International team approach to Project-Oriented Problem-Based Learning in design

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ABSTRACT: The Global Engineering Team (GET) has been a very successful programme for delivering engineering design and sustainable manufacturing via Open and Distance Learning mode by using modern digital technologies. The article reports on the results and discusses the challenges of the Project-Oriented Problem-Based Learning (POPBL) approach of teaching of design in a GET environment. The presentation is based on a study carried out in the 2008 edition of GET. Two questionnaires were administered to students and supervisors participating in the programme. The results indicate that GET promotes development of soft engineering skills such as students' teamwork and communication competencies. The programme also promotes student-centred learning and facilitates industry/university collaboration. However, there is also a need to advance hard engineering skills and issues of design problems within GET programme.

INTRODUCTION

Engineering education is dominated by traditional classroom teaching. In such an environment, the focus is mainly on the lecturer and the student has very little (if any) choice on the learning process. An alternative is Project-Based Learning (PBL) where the students are in an environment centred on learning through project work instead of on teaching. PBL is an attempt to create a student-centred setting in which tasks are attempted and solved. As the task reflects reality, the students feel motivated; so working on a project can be seen as a way of organising various simultaneous and/or integrated learning processes. PBL tries to cultivate students' ability to learn actively, to think critically and to solve problems through an instruction process that focuses on practical tasks. It also encourages students to conduct group discussions. PBL offers an attractive alternative to traditional education by shifting the focus of education from what instructors and lecturers teach to what students learn. In this approach, the emphasis moves from the result to the process and the lecturer transforms from the classroom main actor and *dictator* to an advisor or facilitator. The role of *teacher* changes from one of *telling* students correct answers to one who is *guiding* and *facilitating* learner activity [1][2]. It is aptly described as a shift of a lecturer from a *sage on the stage to a guide on the side* [3].

Project-Based Learning (PBL), using student directed hands-on learning, has a long-standing tradition especially in American education. The roots of PBL may be found in the writings of many distinguished educators, including John Dewey in the 1930s [4], Jerome Bruner in the 1960s [5] and contemporary educators since the 1990s [6]. It has been developed together with two other, closely related methods, inquiry-based (or problem-based) learning and experiential learning. The most distinctive feature of PBL is problem orientation - a problem or question serves to drive learning activities. This was according to Dewey at the core of *scientific* or *reflective* thinking, which in his view, should have constituted the goal of education [1].

The following are major attributes of PBL, it

- is student centred;
- provides teaching through skills;
- is process-centred;
- is group-based, and
- is experiential.

One of the special ways of applying PBL is by engaging students in real-life projects and involving them in active inquiry. In that way, the learning is intensified and improved and such a learning process constitutes Project-Orientated and Problem-Based Learning (POPBL) [7][8], which is widely regarded as a successful and innovative method for engineering education. It has also been successfully applied in medical schools [9].

There are a number of examples of successful introduction of POPBL in engineering education from different parts of the world, such as Australia, America and Europe [10][11]. The reports on POPBL are for specific courses, e.g. design and others [12-15] and for the whole curriculum [7][16][17]. However, the common denominator for all the reports is that the learning process in POPBL is especially useful for an individual course.

The common features of POPBL in different learning environments are:

- Project work is normally supported at the beginning of the course with traditional teaching;
- After introduction, students study new subjects independently;
- A few projects are handled with gradually increasing complexity;
- Students work in teams (cooperate with other team members during group discussions, brain storming, etc);
- Students develop practical skills (information gathering, design, CAD and presentation competencies);
- Generic graduate attributes such as communication, teamwork, project management are promoted.

TEACHING DESIGN

Design is widely considered to be the most important and rewarding engineering activity. Historically, engineering curricula have been based largely on an *engineering science* model, in which engineering is taught only after a solid background in science and mathematics [18]. The first year of engineering curriculum is normally dedicated to basic sciences which is then followed, in later years of study, by engineering science and, ultimately, by some elements of synthesis. In almost all engineering curricula the pinnacle is a final year project (called in US *capstone design course*) [12]. In many developed countries, such projects evolved through the years from mainly theoretical projects suggested by supervisors to projects provided and sponsored by industry [19]. However, the industrial sponsored projects are usually few and are not popular in developing countries [13].

The engineering accreditation authorities require proper integration of design experience across the curriculum [20]. However, it is still common practice in many engineering colleges to view mechanical design as just a regular, stand-alone course [13]. Typical activities and processes that may be included in design course are to:

- produce a system, component, or process to meet specific requirements;
- use creative problem-solving techniques, which require formulation of the problem statement and detail analysis;
- apply an iterative process to arrive at a sound deliberate decision based on engineering principles;
- work efficiently in a team and communicate the results effectively and professionally.

APPLICATION OF POPBL IN TEACHING DESIGN

Project-Oriented Problem-Based Learning (POPBL) is the most-favoured pedagogical model for teaching design [19]. For example, Aalborg University in Denmark has successfully employed POPBL approach to teaching engineering design by using the principle of *Problem-Oriented, Project-Organized, Learning* (POPOL) [16][21]. P*roject-organized education* is multidisciplinary by nature, and it can be divided into two main themes namely, design-oriented and problem-oriented education [16]. *Design-oriented* education deals with practical problems of designing and constructing on the basis of a synthesis of knowledge from many disciplines (*know-how*) whereas *problem-oriented* education deals with the solution of theoretical problems by the use of any relevant knowledge (*know-why*). Aalborg University uses both kinds of project-organised education. For example, in undergraduate studies, project work mainly involves the design-oriented approach, while the problem-oriented approach is used in graduate studies.

The application of POPBL in Design deserves special attention since there is evidence that it enhances design thinking [22]. It also encourages and supports collaborative work and improves knowledge retention in authentic multidisciplinary design scenarios, as well as across geographical and cultural boundaries [19].

Design is both a mechanism for learning and a learning process. The purpose of a design project is to allow students to acquire design experience by solving a problem that may not necessarily lead to the manufacture of a product. From current literature, it is certain that the PBL approach is helping students to learn design thinking more effectively as it promotes creativity and enhances holistic approaches to problem-solving [11][12][19][23][24].

GLOBAL ENGINEERING TEAMS (GET)

Global Engineering Teams (GET) is an innovative global engineering educational programme. GET promotes innovation in student training through multidisciplinary and multicultural project-oriented teamwork. Students of different technical and cultural backgrounds are engaged in challenging industry-sponsored projects, which usually have design components. The main aim of GET is to provide industrial partners with realistic engineering solution to a particular problem. The other aims of the programme are to foster teamwork and digital collaboration skills in students with different backgrounds. Such skills are not taught in university courses, but are essential for engineers who are expected to operate and manage teams [25]. GET offers students a way of learning these skills in an educational environment, while they are at the same time engaged in real problems from industry. The principles of GET can be summarised as follows [26][27]:

- Solving engineering tasks in international groups comprising of students from developed and developing countries;
- Interdisciplinary project-oriented work based on the idea of *learning by doing;*
- A holistic approach considering the engineering tasks under economical, ecological and social-political aspects, as a contribution to global sustainability.

The concept of GET originated at the Technical University of Berlin (Germany) but the current partners include Stellenbosch University (Republic of South Africa), University of Sao Paulo (Brazil), Sociedade Educacional de Santa Catarina (Brazil) and University of Botswana (Botswana). Since 2004, there have been six editions of GET, with over 200 students trained.

Project Phases

Each edition of GET lasts for about six months between April and October and, during that period, there are distinctive phases of the project work (Figure 1).

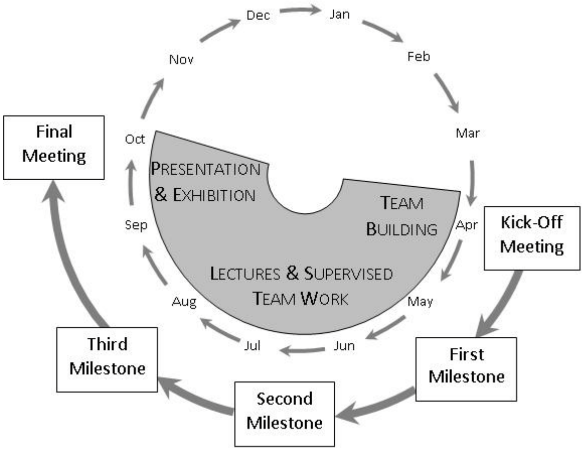

Figure 1: Phases in GET programme.

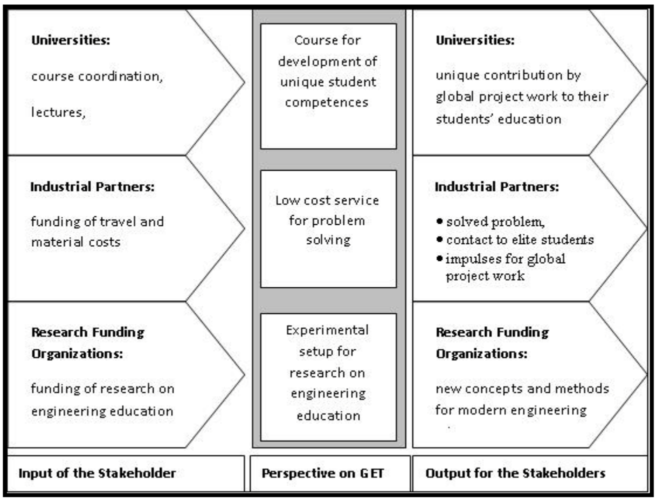

Figure 2: Perception of GET by involved parties [34].

There are two one-week face-to-face meetings, one at the beginning of the programme (Kick-off Meeting) at any of the co-operating universities and the other (Final Meeting) at the end of the programme at the Technical University of Berlin. The Kick-off Meeting is used to create teams, define the concept and scope of assigned projects, e.g. product/component specifications, develop communication strategy and create a spirit of team-building among group members. The Final Meeting provides time to finish the projects, e.g. prototype manufacturing and assembly, and to present the results as a group in a final exhibition. In between the face-to-face meetings, the students have to provide milestone progress reports and presentations.

Project Source

One of the most important aspects of any project work is how the project is obtained. Finding suitable students' projects is difficult as the listed requirements for a project are extensive. In particular, projects should [28][29]:

- be challenging but with good chances for successful completion;
- be common enough so that literature is available;
- emphasise the application of theory;
- involve engineering design work;
- meet specified standards and safety criteria, and
- not involve proprietary information if industry is involved.

There are different sources of projects, for example hypothetical projects chosen by supervisors, industry-sponsored ones, students may find their own project or the university may initiate projects. Some authors claim that the best sources of projects are departments within the university [30].

Opinions vary as to the validity and effectiveness of industry-sponsored projects. Some argue that these projects normally require a low level of analysis, which does not push students hard enough in engineering requirements [31].

Other disadvantages include conflict with students' timetables and schedules do not fit in with course requirements, and, possible issues of invention and patent rights. However, as a *project is valuable only to the extent that it approaches reality* [32], industrial projects have an unquestionable advantage over *make-up* projects. Students will not be able to experience real engineering work unless they work on a real, practical engineering problem. Industry sponsored projects also have additional advantages of greater student commitment [23] and enhancing students interaction with engineers from industry, which promotes students self-confidence and interpersonal skills [33].

The concept of GET is very clear that projects should originate from industry. There are two main conditions for such projects; they should be challenging, and they should be sponsored by industrial partners. The sponsorship aspect of GET is very important as the programme must be self-sustaining through contracts with industry partners who provide financial support for the travelling expenses associated with the Kick-off and Final Meetings (Figure 1). Sometimes funding for GET activities may be obtained from international agencies.

The project acquisition for GET is characterised by the interests of three involved parties: universities, industry and funding organisations, as shown in Figure 2. Each of them inserts requirements and restrictions in the process of acquiring GET projects. It is, therefore, a challenge to acquire industrial partners and negotiate contracts with them.

The main interest of the universities is to maximise education output in terms of competence acquired by students. This results in the requirement to maximise the gap between needed competence to achieve the project objective within the six month and competence available in the participating students. The restriction is to maintain workability of the project considering that some competence must be acquired and subsequently applied. Learning by failing is not suitable for GET from the universities perspective, since each GET project addresses a unique industry problem and the project period is limited. As a result, competence obtained during the course can hardly be checked by a formal examination. Achieving the project objective becomes the criteria for evaluating the competence obtained by the student.

The main interest of the industry to contract a GET project is to get a solution for an actual problem for a price that is around 10% of the price charged by professional consulting companies. Although unbeatably cheaper, the fee is still considerable and the problem addressed by the project must be worth the money provided by the company. When presented with the opportunity to contract a GET project many industrial partners initially ask for solutions for some small independent problems that were not worth to be addressed by internal engineers or external consultants. Experience has shown that some of the problems can turn out to be more serious than expected by the industrial partners. Consequently, it becomes very difficult to keep the same industrial partners for the next edition of GET. This leads to the requirement to select a project scope that addresses only one problem or a group of closely connected problems.

The main interest of funding organisations results from their respective programs. Since 2006, the DAAD (Deutscher Akademischer Austausch Dienst) has been supporting the expansion of the GET network in developing countries. For example, the support has allowed the inclusion of South Africa and Botswana, and Chile is to be included in 2009. Future candidates are Bolivia, Columbia and Nicaragua. The support allows creating reference projects with the local industry to demonstrate the objectives of GET. Therefore, projects from developing countries must be available for the GET programme.

Business Model of GET

The funding of GET results from a business oriented organisation. It can be described by a model according to the three components defined by Stähler [35]:

- Value Proposition, that describes what benefit customers or partners gain from interacting with the institution;
- Architecture of Value Creation, that describes how the benefit is generated and what configuration is used;
- Method of Earning, describing who is paying the institution and for what product.

The value proposition of GET is triple fold. For students, it is to obtain competence. For industry, it is to deliver a solution for an actual problem and to identify high potential students for future employment, and for educators, it is to provide a testing ground for research on engineering education [36].

The Method of Earning used by GET is divided into four parts:

- Industry provides payments for the delivered solution, which is used to cover the majority of travel and meeting costs;
- DAAD provides funds for developing collaboration and creating joint educational structures;
- Some of the involved partner universities provide salaries for part of the engineering education performed by GET;
- All the involved teaching staff provide a significant amount of spare time to teach the students, because of the exciting nature of GET.

METHODOLOGY

The design elements in GET projects were studied through specially designed questionnaires for the students and supervisors. A five-point Likert scale was used where respondents had to indicate the level of agreement or disagreement with statements (1=strongly agree, 2=agree, 3=neutral, 4=disagree and 5=strongly disagree). The student questionnaire consisted of four sections, namely general design issues, teamwork, communication and design processes. A different supervisor's questionnaire consisted of questions on general design issues, students' teamwork, communication, design processes and open ended questions. The analysis was done for the 2008 cohort of students who participated in the programme.

The questionnaire for students was administered at the Final Meeting, with 35 out of 38 available students participating in the programme completing the questionnaire (overall response rate of 92%). As with any self-reported survey, it is not possible to verify if the students completed the questionnaire honestly and accurately. The honesty issue was not addressed directly but the questionnaire was anonymous and did not influence the students' grade. The students were also briefed on the purpose of the survey, and how it could improve future editions of GET and its design component. The question of accuracy was dealt with by using a pilot testing questionnaire, which indicated that the questions were sufficiently comprehensible for the students to answer them accurately.

The questionnaire for supervisors was administered on-line but the number of projects and, therefore, also number of supervisors was limited. All supervisors provided feedback and their responses were analysed providing mainly qualitative information.

RESULTS AND DISCUSSION

The 2008 edition of GET had eight projects as shown in Table 1. All supervisors agreed that the projects had some design elements and four of the projects were considered as *design based* with more than 40% of design content. The design content in other projects varied from less than 10% (1 project) to 30-40% for the remaining projects. The design content in the projects covered system design methodology (4 projects), design drawing and documentation (4 projects), mechatronics (3 projects), machine parts (3 projects), manufacturing (2 projects), instrumentation and control (2 projects) and layout design (1 project). Most of the supervisors were comfortable and confident to supervise design components in projects. However, they also acknowledged that design elements created greater demand for formal and informal contacts with students and increased time for preparation.

Table 1: Characteristics of student groups at the 2008 GET programme.

Group Name	Title of Project	No of Students
NAPRA	Learn Instrument for Sustainable Development in the Low Madeira River	4
ApoNeo	Planning of a Logistics Center for an Internet based Pharmacy	6
Daimler (Ulm)	Design and Production of the lid of a Trunk for Daimler car	6
Inpro	Global Concepts for Automated Manufacturing of Low-Cost Automobiles	6
ThyssenKrupp	Life Cycle Assessment of an Elevator System	6
Hydra Marine	Improvement of a Stealth Diver System	6
Gabriel	Development of a Cleaning Device for Shock Absorber Production	6
Whirlpool	Determination of Correlation to Estimate the Life Time of Metallic Components	4
	Total number of students	44

Obtaining an industry-sponsored project is not easy as it takes a lot of effort, but it also brings great pay-back not only in terms of sponsorship money but also in enhancement of collaboration between university and industry. Design projects are especially hard to obtain as industrial partners rarely suggest new projects. Design tasks proposed are often based on much detailed knowledge of undocumented materials (e.g. experiences from previous designs or from existing production equipment). In addition, the supervisors are hesitant to seek design projects as they foresee possible difficulty in running such projects in the GET programme. From the supervisors' responses, these difficulties are normally related to a lack of willingness of students to spend time on design projects. Design projects take more of students' time and require the ability to synthesise. Neither of these attributes is generally very popular with students. Although the GET programme is a highly advanced course targeted at graduate and senior undergraduate students, there is no doubt that even these groups of students may have some challenges with design tasks.

The majority of students (75%) agreed that there was a design element in GET programme (Figure 3). However, some students (26%) were neutral about sufficiency of design elements in the programme. That comes as no surprise as some projects in GET are not design related. Most students (60%) were of the opinion that there were enough elements of design. However only 51% of them agreed that GET helped them to understand the concept of design. This observation corroborates the statement that a majority of students were familiar with the concept of design before embarking on the programme (57%).

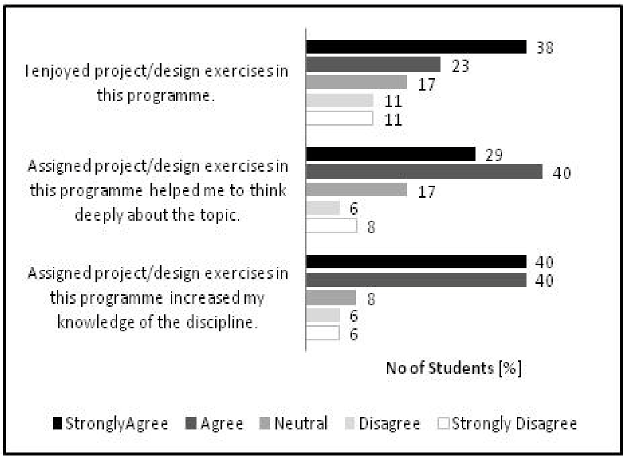

Figure 3: Design concept in GET.

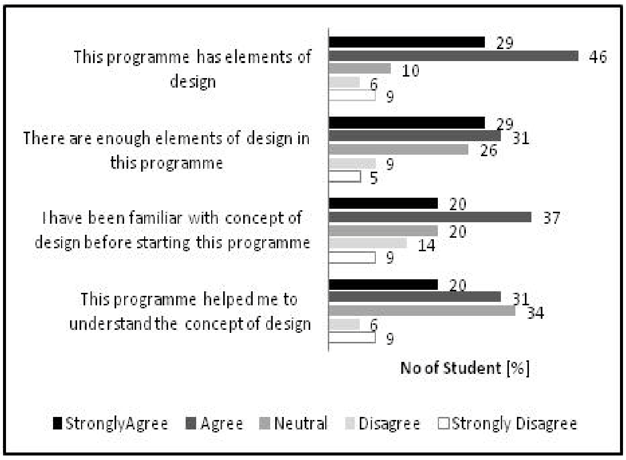

Figure 4: Design project/exercises in GET.

The students generally enjoyed design exercises in the programme (61%) and they strongly supported the statement that such exercises helped them to think deeply about the problem at hand (69%) and increased their knowledge about the discipline (80%), as shown in Figure 4. Students noted that design projects were definitely helping them in understanding the particular discipline, as well as a specific problem. In short, students agreed that design elements in GET enabled them understand in a fuller sense the concept and challenges of design.

It is surprising to see how confident the students were about their design knowledge and ability (Figure 5). The majority of students claimed that they had the ability to design (75%) and that they knew:

- different types of design (72%);
- steps in the design process (81%);
- clearly the concept of analysis, synthesis and design (71%).

There were essential differences between the students' opinion about their design knowledge and skills and that of the supervisors' judgment. Although none of the supervisors questioned the ability of the students to design but half of them were of the opinion that students did not have enough previous background to undertake design exercises in the programme, whereas the other half was rather neutral on the issue (there was only one positive supervisor's response). There were mixed answers from the supervisors on whether GET improved students' ability and knowledge on design; most answers were neutral and one positive and one negative.

Supervisors also had different ideas on whether certain elements of basic design knowledge should be covered in the programme. Since there were no face-to-face lectures or lectures in the electronic form, most of the supervisors stated that such concepts as analysis, synthesis or different types of design were not covered during the programme.

It is clear that there were different ideas and opinions in respect of teaching of design at GET. There were two extreme views; one that the students who were admitted to GET programme should have enough design knowledge and skills *a priori* to apply it in engineering projects and not to be taught; the other was that students should be given formal classes on design and design procedure.

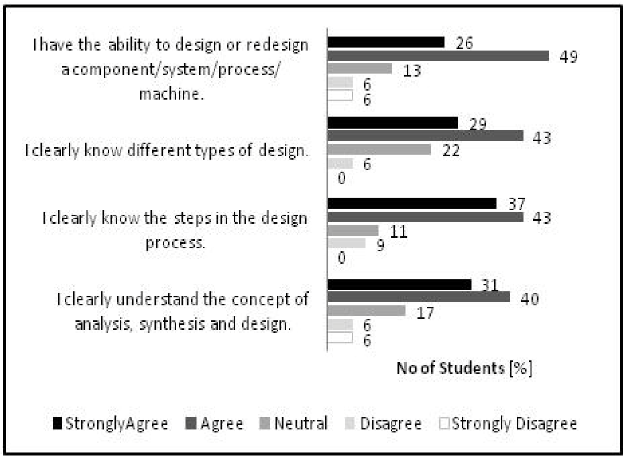

Figure 5: Design ability (by students).

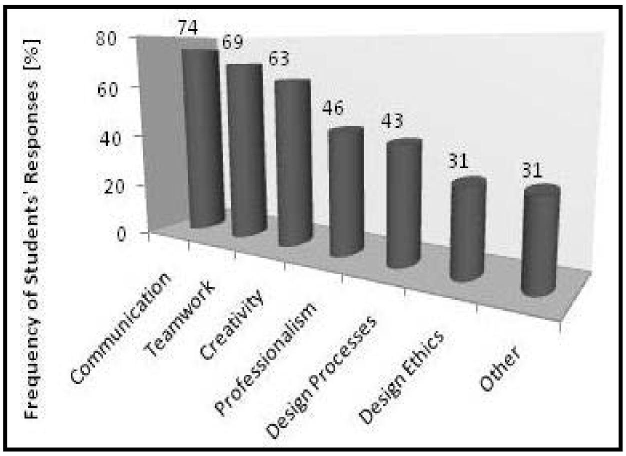

Figure 6: Design domains enhanced by GET.

The students had an opportunity to comment on the domains enhanced by participation in GET (Figure 6). They were asked to indicate which of the following facets of design elements were enhanced: design processes, teamwork, communication, creativity, design ethics, professionalism, and others (which include safety aspects and sustainability). They were not limited to a number of choices so comparison was based on the frequency of their choices (expressed in percentage).

Most of the students were very positive in respect of communication, teamwork and creativity as 74%, 69% and 63% of students, respectively indicated the above domains. The other choices had responses of less than 50%. Especially disappointing were the results for design processes as only 43% of students indicated that it was enhanced by their participation in GET. The students' confident responses on design ability indicated that they must have had certain knowledge of design processes (or at least design courses) prior to the GET experience. Looking at the supervisors views on students' design knowledge and skills (as discussed before) the result supported the idea of the necessity to introduce formal design teaching within GET programme.

CONCLUSIONS

Various methods of teaching engineering have been reviewed. These include PBL, POPBL and POPOL. Two different questionnaires for both students and supervisors who participated in GET were used to obtain information on the perception and views on design elements within the programme.

Students agreed that there were design components in GET programme, they enjoyed design exercises, which increased their knowledge about the discipline and helped them to think deeply about the problem at hand. They claimed that they had prior knowledge of types of design, design process and concepts of analysis and synthesis and that their ability to design was acquired before starting GET.

The supervisors generally did not support students' confidence in their design competence. Supervisors were of the opinion that students did not have enough previous design knowledge and skills or even general engineering background. This opinion could be attributed to the multidisciplinary nature of the students, their different educational background and instructional methods at the various institutions.

Supervisors did not have a common opinion on how to address design in GET. Some were of the opinion that, since participation in GET is restricted to graduate and senior undergraduate students, they should have acquired enough design skills in their earlier studies. However, some supervisors argued that students should receive some design instruction within GET programme. This twofold approach should be addressed and resolved during future editions of GET.

GET promoted soft skills because both students and supervisors expressed encouraging responses on the enhancement in students' teamwork and communication competencies.

The GET programme has been a very successful programme to deliver certain engineering skills via open and distance learning mode by using modern digital technologies. The programme promotes student centred learning and facilitates industry/university collaboration. It shows how to transfer methods of structured problem-solving from design to areas such as process design and managerial concepts. However, there is also a need to concentrate on hard engineering skills and to address design problems within GET programme.

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