Journal of Engineering Design
Vol. 16, No. 6, December 2005, 557–576

Taylor & Francis
Taylor & Francis Group

Skills for effective communication and work in global product development teams

JOŽE TAVČAR*†, ROMAN ŽAVBI†, JOUKE VERLINDEN‡ and JOŽE DUHOVNIK†

†University of Ljubljana, Slovenia
‡Delft University of Technology, The Netherlands

This paper presents a systematic discussion of the specifics of communication and work within a virtual development team, which is of crucial importance for competitiveness in the course of globalization. With advances in technology, work within virtual teams is gaining ever-greater importance. However, in this process, special knowledge and skills of virtual team members are a greater obstacle than technical equipment. Work within a virtual product development team requires intense communication, which is possible via videoconferencing. The contribution of this paper consists of a set of recommendations on how to develop necessary skills for effective communication and work in virtual development teams. The recommendations can be applied in both university and industrial environments. The paper is based on experiences from the international course on European Global Product Realisation that provided students with initial experiences in working within a global team. The authors believe that skills and technical equipment will need to be constantly supplemented and upgraded so that they will become practically independent of personal meetings (*i.e.* the distance between team members).

Keywords: Virtual team; Product development; Communication; Decision-making; Project management; Skills; Creativity

1. Introduction

The development of technology and remote communications has brought about certain social changes. In recent years, remote study and work have become popular, and virtual companies with spatially unrestrained cooperation are now becoming part of everyday life. Their main advantages include quicker responses, new potentials and greater adaptability. New technology and work within virtual teams have resulted in new requirements regarding the character, features and skills of the participants. Remote work demands independence, reliability and initiative. A study by BMW (Niggl *et al.* 2000) showed that 83% of all tasks in the research and development field could be performed at home. Working from home in combination with working at the office represents a gradual transition to completely virtual companies. Virtual teams are rapidly becoming a must, not an alternative. In the coming years, the development of technology will improve remote communication and reduce its price; it will become normal to have a videoconferencing connection in one's home. As remote communications become increasingly more personal, work in virtual teams is expected to expand at an unprecedented rate. As

*Corresponding author. Email: joze.tavcar@lecad.uni-lj.si

Journal of Engineering Design
ISSN 0954-4828 print/ISSN 1466-1837 online © 2005 Taylor & Francis
http://www.tandf.co.uk/journals
DOI: 10.1080/09544820500273797

much as 88% of all companies intend to increase the extent of their operations via virtual teams (Susman and Majchrzak 2003). Nevertheless, the differences in work methods compared with development teams based in one location are not fully known. The way people communicate is different, as are leadership and knowledge management (Susman and Majchrzak 2003). Partial answers on how to adjust development teams to work in a virtual environment and the available communication technology can be found in Susman *et al.* (2003).

This paper is a contribution to a better understanding of the principles of work and communication within the global environment. A review of literature from various standpoints is given first. The European Global Product Realisation course (E-GPR) (Horvàth *et al.* 2003) is then presented and nine recommendations for work in a virtual environment are given on the basis of experiences in product development. Some specific areas (*e.g.* decision-making and skills) are also discussed.

2. Literature review

The review of the literature shows predominant analyses of work in virtual projects in industrial practice (Pawar and Sharifi 1997, Poltrock and Engelbeck 1999, Moenaert *et al.* 2000, McDonough *et al.* 2001, Kasper-Fuehrer and Ashkanasy 2001, Lurey and Raisinghani 2001, Joshi *et al.* 2002, Pirola-Merlo *et al.* 2002, Wang *et al.* 2002, Leenders *et al.* 2003, O'Sullivan 2003). The second group consists of test studies by student teams formed specifically for this purpose (Harvey and Koubek 1998, Jarvenpaa and Leidner 1998, Kayworth and Leidner 2000, Humphreys *et al.* 2001, Larsen and McInerney 2002, Lovejoy and Srinivasan 2002, Huang *et al.* 2003). Cases in which product development is undertaken in virtual development teams that also employ video communication are very rare. The closest example is one from the University of Minnesota (Cardozo *et al.* 2002), but there the international dimension is not emphasized. A review of work in virtual development teams is given from various viewpoints: effectiveness, creativity, communication, conflict resolution, decision-making, trust and virtual team lifecycle.

2.1 *Effectiveness and creativity of virtual teams*

Multinational companies want to increase their competitiveness by involving the best suppliers and partners in their virtual teams. Based on an analysis by Lurey and Raisinghani (2001), good leadership has a very strong effect on the efficacy of virtual teams. The common goals must be clear to all members, and the division of work must be structured and formally prescribed. The project leader must carefully monitor the performance of work. The roles of individual team members must be clearly defined; it is important to include individuals who are appropriately qualified to do their part of the job. For good functioning of the team, personal contacts between the members must be well developed and should provide mutual support. Technology will make work easier, but will not be crucial for the effectiveness of virtual teams (Lurey and Raisinghani 2001). Another role of project leaders in virtual teams is to ensure building of the team, taking into account the cultural specificities of individual members (Kayworth and Leidner 2000).

Complex tasks require very intense communication, which is difficult to ensure in virtual teams. Virtual teams are more effective when they deal with less demanding tasks (Leenders *et al.* 2003). In development teams situated in the same place, there are more opportunities for informal communication and exchange of information, which increases work effectiveness. There are also fewer complications because of unified software and harmonized infrastructure.

However, there is also a risk of 'groupthink syndrome' (Pawar and Sharifi 1997), and virtual teams are believed to have greater innovative potential. Some studies (Pendergast and Hayne 1999) show that anonymous brainstorming in a virtual environment (group brainstorming) yields better results than standard face-to-face brainstorming. Global team performance is lower than the performance of virtual teams or collocated teams. This is because greater project management challenges are associated with lower performance in all types of teams – global, virtual and collocated (McDonough *et al.* 2001).

Creativity requires an optimum level of communication (Leenders *et al.* 2003). Overly intense or overly limited communication reduces creativity. Communication is the driving force of development teams. Both individuals and the team as a whole require an appropriate level of autonomy to develop their creativity. These needs can be fulfilled with regularly scheduled formal and informal communication. Good dissemination of information and distributed communication (each member with all of the others) must be ensured. This is in agreement with a German study (Frankenberger and Badke-Schaub 1998) reporting that 80% of a designer's time is composed of routine work that individuals perform independently, and 20% of conflict situations, which need to be solved, and decisions that have to be made. According to studies, designers solve 88% of all problems in cooperation with others (Frankenberger and Badke-Schaub 1998), by relying on the experience and knowledge of their co-workers and the synergy effect of the team.

2.2 *Communication in a virtual team*

Regular and effective communication is the necessary prerequisite for the functioning of virtual teams. The team leader must prepare the schedules and rules for regular meetings (Kayworth and Leidner 2000). Team members must take the time to get to know each other well, because this improves communication and increases the level of effectiveness. In strong personal relationships, communication is frequent but short. Strong relationship pairs were parsimonious in their communication. They exchanged shorter messages than weak relationship pairs, and the messages were simple and direct. Relationships in virtual teams are developed and strengthened through a proactive effort to solve problems (Hart and McLeod 2003).

In literature dealing with the topic of virtual teams, the majority of authors discuss experiences in the execution of projects that do not require intense communication and use widely accessible equipment, such as email, telephone, fax and the Internet (Hameri and Nihtilä 1997 Kayworth and Leidner 2000, Lurey and Raisinghani 2001, Huang *et al.* 2003). Product development requires intense communication; the use of a video system is therefore essential. Based on studies (Harvey and Koubek 1998), there is no difference between personal face-to-face and video communication in product development. A large difference is seen, however, if only audio communication is used. In complex tasks, such as product development, the type of communication medium employed (email, audio and video) has a strong impact on effectiveness, while in simpler tasks this has no marked effect (Kayworth and Leidner 2000). Communication becomes more effective once the team develops a common vocabulary (Kayworth and Leidner 2000).

As a rule, communication involves a feedback loop between the sender and the recipient, as shown in figure 1 (Spence 1994). It is very important for effective communication that the sender immediately receives a confirmation that the recipient correctly interpreted the information. Whenever one writes a message, a reply is needed in order to know that the intent of the message was achieved. In a conversation, however, confirmation is often expressed simply through mimics. Within a familiar team, even a small hint will suffice and everyone will understand the message. However, recipients from different cultural environments or different

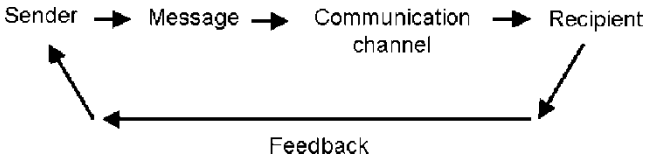


Figure 1. Feedback loop between the recipient and the sender (Spence 1994).

types of expertise will require a clear, modified explanation. Effective communication in a development team requires as many communication channels as possible: audio, video and textual.

2.3 *Conflict resolution*

Global development team members come from different cultural environments, with different levels of education and different work methods. Such variety is on one hand an advantage, but on the other it increases the probability of conflict situations (Joshi *et al.* 2002). Joshi *et al.* find that conflicts between crucial team members are the greatest threat to successful project execution. They recommend that the situation be analysed on the basis of diagrams of intensity of communication, workflow and conflicts between virtual team members, after which appropriate actions should be initiated (Joshi *et al.* 2002). Large changes brought about by virtual development teams cause misalignment in task setting, structure of the project team, and the organization. It is very important for the project team to be able to recognize and admit misalignment, as this opens the door to finding solutions (Susman *et al.* 2003). A greater degree of trust and work skills in a virtual development team reduces the number of conflicts and enables their resolution (Susman *et al.* 2003).

2.4 *Trust in a virtual team*

Trust is one of the important building blocks of virtual development teams (Kasper-Fuehrer and Ashkanasy 2001). Product development requires close cooperation between team members; this in turn requires trust. For trust to develop, it is necessary for team members to share a common history and have personal contacts; this is what trust within development teams at a single location (collocated teams) is built on. However, in many global virtual teams this is not possible. It is necessary to start with initial, 'swift' trust and build on it (Jarvenpaa and Leidner 1998). Initial social contacts are important, as this is when team members really open up and get to know each other. Later, trust can and needs to be solidified through predictable communication, quick responses and individual initiative (Jarvenpaa and Leidner 1998). This portion of trust, which is built within the first 2 weeks and serves as the basis for further solidification of trust via appropriate communication, is what team members can rely upon most (Jarvenpaa and Leidner 1998).

Individual studies have confirmed that well-managed preparation can accelerate the building of virtual teams and thus increase their effectiveness (Huang *et al.* 2003). During their lifecycle, project teams pass through various phases, which need to be taken into account during team management. Members of each virtual team are initially strangers to each other, with a considerable degree of mistrust. Effective communication and functioning of the team as a whole begins only when trust develops between the members. Team management must always take into account the phase the team is undergoing at the time.

Kasper-Fuehrer and Ashkanasy (2001) build trust in virtual teams on a common business understanding and business ethics. Common business understanding includes a correct understanding of the virtual team's goals, distribution of roles, clear definition of tasks, management and a joint identity. This needs to be clear right from the start. Knowledge of all circumstances is the basis for growth of trust. Ethics cannot be built; it should be clearly defined at the beginning in the form of a clear division of responsibilities, set procedures and disciplinary measures. A virtual organization requires clearly set rules to enable trust to be built (Peterson 2003). These rules need to be understood by all. Work in virtual teams also requires dealing with the matters of offer and demand, as well as formalities such as drawing up of contracts. Modular contracts prepared in advance are among the prerequisites of virtual organizations (Hoffner *et al.* 2001). A legally regulated form of cooperation contributes to a more confidential relationship.

2.5 *Virtual team lifecycle*

During its lifecycle, each virtual team passes through several characteristic phases (table 1) (Johnson *et al.* 2002). Knowledge of the features of each phase is very important for adequate project management and correct behaviour of the project team members. In a virtual environment, opportunities for communication are limited; therefore, errors in management or breaches of trust are much more difficult to fix than in teams that meet in person every day.

Members of the project team meet during the initial phase (figure 2). Since this is a new environment for them – they usually do not know each other – good management is very important. Right from the start, team members should feel that the project is managed and it must be clear what is expected of each individual (Jarvenpaa and Leidner 1998). All this is especially difficult to accomplish in the case of the first virtual project, because so much is new. In the next step, team members get to know each other. This can be described as measuring of power and consequential forming of set relationships between individual team members, all of which leads to setting up of an informal team structure. Even in the phase of preparation (PrePhase), it is important for the team to be composed of complementary members as much as possible, because this reduces the probability of conflicts. This phase also leads to the building of trust, which is the basis of the team's good functioning later on.

In the next phase, the team is at its most effective. It has been said many times that good communication and creativity require trust. Now that team members know each other well and know what to expect of each other, they can function effectively. In virtual project teams it is also necessary to make sure that the project is actually completed. If necessary, support and maintenance should be assured for the period after the formal project conclusion. In the final phase, project management must again be very intense.

Table 1. Virtual team lifecycle phases and definitions.

Phase	Phase description
PrePhase	Forming of the team, technical equipment, leader's preparations
Initial phase	Getting to know each other, common goals, determination of procedures for communication and work, training in the use of technical equipment
Trust building	Building of trust through work, development of the work method
Working phase	Project work – the team's most effective phase
Finishing phase	Project conclusion and documenting, presentation of results, agreements on continued collaboration

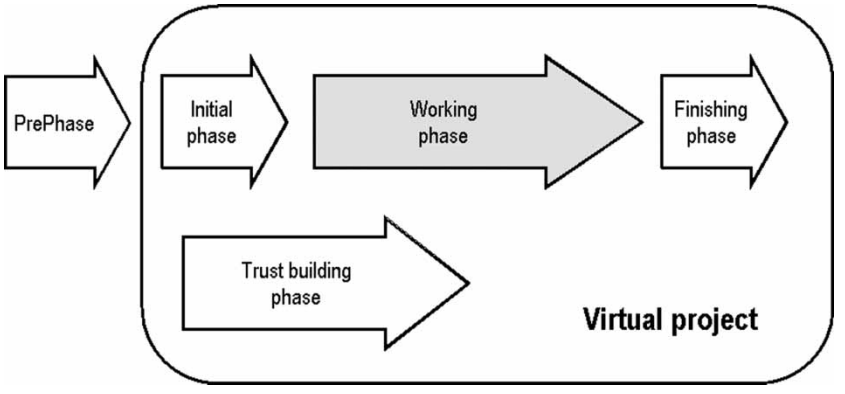


Figure 2. Virtual team lifecycle phases.

2.6 *Product development*

Product development is a creation of good business for a company and a very complex interdisciplinary activity. Nevertheless, three functions are of core importance for almost every product development project: marketing, design (engineering and industrial) and manufacturing. Product development begins with identification of product opportunities and ends with production, sale and delivery of a product (Pahl and Beitz 1993). The phases of the product development process are planning, concept development, system-level design, detail design, testing and refinement and production ramp-up (Andreasen and Hein 2000, Ulrich and Eppinger 2000). The phases contain tasks of each of the core functions; if they are shared among departments, there is considerable risk that a company will fail to achieve its goal (*i.e.* create good business) (Andreasen and Hein 2000).

Product development has certain specifics that need to be taken into account. If the recommendations for concurrent engineering are observed, the core of a development team should be located in a single room, a design studio (Prasad 1997). Direct access and close cooperation between the marketing team, the designers, technologists, manufacturing department, the purchasing service and suppliers will enable quicker product development and improve its quality (Duhovnik *et al.* 1993, Ulrich and Eppinger 2000). It is important to anticipate the consequences and impact of individual decisions throughout the product lifecycle as early as the conceptual design phase (Duhovnik and Tavčar 1999). Concurrent engineering with overlapping developmental phases requires tighter coordination and there is greater intensity of communications (Tavčar and Duhovnik 2000). When development teams are formed, compromises are made between the demand for quickest possible development and the fact that they will be sharing their time between various projects. Cooperation via videoconferencing is opening new possibilities. The aim of the principles presented in this paper is to prepare students and facilitate the creation of a creative environment for global development teams.

This paper presents an analysis of work in virtual development teams during the E-GPR course. A comparison is made with observations in literature dealing with this topic, using various criteria. For successful work in virtual development teams, its members must have some special skills; it may almost be said that they need to develop specific character traits.

In addition, a systematic approach is necessary to develop trust among the participants and distribute work tasks properly. The contribution of this paper lies in a set of recommendations on how to develop the necessary skills for effective communication and work in virtual development teams. Most of the recommendations apply to both university and industrial environments.

3. International product development course (E-GPR)

Personal, hands-on experience is very important for the acquisition of skills in a global development team. The Design Faculty of the Delft University of Technology in The Netherlands has been practising product development within a global development team for 3 years. The main course objective is to develop the type of project and work methods that would most realistically reflect the circumstances, activities and tasks of professional product development teams. The reason for such a large emphasis on realism is that we desired to demonstrate to the students (*i.e.* future members of product development teams) the challenges that professional product development teams are faced with every day. In 2000, Delft University carried out an intercontinental project in cooperation with the University of Michigan, USA, and the National University of Seoul, South Korea (Horvàth *et al.* 2001). Because of financial and time-zone limitations, Delft University continued the project with European partners: Ecole Polytechnique Federale Lausanne, Switzerland and the University of Ljubljana, Slovenia (Horvàth *et al.* 2002).

Lectures and work on this project took place twice a week, four academic hours per week. It was carried out from the beginning of February to the end of May in the years 2002 and 2003. New student project teams are set up every year, and a new project definition is determined each time. The target is to have 15 students at each location. Students eligible for participation in this programme are those attending the fourth year of university studies of mechanical engineering or industrial design. This course is elective at all three universities. Communication was conducted in the English language. Via lectures, students were provided with a systematic insight into the basic knowledge and concrete examples of global products. Academic lectures, case studies from the industry and work on the project were interwoven throughout the semester, but work on the project played a central role for the students. It is well known that independence is the source of motivation and creativity, and this was clearly visible at phase presentations by the project teams. During the last week, the students and their mentors met face to face, finished product prototypes and presented them at the final exhibition.

Lectures and work on the project are performed in a joint classroom, which is supported by basic telecommunication technology: videoconferencing and Internet connections. This international school is giving students systematic knowledge and experience in developing products for the global market. For global products to be successful, technology, marketing and industrial design need to be tightly integrated. This subject is E-GPR. The experiences and knowledge from three universities and the industry have been assembled and integrated. In this manner, students are able to acquire international experience, which is very important for their competitive ability in the global market.

The implementation of the E-GPR course is a considerable organizational undertaking. During the seminar, a technician and a coordinator are required to be available for most of the working hours at each of the universities; the technician ensures undisturbed operation of the communications equipment and the coordinator organizes project implementation. Each of the student project teams also has his/her own instructor. In the majority of cases, these are

postgraduate students or university assistants. The company representative who has determined the project task also plays a crucial role in its implementation. His main task is to provide technical data and information on market requirements, manufacturing possibilities, and so on, for the students. His presence increases the level of the project and brings its execution closer to real circumstances in industrial practice. The project task proposer attends several regular virtual meetings and is available to answer questions via email. Several external associates are involved as well, who participate in lectures. These are company representatives or invited lecturers from the universities, who present topics related to the project task contents.

3.1 *Technical equipment*

Lecture rooms in Ljubljana, Delft and Lausanne are appropriately equipped and have created a joint virtual classroom. The most important of all components is the videoconferencing system, consisting of a camera that follows the speaker, a projector, a videoconferencing multipoint server and ISDN connections (figure 3). High-quality images require rapid transmission of large amounts of data, which was made possible by three ISDN telephone lines in 2002. In 2003 the Internet connection was reliable enough even for the lectures, and reduced the considerable telephone costs. Lectures are normally accompanied by image materials. High-quality transmission of graphics is achieved by projecting computer images onto a screen. Computers for projection are visible on the Internet (IP number) and are interconnected using the NetMeeting program. In this way, the lecturer can present the prepared pictures (PowerPoint) simultaneously at all locations. With a bit of camera operating skill and appropriate coordination by the moderator, we managed to eliminate the distance between Ljubljana, Delft and Lausanne. The lecturer and audiences at all three locations could hear and see each other, pose questions and feel like they were in the same classroom. The cameras in each classroom

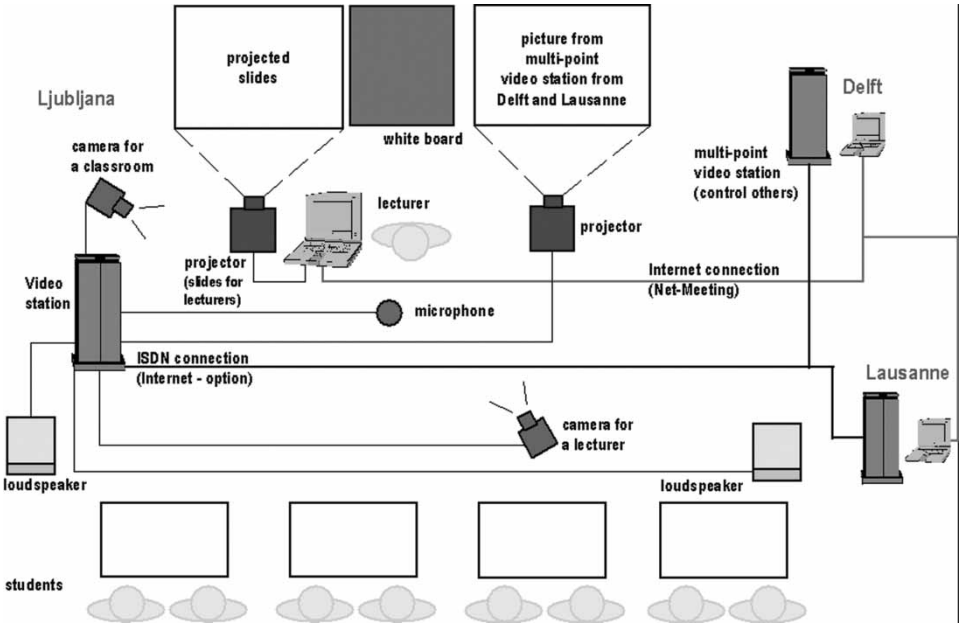


Figure 3. Schematic of the computer classroom in the E-GPR project.

could also be operated by students from other locations. Students used the Internet for their communications – this was free of charge, but slightly less reliable. These arrangements can be further improved with some additional investments. For example, by switching to leased academic lines, we will be able to improve the quality of transmitted images. The television screen has been already replaced with an additional projector, with which communication feels even more real, as everyone is shown in his/her actual size.

Data exchange is performed mainly via the joint server and a homepage created specifically for this project (www.e-gpr.nl). The server contains a collection of all project-related documents, from presentation of project objectives to schedules containing data on lectures, picture materials for the lectures and daily notices. Information on all participants enrolled in the international school is also collected in order to facilitate their communication. Access to this data is possible only via personal passwords, while the general presentation is freely accessible. Communications between the participants take place in many different ways: via emails, chat-rooms and regular videoconferencing.

At the beginning of the course, the communications equipment is briefly presented to the students. Students can learn how to operate the communications equipment relatively quickly. Instructors offer support in the case of complications. Unification of the modelling software was not done. Mastery of modelling skills proved to be a greater obstacle than installation. An additional course in three-dimensional (3D) modelling and unification of software (*i.e.* checking of the software compatibility in advance) would be helpful.

Students have been asked to set up rules for communication within project teams. For example, videoconferencing rules are as follows: every Monday and Wednesday at 11:00 am. Emails should be answered as soon as possible, but in any case within 24 h (if a final reply is not possible, receipt of the question should be confirmed, explaining why a final answer cannot be given yet). Each longer absence (over 36 h) should be announced in advance to all team members. Communication via several channels (videoconferencing) in the lecture rooms was supplemented by emails from home (always accessible and inexpensive). Transfer of large files was an obstacle (transmission speeds are constantly increasing, therefore in time this will cease to be a problem). There were also problems in transferring ideas between individual phases (transition from sketching to 3D modelling). Constant access to the videoconferencing room and video equipment at home would improve communication.

3.1.1 Requirements for communication equipment in the industrial environment. Simple access to communications equipment is important for effective work. The development team should have appropriate equipment in its work environment or at each workplace, especially when more complex tasks are involved. In the case of 3D modelling conducted at several locations, a systematic setup of computer equipment would be necessary (the same computer-aided design package, exchangeable versions, introductory training if necessary). A high level of standardization of communication equipment is required, so that everyone can join the team without any adaptations. The setting up of a virtual team should be quick. Behind technical equipment, there should be skilled users who can work effectively in a virtual team. Nowadays, a new team has to first synchronize the technical aspects and then acquire the operating skills afterwards.

Common software for tasks from conceptual design to 3D modelling is an important part of standardization. It should enable quick transfer of ideas from the designer to the mechanical engineer. There should not be any misunderstandings concerning dimensions and the position of features, as was seen during the E-GPR course. Modelling software should enable concurrent work on a model or text.

3.2 *E-GPR teamwork*

Work on the project is performed within an international team consisting of students from all participating countries, which helps improve their capacity for teamwork. Students from each project team are spatially dispersed across Ljubljana, Delft and Lausanne; they are therefore forced to use modern methods of communication: videoconferencing, emails, a joint Internet server. The target team size is six (*i.e.* two team members per university). Complementary knowledge is very important for the team. Students from the Delft University of Technology are well-versed in industrial design, market analysis, conceptual product design, and so on. At the Faculty of Mechanical Engineering, Ljubljana, there is greater emphasis on technical knowledge: strength analysis of the construction, 3D modelling, manufacturing technology. Participants from Lausanne are students enrolled in the curriculum for the study of product lifecycles with emphasis on recycling and, in the past year, on mechatronics. It was found that teams with complementary knowledge cooperate better than those with related knowledge. During the project, students had different roles in the teams. Some of them focused on 3D modelling, while others did market research and design; one student was good at presentations, and another organized prototyping. Their various types of knowledge have nicely complemented each other – it was particularly interesting to observe at a videoconference how this year's project teams were formed of students with complementary specific knowledge and skills, based on their individual presentations. Later, the teams submitted regular progress reports, again by means of videoconferencing.

Professors and instructors met before the beginning of the project and determined the goals and work methods in detail. Students were informed of the specific features of work in virtual teams such as communication, project management and decision-making. There was enough time and encouragement for personal presentations; a list of email addresses of all students and instructors was available. All team members created their own web pages with their personal presentations. The students composed the teams themselves; therefore, they felt more connected. Project team members at one location knew each other from before. Students were encouraged to develop and maintain trust throughout the project. Lectures took place twice a week, with constant direction and encouragement in times of crisis.

Students were involved in this project for a limited period of time, with the objective of obtaining as much useful knowledge as possible and getting the highest possible grade. Therefore, there were no obstacles to good cooperation. We had an agreement with the participating companies, which defined the project task and provided the necessary support. Companies may use the results of the course without having additional financial obligations. In this manner, they were more motivated to participate in the project and it was easier for them to justify the costs of cooperation to their management.

For students, international connections are a challenge and a source of energy. In an industrial environment, a professional attitude towards the task has greater importance. Project management must additionally stimulate the participants to get to know each other and build mutual trust. A good way to build trust is to have positive experience of joint work. Initiative is very important. A large advantage in composing an effective project team is knowing the team members and their skills and knowledge. A well-balanced team structure has a very strong impact on the results and requires careful consideration. During virtual work, it is important for the participants to be adequately trained in the planned tasks (McDonough *et al.* 2001). In tackling complex tasks, the use of unified tools within the team should also be ensured (*e.g.* computer-aided design modeller). When virtual teams are composed, it is important to select team members with appropriate skills who are capable of performing their tasks independently. Particular attention needs to be paid to those members who are participating in a virtual team for the first time.

3.3 *Project management in global product development teams*

The goals and course of work were first agreed upon by the professors and instructors. The prepared points were clearly presented to the students. If there were any deviations from the project goals during project execution, the instructors alerted the students. A formal leader of virtual teams was not determined, because the students were not known well enough at the beginning of the project; thus a leadership role was partially assumed by the instructors. In the majority of teams, the role of the leader was circulated among the members depending on the project's phase. The problems of lax leadership included difficulties in decision-making, for example. In the future, student teams will receive detailed instructions for teamwork and will be advised to choose a coordinator from among themselves. This personal experience will undoubtedly be valuable.

The project was carefully planned and managed, and the set deadlines enabled the execution. Regular presentations were made of intermediary project phases: market research, conceptual solutions, conceptual design of the selected product, and the final presentation. The instructors monitored the execution and acted immediately whenever they observed any deviations from the plan. Teams with complementary knowledge cooperated better than those with similar knowledge. Mechanical engineers cooperated better with mechatronics than with mechanical engineers from another faculty. Areas of work were clearly divided in advance; therefore, there were fewer conflicts. At the end of the project, there was a public presentation. This was a great source of motivation and clearly marked the conclusion of this project.

In an industrial environment, the leader needs to be additionally trained for work in a virtual team before the beginning of the project. To ensure project execution, a constant overview over the current status of the project and activities of the individuals is necessary. It is very important for the results of the project to match the initial requirements. There must be a correspondingly greater emphasis on unambiguous understanding and pursuit of goals. Proper understanding of goals is directly related to a team's effectiveness. In an industrial environment, meeting of the set deadlines and final product costs are more important. Appropriate division of work is essential – the interdependence of tasks serves as a source of creativity, but it also brings about greater problems in coordination. After project conclusion it is necessary to ensure maintenance and subsequent supplements; for example, via detailed documentation or contracts on later cooperation (O'Sullivan 2003).

According to our experience from the E-GPR course, the most prominent type of conflict involved decision-making. Since it was sometimes impossible to continue work because of different viewpoints; this slowed down our progress towards the final goal. Since 2003, a clear decision-making structure (figure 4) has been presented to E-GPR students participating in each course in order to speed up decision-making.

Coordination of work and decision-making is an important part of every project. A virtual environment requires much more precise definition and implementation of a decision-making system. Early conflicts are typical for highly productive organizations; therefore, the project team structure should be able to manage conflicts (Prasad 1996). Figure 4 shows the elements of an effectively run virtual product development team. The steering committee prepares a project definition and controls the execution of the project at the predefined milestones. The steering committee members are senior managers who have knowledge of the market and manufacturing possibilities. In case of the E-GPR course, the steering committee is constituted of a representative of the company that has defined the project and the participating professors. Project definition is a crucial phase of the project because it determines the direction. If there are new findings that are in a conflict with a project definition, the steering committee should make a decision on how to continue.

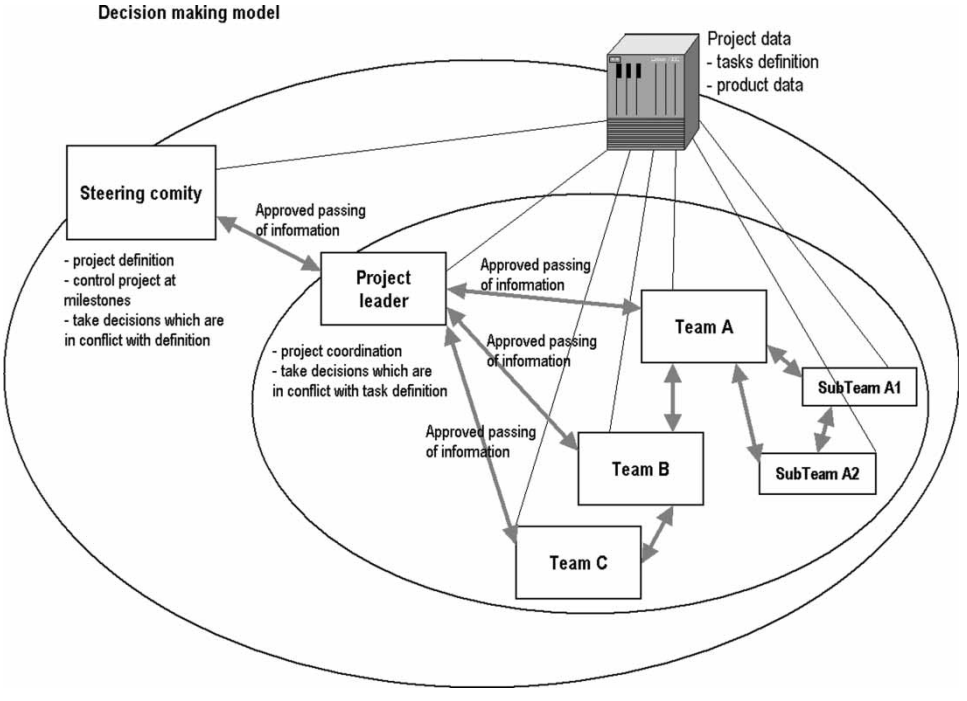


Figure 4. Decision-making in a virtual team.

Goals should be clear and well understood at all levels. Every task given to the project subteam should be documented and checked to see if it was properly understood. A good practice is to have a short videoconference with two-way communication and an approval. Virtual product development is based on empowered members and small teams who should know what their task is. They have to work proactively; they communicate directly with the other teams and manage interactivities (Prasad 1997).

The project leader should split the project into manageable and, as far as possible, independent tasks. Bigger projects have a multi-level structure. Decisions are made within empowered teams (Shim *et al.* 2002). The project leader should know how work in the teams is going, and organize regular meetings in which team members are informed about the project as a whole. Independence between teams makes work more productive, but cross-team communication offers new potential for creativity. Inter-team communication is therefore indispensable, especially in the conceptualization phase.

There is a clear hierarchy on making decisions:

1. Within teams (there should not be any conflict with a task definition).
2. Common decision between two or more teams (a project leader is informed or he/she can be asked to coordinate the decision process).
3. Project leader (there should not be any conflict with a project definition).
4. Steering committee.

There is a common project server where all the project data are kept. Project data include project and task definitions, a time schedule, current product data, concepts, 3D models and the latest testing reports and detailed technical documentation.

3.4 *Project definition and result of the project*

The project task was selected so as to fit the prior knowledge of the students, both in terms of difficulty and extent of work (3 months). It was very important that the company defining the project task provided the necessary support and professional assistance. The data on principles of operation, technical requirements and market requirements immediately elevated the product development project to a higher level and made it more realistic.

3.4.1 Example of a project definition prepared by LIV Postojna company. A vacuum cleaner should be a global product, used for general dry cleaning at home. It will be distributed for sale in Europe and other parts of the world. Functionality, costs, and customer requirements are the most important features in the development of the product. This enables production of large quantities of reliable products at a low price (€100). A vacuum cleaner should not occupy too much space. According to market research results, a project group should define a target user group, product cost and specific technical requirements. The project team has to deliver a verbal presentation, create posters, and make various models of the product (both physical and virtual mock-ups).

The students demonstrated their results at the final presentation. The course of product development, various variants and product prototype were presented. Each year, students surprise us with their creativity and produced prototypes, some of which are shown in figures 5–7. The final presentation served both as motivation and the final milestone. Competition between the teams was also a strong incentive. Each of the teams wanted to present something original and they managed in accomplishing this goal. The project was concluded with the presentation and delivery of project reports. Because of this, the products were partially adapted to the available technology for producing prototypes, while criteria of mass manufacture and technology for planning product use were observed to a lesser extent. Nevertheless, it can be claimed that the objectives were achieved. The E-GPR course enables students to become competent members of global product development teams. Much of the acquired experience in communications and student E-GPR project work therefore also applies to the industrial environment.

A concept of coffee maker is presented in figure 5 in the form of a hand drawing, and two examples of physical prototype are shown in figures 6, 7. Table 2 includes basic data on all three GPR projects.

3.5 *Students' experience working in a global product development team*

We analysed our students' experience working in a global product development team. We would like to improve working conditions; therefore, we focused on limitations of the global environment. The questions (table 3) were sent to 68 students by email at the end of the project in 2002 and 2003. There was a 76% response. The results of the questionnaire are presented in table 4.

Answers were organized into three groups: what are the limitations from a technical point of view, what did they miss from a human point of view, and what are the advantages of global teams? The students have different roles in their team; they therefore focus attention on different details. In general, the experience was very positive. It was a challenge and a very good motivation to work in an international team. People from different countries brought together new ideas. Students from different universities have different backgrounds, and they see the advantage of global teams: specialized knowledge from anywhere in the world is now available.

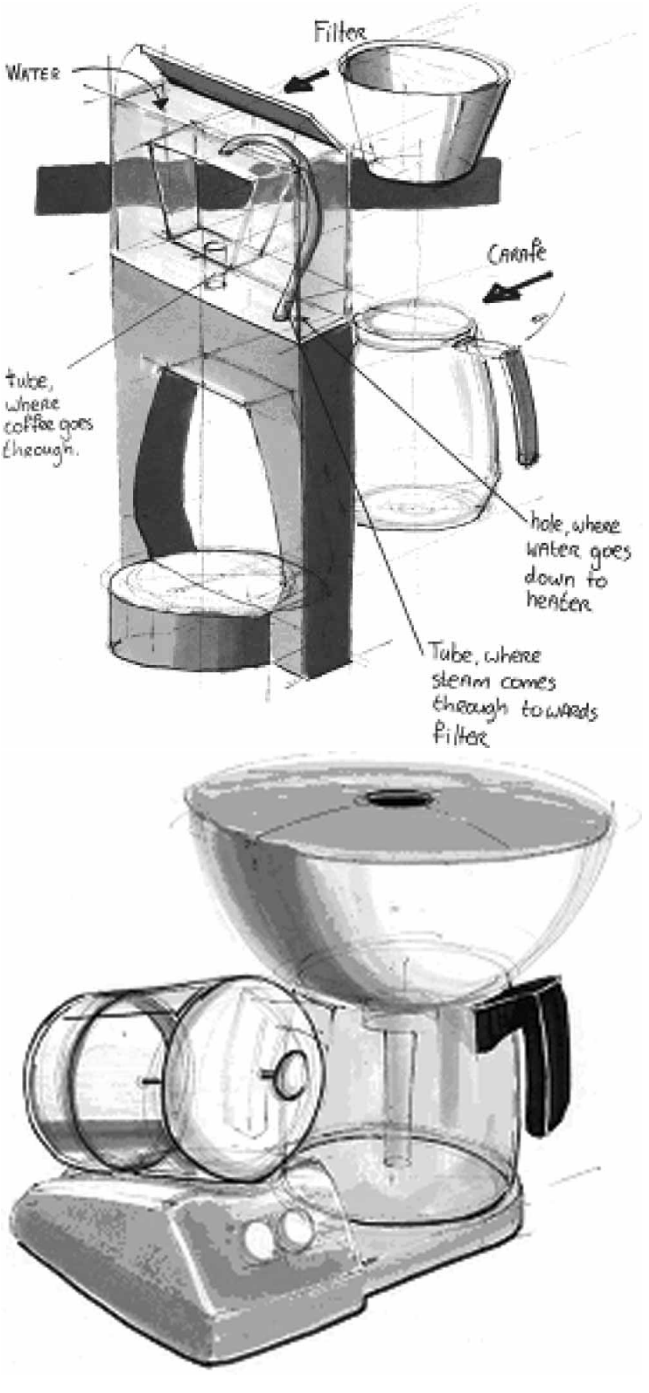


Figure 5. The concept of a coffee maker (Horvàth *et al.* 2001).

Figure 6. The prototype of a vacuum cleaner (front) and one of the mock-ups (back).

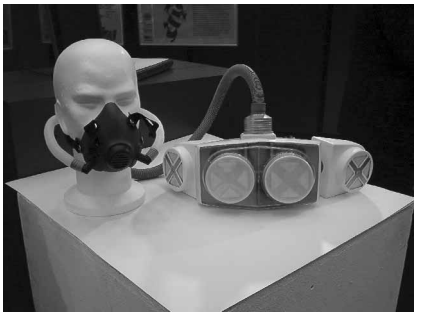


Figure 7. The prototype of a respiratory unit for welders.

There are still many technical limitations. Working in a global team is more time-consuming. All the work results should be transferred in electronic form to the other team members. Video conferencing rooms were not available at all three universities all the time, and they avoided telephone calls because of the cost. Therefore, students were forced to use slower ways of communication such as email or Internet chats. The good news is that the quality of communication will be improved with the development of technology, and the costs will decrease in the near future.

Limited channels of communication was given as a problem by 50% of students. Better technology will improve it in many ways (faster, better picture and sound quality, easily accessible). The team members belonged to 11 different nationalities. Cultural differences was not recognized as a problem, since the way of living and thinking inside Europe is relatively

Table 2. Basic data on Global Product Realisation projects.

Year	Universities	Design assignment	Teams	Students
2000/2001	Delft, The Nederlands; Seoul, South Korea; Michigan, USA	Coffee maker	8	46
2001/2002	Delft, The Nederlands; Lausanne, Switzerland; Ljubljana, Slovenia	Vacuum cleaner	2	32
		Respiratory unit for welders	3	
2002/2003	Delft, The Nederlands; Lausanne, Switzerland; Ljubljana, Slovenia	Protection mask and respiratory unit for welders	4	36

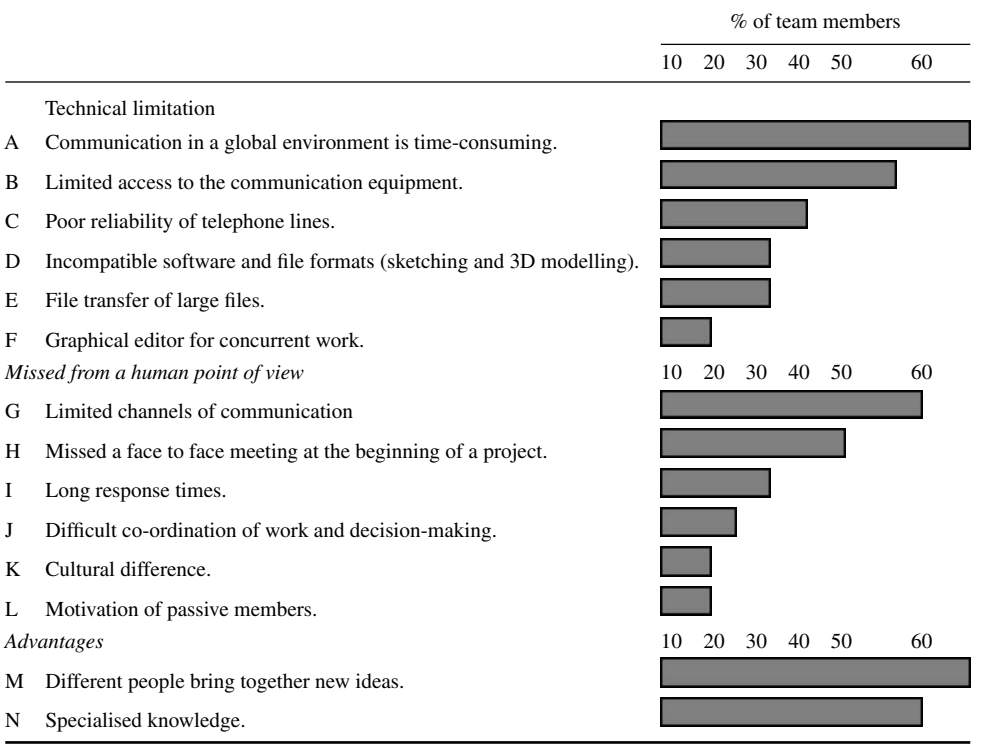
Table 3. Questions used in the questionnaire.

(A)	Was long-distance communication a disadvantage for more effective work in your team? (What were the technical limitations?
(C)	What did you miss from a human point of view?
(D)	Do you see any advantages of working in a virtual team in comparison with a traditional one at a single location?
(E)	What could be better regarding communication; what would you improve (both what is technically possible today, and your vision for the future)?

similar. It was different during the three-continent Global Product Realisation course 3 years ago (Horvàth *et al.* 2001), and there were additional problems with language, ways of thinking and time zones (Koomen and Verhees 2002).

Other recognized problems from a human point of view require more attention. Most of these can be solved by developing of special skills for members of virtual teams. A model of the management decision process in a virtual team is presented in the next section. Team members should be inventive and be able to work independently. The best way to get those skills and personal attitudes is a personal experience such as the E-GPR course. Students are now familiar with the use of communication equipment and they are able to organize work in a virtual environment.

Table 4. Technical and human limitations and advantages of working in global teams according to the questionnaire between students involved in the E-GPR project in 2002 and 2003.



4. Requirements for work in global teams

Experiences from the E-GPR course are presented and a comparison is made with the requirements for virtual teams in industrial practice. A comparison is made with observations in the literature dealing with this topic. The authors have several years of industrial experience. Nine requirements (*i.e.* nine necessary steps for effective work in virtual teams working on product development) are summarized in table 5. The authors claim that compliance with these recommendations increases the probability that product development will run smoothly and will be effective. Successful work in virtual development teams requires certain special skills, as presented in table 6. Most of the recommendations and skills apply to both university and industrial environments.

The main strength of the E-GPR course is that it realistically reflects the work of professional product development teams. Therefore, in most cases E-GPR student team experiences can be generalized to industrial practice. Naturally, each project and team has certain specifics, and

Table 5. Requirements for work in global teams.

A	Preparations for the virtual development project Activities before the beginning of project execution that are the prerequisite of successful work. The goals should be set clearly, adequately trained individuals should be selected, and the necessary infrastructure for communication and work should be provided. For good cooperation, the team members should have complementary, and partially also the same, knowledge
B	Project management Virtual development work requires careful planning and monitoring. In a virtual environment, a competent leader is especially indispensable during the initial phase (Lurey and Raisinghani 2001, Smith and Blanck 2002). The project leader has to adjust his/her role to the virtual team's lifecycle phase. The leader must ensure the clarity of goals, unanimous adoption of the work method and building of trust in the initial phases of the project, as well as encourage communication (Pirola-Merlo *et al.* 2002)
C	Presentation and understanding of goals Work in virtual teams requires a clear understanding of goals (Lurey and Raisinghani 2001). Feedback is necessary during the distribution of tasks in order to confirm that the presentation and agreements were understood correctly
D	Determination of methods of working and communicating within the team A communication timetable and rules have to be agreed on between team members. More complex tasks require more intense communication (Leenders *et al.* 2003)
E	Legal regulation of relationships within the virtual team A clear legal regulation of relationships is the prerequisite for an open dialogue and close collaboration (Hoffner *et al.* 2001)
F	Training of team members In addition to technical knowledge required to use the communications equipment, special features of work in a virtual team also need to be taken into account (*e.g.* regular responses) that are important for building trust. Each virtual team member must be independent and must show initiative. Individual skills, such as, for example, knowledge of a foreign language in a multilingual team, cannot be mastered overnight, which should be taken into account as early as team formation. Training in the use of unified software in the entire team (*e.g.* 3D modeller)
G	Familiarization of project team members and building of trust A personal relationship and trust among team members are very important for a creative dialogue and effective cooperation (Kasper-Fuehrer and Ashkanasy 2001). Via active management and training, it is necessary to ensure that this relationship and trust are built from the beginning and then maintained (Jarvenpaa and Leidner 1998). A comprehensive professional and personal presentation of each team member is necessary at the beginning
H	Project work Current monitoring of project execution and adaptability are important. For effective project execution, work needs to be divided into well-rounded wholes. Reliable and quick data exchange on project work should be ensured. Project documentation is accessible to all members
I	Project conclusion It is necessary to ensure that the project is completed and that crucial team members remain accessible for any subsequent supplements

Table 6. Specification of skills required for effective communication and work in virtual product development teams.

Team members skills	Willingness to cooperate and work for common project goals
	Effective communication in a virtual team (trust building)
	Initiative and ability to find information and make decisions
	Mastery of a common spoken and written language (English)
	Mastery of a common technical language (similar background is an advantage in communication)
	Personal experience of working in a virtual team (communication skills, organization of work, etc.)
	Working with the communications software
	Ability to use the computer in all phases of design (computer-aided design sketches can be transferred to other users without scanning)
	Specialized knowledge (compatible with other team members)
Managing skills	The project leader should be well versed in virtual team management (distribution of tasks, trust building, monitoring of progress, motivation of team members)
	Management of a joint server on which all project and product data are stored
	Operation of the communications equipment (technician)

work in global product development teams cannot be made efficient merely by following a few rules. We believe that personal experience is necessary for effective work in virtual teams. The recommendations presented in table 5 can accelerate the learning process by doing. The recommendations require better preparation and the encountered problems are thus better understood. These methods are practiced at the E-GPR course. Each year, students are taught about the specifics of virtual teams. Special attention is paid to areas that were recognized as problematic in the previous years, such as decision-making. The results of student project work prove again and again that global product development teams can work well.

5. Conclusion

Traditional product development is based on teams that work together at the same location and on physical prototyping. Therefore, a move to a virtual environment is difficult. Contemporary teams combine face-to-face meetings with videoconferencing. Our experience is that it is possible to work effectively in a purely virtual environment.

Global teams and production are on the increase. Communication technology is getting better, cheaper and more widely available. Effective work and communication in a virtual product development team require special skills. The best way to acquire such skills is via personal experience (*e.g.* at E-GPR courses). Training for work in virtual teams is a long-term process. This should be shifted to the period of studies as much as possible, when students are most open to new things. Individuals who have acquired the necessary knowledge and personal experience in working in global teams will be more successful in the global race.

Product development requires intense communication, which is possible via videoconferencing. Studies from a few years ago, which were based only on the use of simple technology (without videoconferencing, for example; Lurey and Raisinghani 2001), are only partially useful for product development. The E-GPR course closely approximates circumstances in industrial practice, but there are certain differences. Students were aware that this was a one-time project. Building of trust was not problematic. The situation would be different, however, if an individual or a team was passing on long-term experience. The E-GPR project will be continued in coming years; new technical capabilities will be added and the acquired experience will be incorporated.

New generations of developers need new features for successful work in global teams. It is well known that, in individualistic societies, individuals are more independent and trusting and are more capable of becoming part of a new team than are representatives of traditional collective societies (Jarvenpaa and Leidner 1998). With time, positive experience will transform people to be able to effectively participate in virtual teams. This process can be significantly accelerated by appropriate education, training and management. An important question is how to instil trust in a development team. Independent individuals who know what they can expect from a global development team and are familiar with communication technologies will become involved in such teams with optimism, and full of trust. At the same time, they will be aware of what is necessary to maintain trust and work effectively: quick responses, good dissemination of information to all, and initiative. Experience and recommendations given in this paper can significantly contribute to better effectiveness of virtual development teams.

We believe that the E-GPR course could also serve as a method of permanent education: company members (engineers, designers, etc.) can be enrolled in the E-GPR course and participate in it as team members. In this way, it would be possible to educate engineers from companies that are planning to go global, in order to minimize initial problems.

References

Andreasen, M.M. and Hein, L., Integrated Product Development, reprint, 2000 (Institute for Product Development, Technical University of Denmark: Lyngby).

Cardozo, R.N., Durfee, W.K., Ardichvili, A., Adams, C., Erdman, A.G., Hoey, M., Iaizzo, P.A., Mallick, D.N., Bar-Cohen, A., Beachy, R. and Johnson, A., Perspective: experiential education in new product design and business development. *J. Product Innovation Manage*., 2002, **19**(1), 4–17.

Duhovnik, J. and Tavčar, J., Concurrent engineering in real and virtual tool production. In *Concurrent Engineering: Research & Applications*, 1999 (Technomic Publishing Company: Lancaster).

Duhovnik, J., Tavčar, J. and Koporec, J., Project management with quality assurance. *Computer Aided Design*, 1993, **25**(5), 311–320 (Elsevier Science: Kidlington).

El.Sabaa, S., The skills and career path of an effective project manager. *Int. J. Project Manage*., 2001, **19**(1).

Frankenberger, E. and Badke-Schaub, P., Influences on design productivity – empirical investigations of group design processes in industry. In *The Design Productivity Debate*, 1998 (Springer-Verlag: London).

Hameri, A.-P. and Nihtilä, J. Distributed new product development project based on internet and world-wide web: a case study. *J. Product Innovation Manage*., 1997, **14**(2), 77–87.

Hart, R.K. and McLeod, P.L., Rethinking team building in geographically dispersed teams: one message at a time. *Organizational Dynamics*, 2003, **31**(4), 352–361.

Harvey, C.M. and Koubek, R.J., Toward a model of distributed engineering collaboration. *Computers & Industrial Engineering*, 1998, **35**(1–2), 173–176.

Hoffner, Y., Field, S., Grefen, P. and Ludwig, H., Contract-driven creation and operation of virtual enterprises. *Computer Networks*, 2001, **37**(2), 111–136.

Horvàth, I., von Breemen, E., Dutta, D., Yip-Hoi, D., Kim, J. and Lee, K., Education for global product realization on a global scale, in *ASME Design Engineering Technical Conferences*, 2001, Pittsburgh, PA.

Horvàth, I., Duhovnik, J. and Xirouchakis, P., Learning the methods and the skills of global product realization in an academic virtual enterprise. *Eur. J. Eng. Education*, 2003, **28**(1), 83–102(20).

Huang, W.W., Wei, K.-K., Watson, R.T. and Tan, B.C.Y., Supporting virtual team-building with a GSS: an empirical investigation. *Decision Support Systems*, 2003, **34**(4), 359–367.

Humphreys, P., Lo, V., Chan, F. and Duggan, G., Developing transferable groupwork skills for engineering students. *Int. J. Eng. Education*, 2001, **17**(1), 59–66.

Jarvenpaa, S.L. and Leidner, D.E., Communication and trust in global virtual teams. *JCMC*, 1998.

Johnson, S.D., Siriya, C., Yoon, S.W., Berrett, J.V. and La Fleur, J., The development and group processes of virtual learning teams. *Computers Educat*., 2002, **39**(4), 379–393.

Joshi, A., Labianca, G. and Caligiuri, P.M., Getting along long distance: understanding conflict in a multinational team through network analysis. *J. World Bus*., 2002, **37**(4), 277–284.

Kasper-Fuehrer, E.C. and Ashkanasy, N.M., Communicating trustworthiness and building trust in interorganizational virtual organizations. *J. Manage*., 2001, **27**(3), 235–254.

Kayworth, T. and Leidner, D., The global virtual manager: a prescription for success. *Eur. Manage. J*., 2000, **18**(2), 183–194.

Koomen, C. and Verhees, M., Collecting and analysing text data from the communication in a collaborative design engineering project. Global product Realization report, Delft University of Technology, 2002.

Larsen, K.R.T. and McInerney, C.R., Preparing to work in the virtual organization. *Information Manage*., 2002, **39**(6), 445–456.

Leenders, R.Th.A.J., van Engelen, J.M.L. and Kratzer, J., Virtuality, communication, and new product team creativity: a social network perspective. *J. Eng. Technol. Manage*., 2003, **20**(1–2), 69–92.

Lindemann, U. and Stetter, R., Restrukturierungsprozesse in Entwicklung und Konstruktion – Beteiligte und Betroffene. In *VDI Berichte 1338, Unternehmenserfolg durch Restrukturierung von Entwicklungs- und Konstruktions-Prozessen*, 1997 (VDI Verlag: Duesseldorf).

Lovejoy, W.S. and Srinivasan, V., Perspective: ten years of experience teaching a multi-disciplinary product development course. *J. Product Innovation Manage*., 2002, **19**(1), 32–45.

Lurey, J.S. and Raisinghani, M.S., An empirical study of best practices in virtual teams. *Information Manage*., 2001, **38**(8), 523–544.

Martinez, M.T., Fouletier, P., Park K.H. and Favrel, J., Virtual enterprise-organisation, evolution and control. *Int. J. Production Econ*., 2001, **74**(1–3), 225–238.

McDonough III, E.F., Kahn, K.B. and Barczak, G., An investigation of the use of global, virtual, and colocated new product development teams. *J. Product Innovation Manage*., 2001, **18**(2), 110–120.

Niggl, M., Edfelder, D. and Kraupa, M., Telearbeit bei der BMW Group, Sterigerung der Wettbeverbsfaehigkeit durch flexibles Arbeiten, 2000.

Moenaert, R.K., Caeldries, F., Lievens, A. and Wauters, E., Communication flows in international product innovation teams. *J. Product Innovation Manage*., 2000, **17**(5), 360–377.

O'Sullivan, A., Dispersed collaboration in a multi-firm, multi-team product-development project. *J. Eng. Technol. Manage*., 2003, **20**(1–2), 93–116.

Pahl, G. and Beitz, W., Konstruktionslehre, 1993 (Springer Verlag: Heidelberg, New York).

Pawar, K.S. and Sharifi, S., Physical or virtual team collocation: does it matter? *Int. J. Production Econ*., 1997, **52**, 283–290.

Pirola-Merlo, A., Härtel, C., Mann, L. and Hirst, G., How leaders influence the impact of affective events on team climate and performance in R&D teams. *Leadership Q*., 2002, **13**(5), 561–581.

Pendergast, M.and Hayne, S., Groupware and social networks: will life ever be the same again? *Information Software Technol*., 1999, **41**(6), 311–318.

Peterson, J.W., Virtual organization: toward a theory of societal transformation stimulated by information technology. In *Technological Forecasting and Social Change*, edited by Abbe Mowshowitz (Greenwood Publishing Group, Inc., Quorum Books: Westport, CT).

Poltrock, S.E. and Engelbeck, G., Requirements for a virtual collocation environment. *Information Software Technol*., 1999, **41**(6), 331–339.

Prasad, B., *Concurrent Engineering Fundamentals, Vol. 1 Integrated Product and Process Organization*, 1996, Upper Saddle River, NJ: Prentice Hall (Technomic: Lancaster).

Prasad, B., *Concurrent Engineering Fundamentals, Vol. 2 Integrated Product and Process Organization*, 1997, Upper Saddle River, NJ: Prentice Hall (Technomic: Lancaster).

Shim, J.P., Warkentin, M., Courtney, J.F., Power, D.J., Sharda, R. and Carlsson, C., Past, present, and future of decision support technology. *Decision Support Systems*, 2002, **33**(2), 111–126.

Smith, P.G. and Blanck, E.L., From experience: leading dispersed teams. *J. Product Innovation Manage*., 2002, **19**(4), 294–304.

Susman, G.I., Gray, B.L., Perry, J. and Blair, C.E., Recognition and reconciliation of differences in interpretation of misalignments when collaborative technologies are introduced into new product development teams. *J. Eng. Technol. Manage*., 2003, **20**(1–2), 141–159.

Susman, G.I. and Majchrzak, A., Research issues in knowledge management and virtual collaboration in new product development: an introductory essay. *J. Eng. Technol. Manage*., 2003, **20**(1–2), 1–5.

Lockhart, S.D. and Johnson, C.M., *Engineering Design Communication, Conveying Desing through Graphics*, 2000 (Prentice Hall).

Spence, W.R., *Innovation, The Communication of Change in Ideas, Practices and Products*, 1994 (Chapman & Hall: London).

Tavčar, J. and Duhovnik, J., Model of communication in the design process, in *International Conference Design 2000* (Centre of Technology Transfer: Faculty of Mechanical Engineering and Naval Architecture) Dubrovnik, Croatia, Zagreb.

Ulrich, K.T. and Eppinger, S.D., *Product Design and Development*, 2000 (McGraw-Hill).

Wang, L., Shen, W., Xie, H., Neelamkavil, J. and Pardasani, A., Collaborative conceptual design – state of the art and future trends. *Computer-Aided Design*, 2002, **34**(13), 981–996 (Elsevier Science: Kidlington).