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# A Concept of Academia–Industry Collaboration to Facilitate the Building of Technical and Professional Competencies in New Product Development*

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The development of innovative and competitive products is crucial for any company's long-term success in the global information society and the global market. Educational engineering programs should facilitate the building of both technical and professional engineering competences. Project based learning, teamwork and real-life product development in collaboration with industrial companies seem to be appropriate ingredients of such programs. A concept of academia–industry collaboration and its realisations were developed and applied by a strategic alliance of European universities. Initial results of the communication-trust building-creativity triad showed some properties of one of the applied concept realisations. Although the concept and its realisations were deemed successful, identified issues have to be addressed in the future.

**Keywords:** product development; teamwork; communication; collaboration; engineering competences

## 1. Introduction

The development of innovative and competitive products and mastery of information and communication technologies (ICT) are crucial for any company's long-term success in the global information society and the global market. It is vital to understand that winning in a competitive environment is based on the combination of low-cost, innovative, high-quality products and responsiveness to market demand [1, 2]. It also needs to be emphasized that in a world that can only survive through global collaboration, international cooperation is indispensable [3]. The main flag bearers for development are product developers, but it is questionable whether the existing educational engineering programs are appropriate to achieve the needed competencies (this question was posed by our team already in the late 1990's). It is also a question of which competencies engineering graduates/employers find to be the most important. Such competencies can be grouped into two categories, namely technical and professional ones. Technical competencies have to be integrated with the professional ones to be successful in the global information society [2].

According to Passow, competencies mean "the knowledge, skills, abilities, attitudes, and other characteristics that enable a person to perform skilfully (i.e., to make sound decisions and take effective action) in complex and uncertain situations, such as professional work, civic engagement, and personal life" [4]. It has to be stressed that the importance ratings of competencies depend strongly on the work environment (academia, industry, government); this is of great importance because engineering faculty (as curriculum designers) should be informed by the opinions of engineering graduates from all environments [5, 6].

Grimson stated that the constraints on engineering problem-solving today are increasingly no longer technical, but rather lie on the societal and human side of engineering practice [7]. Beitz and Helbig [8] e.g. found large deficiencies in the areas of group interaction skills, ability to present and represent knowledge, and ability to translate thoughts into action. Similar shortcomings (e.g. lack of skills required to work in multidisciplinary teams and insufficient communication skills to present, argument and defend alternative solutions) were also identified later on by managers of development departments of Slovene companies in a survey conducted in 2006 for the needs of curriculum updating at the University of Ljubljana (UL), Faculty of Mechanical Engineering [9, 10].

Based on these and similar findings [e.g. 1, 11–14], a decision was made in the academic year 2001/2002 to organize an international course/project that would facilitate building of competencies and would also enable students to become competent members of product development teams.

New product development (NPD) is a demanding and complex activity as it is, and its level of difficulty is additionally increased by the ever-changing business environment, primarily by functional association of geographically dispersed human resources [9, 15–17].

Changes in the business environment, the



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responses of companies and the available ICT pose a number of challenges to current and future product developers, as well as to educational institutions (universities, colleges and continuing education institutions within or outside companies), including [1, 2, 9]:

- work in geographically dispersed teams,
- work in multinational/multicultural teams,
- work in cross-functional teams,
- work in multidisciplinary teams,
- work with a global customer base,
- development of communication skills,
- learning to apply and further improve engineering knowledge and skills,
- transfer of tacit knowledge,
- selection and everyday use of appropriate ICTs.

Naturally, our intention in 2001 was merely to design a single course, not an entire engineering program (entire engineering programmes were reorganized in the period 2006–2008, and in 2012 the University of Ljubljana, Faculty of Mechanical Engineering received ASIIN and EUR-ACE accreditations for its B.Sc. and M.Sc. engineering programmes).

Our efforts coincided with the so-called "paradigm shift", when ABET's (the U.S. accrediting agency for engineering programs) focus on inputs, such as topics taught until the year 2000, was completely replaced by focus on outputs, i.e. competencies achieved by students [18, 19].

Focusing on competencies has been an on-going process; the importance of technical and professional competencies was analysed in 2008 by Passow using meta-analyses of various research work. She found that the most important competencies (with few exceptions) are problem solving, communication, decision-making and data analysis, followed by teamwork, commitment to achieving goals, ability to integrate theory and practice effectively in professional work settings, leadership skills and project management, design, life-long learning, engineering tools and math, science and engineering knowledge. The least important ones (relatively) are contemporary issues, experiments (without data analysis) and impact of engineering work [4, 5].

The importance of professional competencies (sometimes called soft skills or transferable skills) is recognized by many studies/authors, e.g. [1–3, 20–25]

The purpose of the paper is to present a concept of academia–industry collaboration and actual realization of this concept when used as a methodology to promote and facilitate the building of technical and professional engineering competencies, to offer partial insight into the communication-trust-creativity triad of one of the concept realizations, and emphasize issues/challenges that have emerged from performing the concept realizations.

## 2. Concept of the Academia–Industry collaboration

It was the intention of the authors (as well as other course developers and organizers; see [26, 27]) to develop a course that would address as many important engineering competencies as possible.

Academia–industry collaboration as a concept of product development education provides a good dose of reality and exposes stakeholders to the challenges of the business environment, as presented in the previous section. It also stimulates learning motivation by relating technical knowledge to its applications [2].

In our case, project-based learning was selected as pedagogy of the concept. It is believed that this pedagogy is one of the most suitable pedagogies for learning engineering design [12, 14, 21]. Project-based learning addresses transfer of knowledge, which may be defined as the ability to extend what has been learned within one context to other, new contexts [28, 29]. This is an important component of engineering competency development [30]. Emerging evidence suggests that project-based learning encourages and supports collaborative work [12]; it also improves retention and enhances design thinking [21].

An important characteristic of product development is a high proportion of tacit knowledge. Project based teamwork enabled the transfer of tacit knowledge between individual students, as well as between students and company engineers or the faculty. Knowledge transfer was also facilitated via ad-hoc interaction of team members with other members, the faculty and professional engineers from the involved company. These modes provided many possibilities for individual knowledge transfer, which are believed to be a successful way to transfer tacit knowledge within organizations and among collaborating organizations [31–34].

Engineering design is a social process, practised in teams [e.g. 35–37]. Therefore, project-based design courses are seen as opportunities to improve the ability of students to work in teams, as well as their communication skills [21].

## 3. Concept realizations

### *3.1 Design methodology course*

Our first alternative concept realization (developed a couple of years before European Global Product Realization) was project work within our one-semester Design Methodology course (mandatory for approx. 45 students attending the Mechanics and Engineering Design module each year). Our aim was to somehow balance out the prevailing engineering-science content of the 9–semester engineering programme. Students were asked to form teams (consisting of 3–5 members, although they were also allowed to do their project work individually), choose a problem to be solved, make specifications for alternative solutions to be synthesized, generate alternative concept designs, and then evaluate and rank them. Concept selection was followed by embodiment and detailed design. This project work resulted in technical documentation (3D digital models, calculations, engineering drawings and bill of materials) for a solution to the chosen problem. The students then had to make two public presentations and submit a written report on their work/results. Table 1 illustrates basic characteristics of three concept realisations (i.e. Design Methodology course, European Global Product Realization and Search for Product Opportunities).

Judging from informal interviews with the participating students, the course was a success. Almost all of the students praised the project-based work and working in teams, in spite of the challenges regarding e.g. time constraints and organization of work. They also liked free problem selection, in spite of e.g. vast problem space difficulties that made it hard to select a single problem, and the fact that the instructor(s) did not provide any specifications. They also appreciated decision-making during concept design selection, in spite of e.g. incomplete information during the conceptual phase of product development, as well as public presentations and comprehensive written reporting. The main disadvantage, as seen by the students as well as the faculty, was the lack of prototyping and prototype testing. This, however, was financially and organizationally impossible to achieve based on the circumstances.

The course was deemed to be successful and valuable, and later became mandatory for all third year students of the reformed BSc degree program (following the Bologna reform).

### 3.2 *European global product realization*

In 2001, we were fortunate to be approached by the Delft University, Faculty of Industrial Design Engineering.

To simulate the situation in the ever-changing business environment and expose students to challenges of its constant changes, three European universities, namely the Delft TU—Faculty of Industrial Design Engineering (TUD), Ecole Politechnique Federale Lausanne (EPFL), and University of Ljubljana—Faculty of Mechanical Engineering (UL), decided to form a strategic alliance. Its main objective was to design, organize and conduct a competitive, international (elective) master's course in the field of collaborative product development.

This course was named "European Global Product Realization" (E-GPR), and each university contributed its specific knowledge. Students from Ljubljana were specialists in mechanical engineering, students from Delft were proficient in industrial design, and students from Lausanne contributed their knowledge on micro-engineering. The alliance was expanded in 2005 with mechanical engineering students from the University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Croatia (FSB), in 2006 with students from the London City University, School of Engineering and Mathematical Sciences, United Kingdom (CUL), contributing knowledge on aerospace, electrical or mechanical engineering, and finally in 2009 with students from the Budapest University of Engineering and Economics (BU), who provided additional knowledge on industrial design. According to Dym et al., engineering design courses should be taught across geographically dispersed, culturally diverse, international networks of universities [21].

The E-GPR course is described in greater detail in section 4.

### 3.3 *Search for product opportunities (SPO)*

The University of Ljubljana, Faculty of Mechanical Engineering has been strongly involved in industrial cooperation. Among other things, this has shown that SMEs (small and medium-sized enterprises) possess insufficient knowledge on systematic approaches to product development and also lack appropriate development staff.

Because of that, SMEs may try to expand their

**Table 1.** Basic characteristics of our three concept realizations

| | **Design Methodology Course** | **E-GPR** | **SPO** |
|---|---|---|---|
| Project-based work | x | x | x |
| Free problem selection | x* | | |
| Teamwork | x | x | x |
| Multidisciplinary teamwork | | x | x |
| Geographical dispersion of team members | | x | |
| Multinational team | | x | |
| Physical prototype realization | x* | x | x |
| Search for new product opportunities | | | x |
| Industrial partner | x* | x | x |
| Industrial project owner | x* | x | x |

* Not mandatory.

product portfolios via trial-and-error, thus potentially putting their future at risk. On the other hand, SMEs could also approach these problems in a standard manner. For example, they could hire an external consulting company to develop new product(s) for them, but in such cases there is no transfer of systematic product development methods from the consulting company to SME engineers. SMEs can also hire an external company or engineering school to educate them on systematic methods for product development, but in such cases education would be done on the basis of case studies and would not include concrete product development for them [38].

Based on these findings, in 2006 our department developed and offered the third possible concept realization. Presentations of individual steps of various systematic methods were accompanied by reflection sessions to analyse and evaluate individual activities (e.g. what was done and why) within each specific step. The reflection sessions were performed to facilitate learning through experience for engineering students and industrial engineers. The sessions were led by an advisor from the University. This concept realization integrates simultaneous transfer of new knowledge and development of engineering competencies of both company engineers and students, as well as actual product development and temporary replacement of human resources [38].

## 4. E-GPR- course description

The course consists of several concurrent activities. Twice a week, students have to follow carefully selected, tailored lectures on particular aspects of project needs and current progress. However, the main focus is on the real problem-solving case; each year, this case is assigned by another industrial company partner, in collaboration with host university and course staff. Naturally, the problem has to involve a demand to develop a new product, since the course covers the entire design-development chain, from idea to the first, fully functional prototype [39]. The company is expected to provide the full range of the relevant knowledge, including some market research, as well as material, financial and managing support, and as payment it receives five working prototypes, including full documentation that covers the whole R&D process.

The lectures consist of general topics intended to equip students with the necessary knowledge for active work within the NPD process, such as ICT technologies, working in multi-x (multi-disciplinary, multi-national and multi-cultural, i.e. multi-x) virtual teams, harnessing modern trends in R&D processes, etc. They also address other specific knowledge, which is annually adapted to each assigned work task. Some details of the implementation of the early E-GPR course are described in [9].

Since the participants are dispersed over several different countries, most of the communication between them is done via electronic communication channels, employing various internet communication tools. Using videoconferencing equipment, all the lectures are held simultaneously at all universities, providing active cooperation of all participants, regardless of the course organizer's location. The participants are not limited solely to the use of professional VC equipment provided by their institutions, but can also use various other available technologies and services which best suit their needs [40].

The whole course is limited to one semester and starts with team formation (see Fig. 1). In 2002, the first E-GPR year, teams were formed according to the brokerage system, but in the subsequent courses this system was replaced with preliminary assignment of participants to the teams based on their skills and geographic positions. This was done for several reasons: the brokerage system takes more time than preliminary assignment; school semesters begin at different times at each university, which means that several brokerage meetings are necessary; the professional, cultural and geographical dispersion of the participants is uncertain; the brokerage system is often based mostly on subjective, personal opinions about other participants.

Figure 1 shows that the E-GPR project starts before the course. A few months before the beginning of the course semester, university staff chooses an appropriate company and discusses the details of the project with its representatives. Over this time, a need for a new global product is recognized. Comparison of the flow diagram shown in Fig. 1 with a modern design-development process scheme [8] clearly shows that the E-GPR project follows the whole design and development process. The first loop of this process (i.e. problem recognition, problem definition and definition of design goals) is started by company representatives and the educational staff. Once the course begins and teams are formed, the process is taken over by student participants.

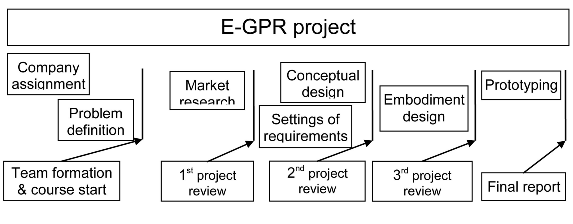


**Fig. 1.** Phases of the E-GPR project and important realization milestones.

The New Product Development (NPD) research and development process within the scope of this course is very multidisciplinary and covers marketing, design and development phases. Although the participants are of different professional backgrounds and their contribution to the course corresponds to their profession, they all need to understand all phases of the NPD process, as well as their mechanisms and importance.

Each team is guided by a coach who is a member of the university staff. However, experience has shown that during the course of work teams usually also choose an informal manager from among their members, who guides and coordinates the entire process. It is also common to see different members managing individual phases of the course, depending on their professional skills.

As in real industrial cases, there is a constant lack of time because each E-GPR course is planned with several strict deadlines, at which predefined results need to be presented. Therefore, the coaches constantly monitor the progress of work via regular meetings with their teams. There are also 4 official presentations of work done (see Fig. 1), namely three project reviews and a final presentation with the corresponding reports.

In the last phase of an E-GPR course, the members finally meet each other in person. This happens during the week of the final workshop, which takes place in the host university's city, usually during the last week of May or the first week of June. At that time, the prototypes are detailed and finished, and the results are presented to the professional public and the media. In addition to the benefits of collaborative working experience, the final workshop also provides an opportunity for more intense socializing of all course participants.

The results of each E-GPR course are monitored in several different ways. During each course, the progress of work is overseen by the staff and company representatives through informal/formal interviews with the participants and three project reports. The final evaluation of each team's work is based on final presentations and reports (Fig. 1). Each year, the students, the staff and company representatives fill out various questionnaires to monitor several aspects of the EGPR project. At the end of every course, the students are also given assessment sheets to evaluate their team colleagues, the coaches and themselves in aspects of social effort, contribution, collaboration, creativity and other factors. This provides better insight into what happens within the teams.

During all twelve years of the E-GPR course, it solved problems for various European companies, which had little in common. Table 2 shows that these companies are evenly distributed throughout Europe. Some of them were so satisfied with the results that they even expressed an interest in collaborating for the second or third time. In such cases, we ask them to propose a new type of problem in order to foster creativity and prevent coaches from influencing the process with ideas from previous years. Table 3 illustrates the extent of E-GPR project work and the aims distributed over several phases.

Table 2 also demonstrates the wide range of the studied industrial problems, which span from small and complex household appliances to professional tools and machines, and even large and complex products for public use, such as urban bicycle infrastructure or ecological, self-sustainable mobile housing. Fig. 2 shows only a few of the most successful results from the past E-GPR courses. All these problems addressed specific needs and each year the course was adapted accordingly. However, for the E-GPR courses we strive to undertake projects that allow each team to fully develop its own working prototype.

Last year's project for the development of an ultra-light airplane for disabled pilots turned out to be too complex and too large. Therefore, the staff and the involved company decided to focus on only one prototype, with different teams working on different sub-assembly modules. Nevertheless, it

**Table 2.** List of participating companies, their task assignments and involved universities for each year of the E-GPR course

| Academic/Year | Problem owner | Problem/Product | Participants |
|---|---|---|---|
| 2001/2002 | LIV (SI), Vlamboog (NL) | Modern vacuum cleaner and welding respiratory unit | UL, TUD, EPFL |
| 2002/2003 | Vlamboog (NL) | Welding respiratory unit and mask | UL, TUD, EPFL |
| 2003/2004 | Vlamboog (NL) | Welding masks | UL, TUD, EPFL |
| 2004/2005 | Avidor (CH) | Autonomous vineyard spraying robot | UL, TUD, EPFL, FSB |
| 2005/2006 | Niko (SI) | Cargo staircase crawler | UL, TUD, EPFL, FSB CUL |
| 2006/2007 | Kesslers Int. (UK) | Interactive point of display | UL, TUD, EPFL, FSB CUL |
| 2007/2008 | Tehnix (CRO) | Ecological mobile house | UL, TUD, EPFL, FSB, CUL |
| 2008/2009 | UMC Utrecht (NL) | Diagnostic rehabilitation device | UL, TUD, EPFL, FSB, CUL |
| 2009/2010 | Kolektor LIV (SI), BSH (SI) | Economical flushing system, hand blenders for men | UL, EPFL, FSB, CUL, BU |
| 2009/2011 | Direct Line (HU) | Urban biking equipment | UL, EPFL, FSB, CUL, BU |
| 2011/2012 | Suman (CRO) | New parasol concepts | UL, EPFL, FSB, CUL, BU |
| 2012/2013 | Kondor ltd. (UK) | ULA airplane for disabled pilots | UL, FSB, CUL, BU |

**Table 3.** Summary of the extent of project work

| Review # | Aims of project review | Issues to be addressed in the report |
|---|---|---|
| 1 | Presentation of findings in the problem definition phase of designing a product. Additionally, the management issue of the design group should be shown by presenting organizational tools, such as the Gantt chart and the calendar. | Analysis of company needs and understanding of the design task. Market research, available methods used for transport devices. Review of equipment available on the market. Requirements & objectives. SWOT analysis of the company. Functional model of a product. Constraints – boundaries within which a product is designed. Managerial issues of the group: Scope-Spending-Scheduling. Work breakdown structure; Gantt chart, Calendar of activities. |
| 2 | Presentation of the conceptualization phase of product development. The developed concepts should be evaluated against requirements. | Report on at least three different (!) concepts which are reasonably feasible and manufacturable within the scope and resources of the EGPR course. Specification of advantages and drawbacks of all listed concepts. Addressing the fulfilment of each requirement stated by the company. Specification of criteria with which the team believes it is possible to assess the concepts. Estimation of the necessary resources and time needed to manufacture the prototype. Estimation of prototype costs. Estimation of product costs in mass production. |
| 3 | Presentation of the final designs which will be carried forward for prototype development during the workshop week. The design should be finalised by this time and the manufacturing plan should be prepared. | Elements of the final design. Analysis of the manufacturing or procurement methods needed for components in the final design. Cost estimates for manufacturing or procurement. Time schedule for completion of prototype components. |
| (4) | Workshop preparation phase – its aim is to get the view and give necessary support over production (preparation) process. | The deliverables of this phase are missing documentation files, 3D CAD models for manufacturing, bill of materials, purchase lists and summary of preproduction activities. Students usually present them briefly in presentation form. |
| Final | During the workshop, the team will assemble and test the prototype and present the project and its final results. Each team will have Power Point and poster presentations at the workshop and the final report will be submitted one week after the workshop. | Market analysis and customer evaluation. Evaluation of competitors' products. Project objectives and requirements. Process of product conceptualization and definition. Description and validation of design proposal. Prototype explanation and product features. Material selection and sizing considerations and actions. Manufacturing considerations and actions. Consideration of costs, sustainability and life cycle. Conclusions and assessment of fulfilment of the project objectives. |

was a great organizational challenge to keep all the teams constantly working in tune.

During the 2008 E-GPR course, it became obvious how crucial the communication is between the project owner (company) on the one hand and work teams (student participants and university staff) on the other. There were frequent information interruptions and ambiguities in this communication flow, which caused project delays and changes in project assignments. This resulted in a loss of motivation among team members, killing creativity in teams and individuals. To cope with such situations, which can arise in any creative team, it is necessary to have a team member who can act as a crisis manager. Since this should be a person with a lot of experience, team coaches and other university staff assumed that role in situations of this kind.

### *4.1 E-GPR in numbers*

Every year, there are approximately 30–40 student participants, i.e. 8–12 from each university. The students are grouped into 5 teams, which are led by coaches from different universities. Each university participates with one professor as the course leader and one or two coaches. Other professors are also invited, based on their competences and course demands. This means that the E-GPR course has a very low teacher-student ratio (in our case approx. 1:4.5), which varies each year, depending on the number of participating students.

The total hourly workload (net) of the coaches is shown in Table 4 and does not include the work of leading professors.

There is a need for at least one professional videoconferencing system per institution. The majority of material costs are related to prototype production, final workshop organization and the workshop visit. There is an informal rule that prototype costs are fully covered by the industrial partner, but should not exceed EUR 1.000 per team, although this issue may also be negotiated differently. The costs of workshop organization are jointly covered by the industrial partner and the hosting university. These costs include student and

**Fig. 2.** Some prototypes from our E-GPR courses: 2011—urban biking equipment (upper-left); 2012—new parasol concepts (upper-right); 2010—hand blender for men (bottom-left); 2013—fuselage of an airplane for disabled pilots (bottom-right)

**Table 4.** Coaches' workload in hours (net) by activity

| | Hours per week | No. of weeks | Total hours | No. of coaches | Total |
|---|---|---|---|---|---|
| Lectures | 4 | 18 | 72 | 5 | 360 |
| Meetings* | 3 | 18 | 54 | 5 | 270 |
| Other work** | 5 | 30 | 150 | 5 | 750 |
| Total | 12 | | 276 | | 1380 |

* Meetings of coaches, coaches' meetings with their teams and coaches' meetings with local students.
** Preparation of various materials and the course, checking of documents and reports, communication with the company and third parties, etc.

staff meals, local logistics, organization of social events, etc., and vary strongly depending on the event's location. However, travel and accommodation costs are not included and have to be paid by each university. There are also major differences in local rules; some universities cover all student costs, while others leave the students to solve this problem by themselves.

### *4.2 Improvements to the course*

To gradually increase the quality of the course, the staff carefully selected appropriate measures and intensified preparatory activities, project progress monitoring and final organizational activities for the workshops. We believe that the following actions had an important impact on the improvement of the course results [63]:

- *Organizational efforts were increased.* In 2002, only three staff preparation meetings were held to prepare the course details, while in 2006, for example, a total of 14 staff meetings were held prior to the course start. During the preparation meetings, numerous official documents were prepared and consolidated, the alternatives were discussed, the selection of the industrial partner was evaluated and confirmed, assessment schemes were consolidated, and future actions were defined. In the past three years, staff activities were conducted routinely and continuously during both semesters, while staff meetings were held on a weekly basis. The work included strategic activities of constant searching for new challenges and new industrial and academic partners.
- *The preparatory documentation was improved.* In 2002, only three documents describing the course were issued. In 2006, however, 10 such documents were prepared in advance. Thus, the staff prepared a formal agreement to be concluded by the partners, contract templates, NDA agreement letters, course description, project task description, the necessary project deliverables for all project phases, an IT and communication guide, the course time schedule, a selection of academic lectures, the expected content and quality of student reports and presentations, assessment schemes, testing conditions and so forth. All documents were made public prior to the start of the course. The intent was to present all aspects of the course to the participant candidates in the best possible way.
- *The accessibility of communication equipment was improved.* In 2002, the Ljubljana partner, for example, used a single videoconferencing device attached to ISDN phone lines with a data rate of 384 kB/s, while in 2006 it used three such devices connected to the internet with a 768 kB/s connection. No limitations regarding the time schedule of using the connections were imposed on the students. The students were also encouraged to use videoconferencing during their work as much as possible. While virtual environment communication has become ubiquitous in recent years, the need for professional videoconferencing devices has been on a decrease. However, in Ljubljana there are always four professional VC devices available for the project. At present, the greatest challenge involves the setting up of appropriate IT tools for collaborative work in virtual environments. One of the most important tools is a functional PDM system, which enables secure work with sensitive documents, but allows the same flexibility as free (cloud) tools available on the internet regardless of the or system used.
- *The project task definition was improved.* The E-GPR staff helped companies formulate an acceptable set of requirements, which were clearly identified and were feasible within the scope of the project. In 2005 and 2006, official field testing of the prototypes was carried out with multiple functional tests to quantify the performance; this now constitutes the standard prototype evaluation procedure. In 2006, the prototypes were evaluated for speed, load, weight, overall dimensions and their expected mass manufacturing costs. Today, prototype user tests are among the most important elements of project success evaluation.
- *Advanced prototyping techniques were made more accessible.* In 2003, vacuum thermo-forming was extensively used to manufacture the prototype housings. In 2004, direct 3D printing from ABS was made available by our Croatian partner, which enabled the design of complex parts integrating multiple functionalities. In 2005, 3D printing was used once again. Technology overview is also one of the important elements of the project; it enables the students to adapt their designs to the available means of production.
- *Manufacturing help was provided by an industrial company.* In 2005, 2006 and 2007, the industrial partner provided extensive manufacturing help to the students. In 2005, help was provided only during four days of the final workshop. Later, the majority of the parts were provided by the industrial partner prior to the workshop, and extensive help was also provided during the workshop.
- *Active monitoring of student work.* The number of project reviews was increased from two to three. The amount of reporting material was also severely constrained in order to save time for the students while still keeping the staff properly informed (Table 3). Formal team leadership was not established; however, each team was assigned an active staff member to monitor progress and act as an advisor. During the manufacturing stage, checking tables were provided with the necessary components and the level of completeness was listed. In addition, cross-team evaluation forms were introduced after each project phase in 2010 in order to facilitate the evaluation of contributions and activities of each individual within the team, since the coaches had limited insight into student relations and activities due to the complexity of the used communication channels. Starting in 2014, the quality of the lectures will also be monitored by giving short questionnaires to the students after each lecture.
- *Raising the complexity of the projects.* The increasing complexity and size of the projects necessitated some additional organizational activities. It soon became clear that a one-week

workshop was not enough for the entire production process to be completed. Therefore, the last project review, at which product design is usually detailed and finalized, was moved to an earlier stage, thus leaving some time for preproduction activities. These included the preparation of the necessary production documentation, purchase of the components and start of the production activities (either by the industrial partner or at the participating universities).

In 2013, the complexity of the project was even higher, since the students developed an open-source ultra-light aircraft for disabled people. For this reason, the organizational staff faced new challenges, primarily related to the issue of how to effectively coordinate all of the teams working together on different parts of the same prototype. A cross-team board was therefore created, which included one or two students from each team. This cross-team board was responsible for decision-making on the overall project scale and also for communicating with the rest of the students.

- *The lecture structure was adapted.* Our research and experience had shown that proper timing of the lectures played a crucial role in helping the students acquire the right knowledge and then implement it correctly during the work process. We noticed that it was easier for the students to implement the knowledge from the earlier lectures, certainly more than from those at the end of the course. Therefore, this time most of the lectures were given in the first half of the course semester, paying special attention not to position them too late or too early in the course of the development process. For this reason, it is quite common for the academic calendar to vary slightly during the course in order to accommodate the actual situation.

All of the above improvements were based either on experience gained during course management and organization or by collecting information via student questionnaires at the end of each course. Each partner contributed several part-time staff members to help with organizational activities for the course. It is estimated that at least one instructor per partner should be engaged on a full-time basis in E-GPR preparation and execution, whereas during the culmination of the workshop, the help of others would also be necessary.

## 5. Findings on the communication-trust-creativity triad in virtual teams

Due to the complexity of building competencies in product development and space constraints, this paper presents only a limited range of findings on the communication-trust-creativity triad in virtual multi-x teams. In a virtual team (and also in co-located teams), good communication is needed for trust building [41], and trust is a prerequisite of creativity in virtual multi x-teams.

The ability of good communication is regarded as one of the most important elements of technical and professional competencies. The ability to use communication tools is a part of the overall ability to use the techniques, skills and modern tools necessary for engineering practise (i.e. technical competence) [4, 5]. The use of diverse methods to communicate effectively is also a part of transferable skills (i.e. professional competence), as defined in EUR-ACE framework standards [25].

### *5.1 Communication*

Minneman has argued that ambiguity and negotiation are inherent to design and constitute a condition and a mechanism for understanding and structuring design activities [21]. Products (i.e. designs) are developed through a social process of negotiation between stakeholders (e.g. team members themselves, team members and faculty, team members and company representatives), where information is actively communicated and made sense of [42].

Due to the virtual nature of NPD teams, most of the work process required various means of electronic communication. The communication methods and information contents to be shared within the teams were in a strong correlation with the phase of the NPD process, and each of the tasks required appropriate ICT infrastructure [12]. However, the results of some research studies have shown that the mere availability of ICTs does not necessary lead to their use. Therefore, it is essential to establish some standards for availability and acknowledgement of communication to define when dispersed team members should be available for collaboration and how quickly they should respond to the messages [43].

These standards should be specified carefully, since other studies have shown that the frequency of communication has a subtle influence on creativity within the teams. There is an optimal frequency of communication, while a too low or too high frequency can have a negative impact on creativity [44].

However, during the E-GPR course these standards were only vaguely specified by the course's organizers (e.g. regarding the use of VC equipment or formal weekly meetings), while the choice of other communication channels depended on the team members, e.g. regarding the file exchange service and instant messaging programs.

Many studies also confirmed that different ICT tools have different influences on the market performance, innovativeness and product quality, but mostly they foster the results [45]. For example, e-mail communication has been proved to be an excellent tool for engineering project management and information sharing, but was not that useful as a problem-solving tool [46, 47].

The last study [40] showed not only that ICT tools were less suitable for problem solving than for communication purposes, but also that web tools in general are more suitable for information sharing, project management, data mining and research than for creative work. This is because creative work requires more complex services or programs and more computer power, as well as the optimal rate of filtered information flow [48] to establish the best conditions for the creative process and good decision-making.

### *5.1.1 Internet services and information safety*

During each course, monitoring was done to see which services were used by students to complete various NPD tasks. As was mentioned in the introduction, students had a lot of freedom to establish their own protocols and standards for synchronous and asynchronous communication, document exchange and sharing. It should be noted that specifically for this course, the organizers established the infrastructure for the file depository (FTP server) and the teleconferencing equipment for regular VC meetings.

Figure 3 shows the services used for file exchange. It can be seen that apart from the FTP server, which students mostly used to send various materials to the coaches and the company, they also used Google Documents and e-mail services, but those were preferred for internal communication.

The reason for this lies in the fact that younger generation shave more experience with such services. They want to use those services which they are familiar with and know how to use. Therefore, they used third-party online services for information exchange, while many still had to learn how to use the FTP, despite the fact that it is an old and most common file transfer protocol operating behind many cloud services. The students also found another advantage in Google Docs, which offers the opportunity for several team members to concurrently work on the same document while communicating over some synchronous communication channel.

Another advantage of online cloud services (e.g. Google Docs, Dropbox, etc.) is also the possibility to access documents through any web browser or special application which makes such documents independent of the operating system, hardware platform and specifications. This fact, along with the availability of highly portable ICT devices, increases the possibilities to move the NPD out of the office, if necessary.

Checking the services used for communication within the team (Fig. 4), a similar pattern can be noticed as before. In addition to the VC equipment provided for formal meetings of the teams and coaches, all teams also established their own communication channels. In this case as well, most students used e-mail as a tool for asynchronous communication and Skype for synchronous communication. Surprisingly, the use of Skype conferencing was almost 100%, which is more than for the VC equipment, and there were no other real alternatives, despite availability. This was followed by Google at 63%, while social networking communication channels such as Facebook chat were almost unattended.

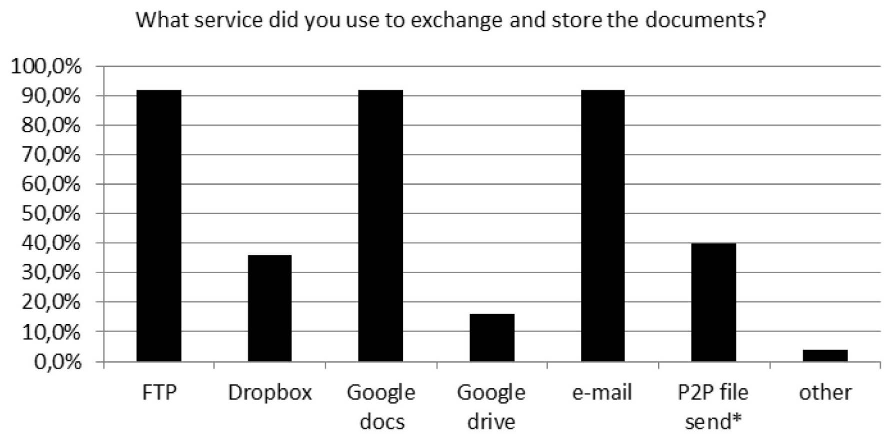


**Fig. 3.** Services used by students for document transfer (*peer-to-peer file send using Skype, Google Talk, etc.)

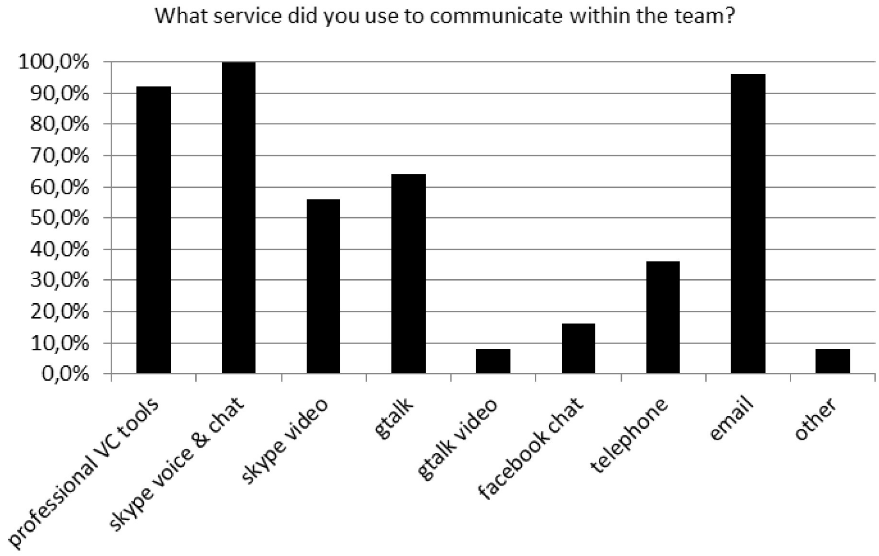


**Fig. 4.** Communication services used for the 2012 E-GPR course.

The use of the telephone as a communication tool should also be mentioned. With the development of smartphones, a telephone is no longer just a tool for classical voice communication, but can also serve as a platform for chat and VoIP talks. 55% of the students said that they used internet access on their phones, which only confirms our statement. However, classical phone service was still used, but mostly for local research work and for communication with local team members.

Returning to e-mail, the origin of e-mail accounts was also observed. Almost 90% of the participants (students and even coaches) used their private e-mail addresses created at various web e-mail providers; among them, Google again held the biggest share of approx. 80%. A similar phenomenon was observed in previous years, when the students applied to the course using their faculty e-mails, but usually within a few weeks they switched to their Google mail account due to the services provided by Google and its conditions of e-mail use, e.g. Google groups or Google documents (Fig. 5).

Since every third-party ICT service comes with a License Agreement and Terms of Use, the participants of the E-GPR course were asked if they normally read the conditions of use. Over 70% of them answered negatively (Fig. 6). This means that most course participants do not even know with whom they share their information and how this information will be treated by potential third-party persons.

As the course involves the cooperation of an industrial partner, the participants also handle some sensitive company information. In the year 2011, the representatives of the company involved in that course demanded that students not be

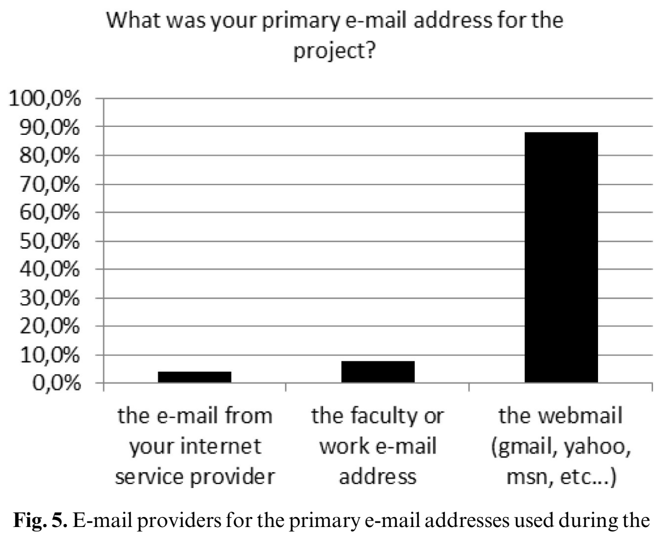


**Fig. 5.** E-mail providers for the primary e-mail addresses used during the course.

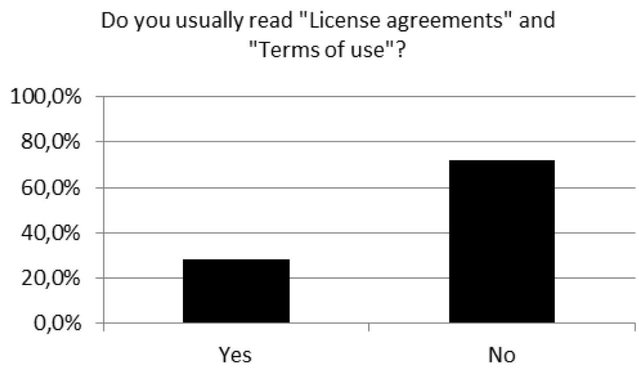


**Fig. 6.** Most of the participants do not read License Agreements and Terms of Use when using internet services.

allowed to use Google services for the course tasks. Furthermore, signing of an NDA (non-disclosure agreement) prior to the course start is already a standard procedure at the beginning of this course.

Therefore, it will be necessary to establish an educational cloud service for information exchange during this course. This service should allow concurrent work on the same document by several participants as an alternative to free web-based services.

The results of this research show that it is better if the course organizers prepare the ICT protocols and standards which can be used by the students for this course, instead of the teams doing this by themselves. This might require additional learning from the students, but also more effort from the organizers to establish an ICT system that will not limit communication between the students, regardless of their location and the electronic devices they use.

### *5.2 Trust building*

One of the necessary conditions to achieve and maintain a high level of team creativity is the trust amongst all team members. Thompson [49] has shown that in uncertain and complex conditions requiring mutual adjustment (which is characteristic for product development); effective and sustained action is only possible where there is mutual trust [17]. In order to maintain a high level of trust, constant and frequent communicating is required, and this additionally increases the need for communication [50].

Trust building is a long and difficult process of socializing. Socializing in virtual teams is very important and even more complicated as there is no personal contact between team members, which means that greater efforts are required for the development of interpersonal relationships within the team, which consequentially increases the need for communication—electronic socializing [51]. This is done mostly by exchange of personal or non-professional information, such as hobbies, movies they watch, music they like, sports they practice, etc. [9, 51, 52].

Everyone involved in the NPD process knows that creativity is the crucial element of any problem-solving and enormous research effort is invested just in answering the question of how to foster creativity in different phases of the product development process. During the E-GPR project, different aspects of creativity and effectiveness were also investigated.

Some results of our survey on creativity during the NPD process are shown in Fig. 7 (e.g. E-GPR 2008). The first diagram in Fig. 7 reveals the answer to the question of how effective the team's overall creative process was in leading to promising creative results. It is clear that the students were mostly satisfied with the results of creative work in their teams, although the project work was mostly parcelled out to individual team members (Fig. 7 (b)), but this was not deemed a disadvantage [53]. Since at their NPD meetings the teams used many of the well-known group creativity methods (e.g. brainstorming, morphologic analysis, etc.), no direct correlation of the above results are expected, in spite of the individuality of realization work. However, the creative process can also continue during individual work, with the use of other creativity methods (check lists, flowcharts, etc.).

Figure 8 shows the rate and structure of informal information shared among team members (columns) as well as students' estimation of trust among them. Comparing the results, one notices their congruity. The trust among the members was relatively strong, although some people did not want to share private details (personal issues, crises or things of interest). However, there was still a lot of impersonal, non-professional communication among the participants, which also served for socializing and trust building.

### *5.3 Creativity*

Analysis of student performance in those academic

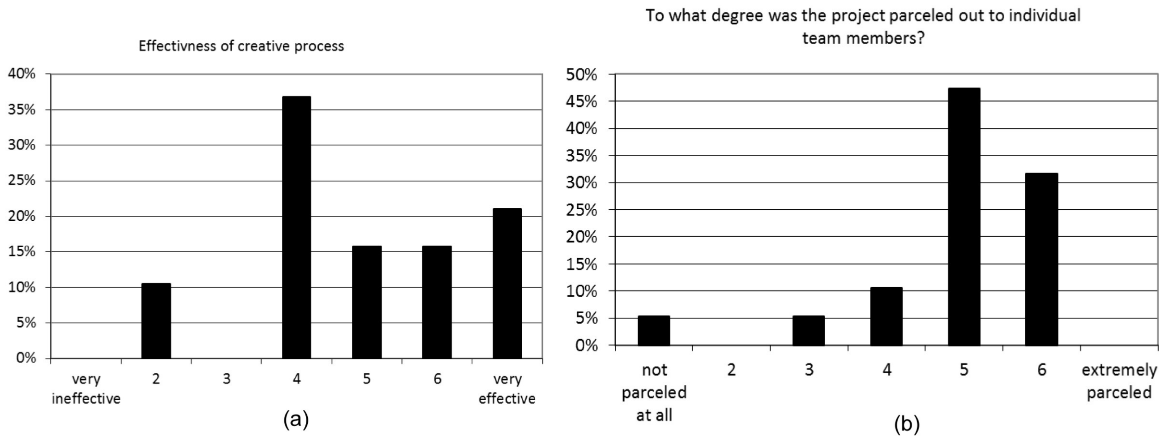


**Fig. 7.** Results showing the rates of (a) effectiveness of the creative process in the E-GPR course; (b) individuality of work among the team members

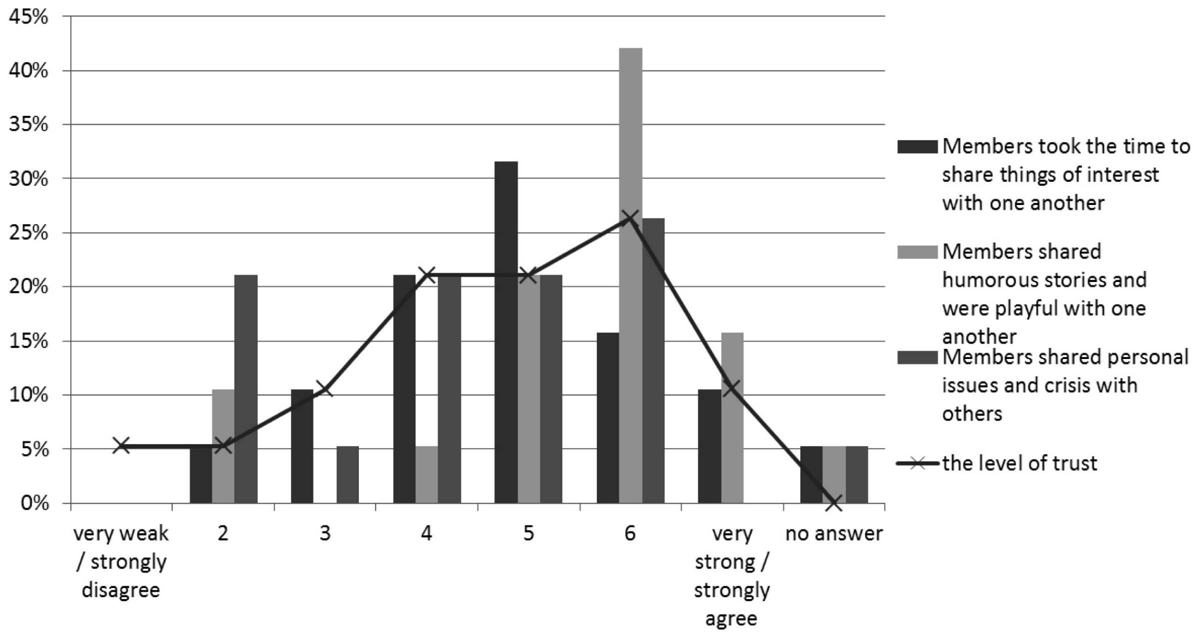


**Fig. 8.** Diagram showing the level of trust among team members and the activities necessary to build personal bonds between team members.

subjects for which the same (local) staff is responsible as for the E-GPR course [54] showed that the percentage of students who complete the course and the average positive grade are the highest for the E-GPR (local) course group. One of important reasons for good performance is motivation, as well as the creativity associated with it.

Maslow proposed a framework of five basic human motivations that are active in a hierarchical order. That is, as one becomes satisfied, the next one in the hierarchy becomes dominant [55]. However, research [56] has shown that in the work environment the basic needs related to physical satisfaction, safety and the sense of belonging are already satisfied by actually having work. Therefore, focus should be on self-esteem and self-actualization.

These two motivational categories are the ones most widely connected to creativity, the sense of a mission and professional creativeness [57]. As creativity is considered to be one of the major contributors to effective product development, these are the aspects to be considered in motivating students within the educational environment. Creativity is exhibited when a product is generated that is novel and useful with respect to the firm [58]. A creative output must be relevant, effective and appropriate, and must offer a genuine solution to a particular problem or presented task [56].

It seems that the E-GPR course has indeed provided such a motivational (i.e. interesting, involving, exciting and satisfying (adapted from [58])) environment. It has delivered creative solutions/

products throughout all the years of its execution. A substantial portion of the participating students have stated: "The E-GPR course really forced us to employ a lot of various resources, sometimes even at the expense of other courses, but we liked the project anyway."

## 6. Discussion

One of the key problems related to the use of the presented concept and its realizations in regular education of students is certainly the availability of appropriate projects. Such projects would need to be performed at the right time and in adequate numbers, and their content would have to be harmonized with the students' competence level. Furthermore, the participating companies would need to agree with the team's composition [38]. Nevertheless, cases may emerge when students simply have not yet acquired a level of competence high enough to solve some specific challenges; such cases might serve as a stimulus to search for additional knowledge/skills.

According to Dym et al., the level of authenticity of project-based learning remains an open research question [21]. The difficulty related to solving of authentic problems using "pure" student teams may be its limited power to impact a solution, but the use of the concept of academia–industry collaboration and its realizations has seemed to remove this problem.

Decision-making is another important issue that came up during realization of the E-GPR course. It was found that taking decisions has often been delayed (the coaches and students expected too many decisions from the company) and this has unnecessarily extended product development time. It is our hypothesis that one of the reasons for this lies in the cultural characteristics of the participants (especially the coaches), such as power distance and uncertainty avoidance. For example, one type of national culture (based on the university location) is characterized by a strong orientation toward collectivism, high power distance and high uncertainty avoidance levels (e.g. Hungary, Croatia, Slovenia), while another type is characterized by individualism, low power distance and uncertainty avoidance levels (e.g. the Netherlands, Switzerland and Great Britain) [59]. In one of our empirical studies, we found e.g. different perceptions (based on the above-mentioned cultural characteristics) of what are the relevant factors for effectiveness of the NPD process [60].

The availability and increased workload (also see subsection 4.1) of faculty members in performing project-based learning have to be taken into account, and such education is also more costly than traditional curriculums [21]. This has a direct influence on the available posts offered to students. Todd [61] has presented a broader issue of evaluation and rewards for faculty members involved in engineering design education, because research activities are often found to be more significant in the evaluation of faculty members. Or, to be more explicit, faculty members involved in multi-x based project-based learning may have problems in pursuing their promotion due to the increased workload of project-based learning. On the other hand, multi-x project-based learning, as suggested by Dym et al., can be viewed as a potential laboratory in which research can be performed [21]. Herein lies the potential to balance educational work with better rewarded research work of engineering educators involved in design activities.

The issue of intellectual property is another concern related to the concept of academia–industry collaboration. Is it the property of the company, the students, the participating university staff or the University, or should it be owned jointly by all of the relevant stakeholders? Companies (problem owners) expect firm agreements concerning intellectual property rights for project results. In order to avoid the problems related to intellectual property, these things need to be agreed upon in advance, at the beginning of each project, taking into account the rules and regulations of the involved company, the participating university and any other institutions which will provide experts for the project [38]. The authors are aware of other projects which had to be stopped due to the lack of intellectual property agreements before a project was started [62]. For the purpose of the E-GPR, host University signed a contract with a company. Other, non-host universities signed a non-disclosure agreement.

The security of information exchange (see section 5.1.1) is an important issue and has to be resolved before the start of serious engineering education based on project-based learning. Potential leaking of critical information should be prevented in order to secure authentic academia–industry collaboration.

Team composition based on personal (student) preferences and brokering (i.e. personal presentation of all the participants followed by team composition) has been practised until now within all the three concept realizations. However, the product development process could have been more effective and the products better if the team composition had been based on psychometric measurements of personality type. There have been reports in literature that composing teams with the use of psychometric methods has been successful, although some reports have also shown no relationship between the ways the teams were composed and their success [21].

## 7. Conclusion

The presented concept and its realisations have their own characteristics and requirements. Appropriate preparation is therefore one of the key prerequisites for successful realization. They also have some issues but they are manageable and do not represent an obstacle to employ project based learning paradigm.

To students, participation in a real-world engineering project (i.e. an E-GPR course) was—and still is, because we have already started activities for the E-GPR course in the academic year 2013/2014—an opportunity to engage in multidisciplinary teamwork and project-based learning, and to learn about the application of various methods/techniques to a given problem in a (near) industrial setting.

Through such and similar real-world engineering projects, the students gained initial experience of their role as future product developers, they faced various real-life constraints (e.g. economic, marketing, environmental and social), they were able to evaluate their existing technical and professional competences in new product development, and they built new ones. The authors believe that the students educated in such ways have steeper learning curve when they enter professional career.

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