handling the semester project was improved. The students could go through the tasks of market analysis, product definition, product conceptualization, and virtual and physical prototyping and testing more systematically. The progress of the students was recurrently checked during the three mid-term project reviews, and evidenced by the high quality prototypes that were put on show at the exhibition on the last day of the week-long closing workshop. The instructive part of the course (navigation) facilitated an intense transfer and absorption of knowledge and information. The acquired knowledge was directly activated in the more creative parts (exploration and innovation) of the course, based on some intensive forms of thinking such as inquiry, analysis, synthesis, evaluation and application. The different solution concepts the student teams ideated required them to selectively activate and use their knowledge in context. Eventually, as the students formulated, what the used pedagogical framework provided for them was a widely based active experiencing with collaborative problem solving, self-management, self-motivation and self-critique [3].

4 CONCLUSIONS

Our impression has been that combining learning theories in one pedagogical framework provides benefits in project oriented design courses. Instructive learning can be used to intensity of knowledge transfer in time-constrained situations such as acquiring knowledge for the fuzzy front end and conceptualization parts of product innovation within a semester project. Instructive learning reduces the time spent on the aggregation of artifact, process and task specific factual information and also allows an intensive transfer of know-how type of knowledge. Though it is typically considered one-way communication, it can be converted into a two-ways communication by enforcing interaction between the educators and the learners, even in a virtual environment. Various forms of instructive learning can also be used to familiarize the students with the general concept of operative design research, inform them about relevant research methods, the best practices, and the correct way of combining design and research activities. They can apply and practice with these pieces of knowledge immediately in the semester project. This creates a bridge between the instructive and the explorative approaches of learning. Exploratory research activities have been found very useful to improve the analytical skills of the students. That is, the three theoretical foundations and the related methodological approaches complemented each other in a powerful pedagogical framework. The mixed application of the principles of the three major learning theories enabled us to increase the efficiency of the E-GPR courses and achieve optimum results over multiple years.

REFERENCES

[1] Horváth, I., Duhovnik, J. and Xirouckakis, P. Learning the methods and the skills of global product realization in an academic virtual enterprise. *European Journal of Engineering Education*. 2003, 28(1), 83-102.

[2] Horváth, I., Wiersma, M., Duhovnik, J. and Stroud, I. Navigated active learning in an international academic virtual enterprise. *European Journal of Engineering Education*. 2004, 29(4), 505-519.

[3] Horváth, I., Xirouchakis, P., Duhovnik, J. and Wiersma, M. Reflections of teaching global product realization in academic virtual enterprise. in *Proceedings of ASME 2004 Design Engineering Technical Conferences - DETC'04*, 28 Sept.-2 Oct., 2004, Salt Lake City, Utah, DETC2004-57626, CD-ROM, pp 1-10 (ASME, New York).

[4] Bufardi, A., Xirouchakis, Duhovnik, J. and Horváth, I. Collaborative design aspects in the European Global Product Realization project. *International Journal of Engineering Education*, 2005, 21(5), 950-963.

[5] Horváth, I. Design competence development in an academic virtual enterprise. in *Proceedings of ASME 2006 Design Engineering Technical Conferences - DETC'06*, September 10-13, 2006, Philadelphia, PA, DETC2006-99162, CD-ROM, pp 1-10 (ASME, New York).

[6] Coleman, E. B., Brown, A. L. and Rivkin, I. D. The effect of instructional explanations on learning from scientific text. *The Journal of the Learning Sciences*. 1997, 6(4), 347-365.

[7] Reigeluth, C. M. (ed.) Instructional-design theories and models: A new paradigm of instructional theory. Vol. II, 1999 (Lawrence Erlbaum, Mahwah, N.J.)

[8] Reeves, T. Pseudoscience in computer-based instruction: The case of learner control research. *Journal of Computer Based Instruction*. 1993, 20(2), 39-46.
[9] Chu, K. C., Urbanik, N., Yip, S. Y. and Cheung, T. W. The benefit of virtual teaching to engineering education. *International Journal of Engineering Education*. 1999, 15(5), 334-338.
[10] Jonassen, D. H. Objectivism vs. constructivism. *Educational Technology Research and Development*. 1991, 39(3), 5-14.
[11] Villalba, C. and Romiszowski, A. Current and ideal practice in designing, developing, and delivering web-based training. in *Web-based training*, ed. by Khan, B. H., Educational Technology, 2001, pp. 325-342 (Englewood Cliff, New York).
[12] Sfard, A. On two metaphors for learning and the dangers of choosing just one. *Educational Researcher*. 1998, 27(2), 4-13.
[13] Gascueña, J. M. and Fernández-Caballero, A. An agent-based intelligent tutoring system for enhancing e-learning/e-teaching. *International Journal of Instructional Technology and Distance Learning*. 2005, 2(11), 11-24.
[14] Oppermann, R. User interface design. in *Handbook on Information Technologies for Education and Training*, ed. by Adelsberger, H. H., Collis, B. and Pawlowski, J. M., 2002, pp. 233-248 (Springer Verlag, Berlin).
[15] Shih, J.-L. A pedagogical design strategy for effective technology-based learning: iLEARN model. *International Journal of Instructional Technology and Distance Learning*. 2004, 1(8), 71-81.
[16] Billett, S. Towards a theory of workplace learning. *Studies in Continuing Education*. 1992, 14(2), 143-155.
[17] Prawat, R. S. and Floden, R. E. Philosophical perspectives on constructivist views of learning. *Educational Psychologist*. 1994, 29(1), 37-48.
[18] Piaget, J. To understand is to invent. 1973, (Grossman, New York).
[19] Cobb, P. Where is the mind? Constructivist and sociocultural perspectives on mathematical development. *Educational Researcher*. 1994, 23(7), 13-20.
[20] Phillips, D. C., (The good, the bad, and the ugly: The many faces of constructivism, *Educational Researcher*. 1995, 24(7), 5-12.
[21] Shih, Y. E. Seize teachable and learnable moments: SMSE instructional design model for mobile learning, in *Proceedings of the International Conference on Mobile Learning*, International Association for Development of the Information Society, 28-30 June, 2005, Malta, pp. x-x.
[22] Delson, N. J. Increasing team motivation in engineering design courses. *International Journal of Engineering Education*. 2001, 17(4/5), 359-366.
[23] Sclater, N., Grierson, H., Ion, W. J. and Macgregor, S. P. Online collaborative design projects: Overcoming barriers to communication. *International Journal of Engineering Education*. 2001, 17(2), 189-196.
[24] Cheaney, J. and Ingebritsen, T. S. Problem-based learning in an online course: A case study. *International Review of Research in Open and Distance Learning*. 2005, 6(3), 1-18.
[25] Cronjé, J. Paradigms regained: Toward integrating objectivism and constructivism in instructional design and the learning sciences. *Education Technology Research and Development*. 2006, 54(4), 387-416.
[26] Hadgraft, R. G. Problem-based learning: A vital step towards a new work environment. *International Journal of Engineering Education*. 1998, 14(1), 14-23.
[27] Schmidt, H. G. Foundations of problem-based learning: Some explanatory notes. *Medical Education*. 1993, 27(-), pp. 422–432.
[28] Barrows, H. A taxonomy of problem-based learning methods. *Medical Education*. 1986, 20(-), 481-486.
[29] Lehmann, M., Christensen, P., Du, X. and Thrane, M. Problem-oriented and project-based learning (POPBL) as an innovative learning strategy for sustainable development in engineering education. *European Journal of Engineering Education*. 2008, 33(3), 283-295
[30] Barron, B. Doing with understanding: Lessons from research on problem- and project-based learning. *Journal of the Learning Sciences*. 1998, 7(3&4), 271-311.
[31] Annand, D. Re-organizing universities for the information age, International Review of Research in Open and Distance Learning. 2007, 8(3), 1-9.
[32] Lowman, J. Mastering the techniques of teaching. 1984, (Jossey-Bass, San Francisco).

[33] Oliver, R. and McLoughlin, C. Using web and problem-based learning environments to support the development of key skills. in *Proceedings of the 16th Annual Conference of the Australasian Society for Computers in Learning in Tertiary Education*, 1999, pp. 249-256 (Queensland University of Technology, Brisbane).

Contact: Dr. Imre Horváth
Delft University of Technology
Faculty of Industrial Design Engineering
Section of Computer Aided Design Engineering
Landbergstraat 15
2628 CE Delft
the Netherlands
Phone: +31 15 278 3520
Fax: +31 15 278 1839
E-mail: i.horvath@tudelft.nl
URL: http://www.io.tudelft.nl/live/pagina.jsp?id=23c72e37-69b4-42e0-a254-6c535e4e7e28&lang=nl

Dr. Imre Horváth is a professor of computer aided design engineering at the Faculty of Industrial Design Engineering, Delft University of Technology, the Netherlands. Prof. Horváth received his PhDs in the field of computer aided of engineering design and advanced design support systems. His research focuses on future design support environment, design application of mobile communication and ubiquitous technologies, methodological frameworks of integrative design research, and learning object-based design systems. Prof. Horváth resides in Delft, the Netherlands.