DESIGN THINKING ORIENTED METHODOLOGY IN GROUP PROJECT AS A STEP IN THE CDIO APPROACH

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ABSTRACT

Recently much scientific research and industrial work is conducted in multidisciplinary teams, where cooperation between specialists from different areas of expertise is required in order to successfully address the challenging goals. Moreover, in start-up small companies the lack of supporting departments calls for additional multidisciplinary, economic and networking skills known as T-shaped personality.
Recognizing these shortcomings Group Project was introduced to provide the students with an opportunity to work in start-up-like conditions on development of an IT product according to customers' needs within limited time and budget. In this paper we present aims and organization of the Group Project, used methodology, analysis of problems that appear during the team work as well as case study of selected student projects.

KEYWORDS

Design-Implement Projects, Design Thinking, Group Project, Introduction to Engineering Courses, CDIO Standards 5 (Design-Implement Experiences), 4 (Introduction to Engineering), 7 (Integrated Learning Experiences), 8 (Active Learning)

INTRODUCTION

Academic education has traditionally emphasized individual work of students performed under the tutelage of experienced scientific researchers. This approach does not require substantial co-operation with the peers, and in some cases it can even affect the creativity and innovative thinking of students, obliged to follow the route defined by the tutors. However, at present much scientific research and industrial work is conducted in multidisciplinary teams, where cooperation between specialists from different areas of expertise is required in order to successfully address the challenging goals. Moreover, in start-up small companies the lack of supporting departments calls for additional multidisciplinary, economic and networking skills known as T-shaped personality (Oskam 2009). Thus, aim of the engineer is not only to design technical equipment itself, but also to analyze client needs and possible solutions. These skills are not properly developed during the traditional course of study, making the students ill-prepared for working in innovative SME company environment.

GROUP PROJECT AT OUR FACULTY

History of the Group Project

Recognizing shortcomings presented above the Group Project was introduced at the Faculty of Electronics, Telecommunications and Informatics at the Gdańsk University of Technology in 2005 as a compulsory subject at the Master level studies. At present, the Group Project lasts two semesters, with expected amount of work of 30 hours per student per semester.
The main objective of this project is to provide the students with an opportunity to work in start-up-like conditions on development of an IT product according to customers' needs within limited time and budget. Developed products range from software, to equipment and measurement systems, covering an almost infinite spectrum of applications.

Organisation

The Group Project is taken by approximately 350-400 students each year. At the beginning students are presented with a list of design problems from a list of topics/needs prepared by customers. The title and a brief description of each problem provide a general idea about its objectives, without stating detailed requirements or restricting expected design methods. The range of problems is very broad, covering specialized software development, applications of analog and digital electronic systems, sensing and detection, assistance for special needs persons, communication and data transmission. The expected amount of work should be greater than that required for a M.Sc. degree thesis.
Problems are provided via a dedicated secure Group Project website (https://projektgrupowy.eti.pg.gda.pl/) by:

- our faculty staff,
- staff of other faculties
- outside companies, especially those cooperating with the Faculty.

Persons providing the problems can become Clients in the Group Project process. For each problem an Advisor from the Faculty staff is selected. He acts as an advisor, and a liaison between the project group and the external client, for groups working with companies.
Faculty and its departments take big care about offering students diverse topics and providing opportunities to choose the theme according to your preferences and interests. Developed products range from software, to equipment and measurement systems, covering an almost infinite spectrum of applications. For example, in 2016 Edition of the Project only the Department of Metrology and Optoelectronics offered students 28 own proposals and 2 external. The proposals of the Department were selected by 7 students groups.
Students select the design problems in which they would like to take part in the Group Project website. Their decision is based on their personal preferences, the additional information obtained from the Client and the Advisor, and often on dislike for certain staff members. Moreover, a network of Project Coordinators (Faculty coordinator and Department coordinators) monitors the progress of the Design Teams. The teams of three to five students are formed for the design problems for which the required number of volunteers is at least three. Students select the Team Leader, who will be responsible for coordination of their work. Having formed the Design Team, students prepare a work plan for the two semesters and start the design process. First, in contact with the Client they should analyze his needs and formulate detailed requirements for his problem. Second, they present possible design approaches and expected results. Based on the input from the Client and the Advisor, the students select the design approach and prepare the project schedule which defines task to be completed and respective deadlines. Following, they start the design process. As one of the Group Project aims is to develop T-shape skills including economical competences and

budget planning, the Team Leader and in some teams one other Team Member, supported by the Advisor, are responsible for budget and contact with university accountings. The teams are granted approx. 50 USD for rapid prototyping (e.g. purchase of dedicated components). In justified cases budget can be increased.
By the end of the first semester, the Team prepares a poster describing project objectives, requirements and achievements. Work in the second semester is typically devoted to implementing the design. Depending on the project type the implementation may involve writing and testing software, building, testing and troubleshooting hardware, or integrating hardware with software. During the testing phase of the project, all problems are identified and remedied. Finally, the Team prepares a final presentation and a poster detailing their accomplishments.
The project team is graded for their work twice: first time after first semester and the second time at the end of the second semester. The grade is based on prepared documentation, oral presentation of results and, in the second semester, on the evaluation of the product developed by the project team. The grade is awarded by the Advisor, with the input from the Client. In some cases the Coordinators have the right to change the grade.
Selected projects, deemed by the Coordinators or Advisors as being very good, are submitted to the Group Project Dean Award Advisory Committee for further assessment. The committee members evaluate submitted documents, attend the presentations prepared by the project teams and prepare a recommendation to the Dean of the Faculty listing projects for awards and honorable mentions. During discussion with the committee, the Dean arrives at the final decision about awards and honorable mentions.

Problems

During the Group Projects several types of problems can appear. They stem from e.g.:
- lack of experience in problem analysis,
- lack of properly defined requirements,
- inadequate communication in or outside the group,
- students' attitudes,
- feature creep,
- lack of resources,
- design mistakes,
- other sources.

Problems encountered during the Group Project can be divided into two categories. First category which covers problems present in any engineering team, such as groupthink, feature creep or incompetent leaders, will not be discussed here. Second category encompasses problems that may be considered specific to the Group Project. The three key areas where the problems arise are: communication and planning, engineering skills, and attitude. In practice, there is a certain overlap in these problem areas. For instance, poor communication and planning often has its roots in limited design skills.
Time management-related problems are probably the most common problem type in the Group Project. Students have to allocate their time to several other courses and, in most cases, to a range of activities outside the university. This reduces their involvement into the project. In the case of a delay in the project schedule, the situation worsens during the exam session at the end of the semester. This can endanger the completion of the project. Solution of this problem is strict control of the time schedule by the Advisor and the Coordinator, with the use of pre-scheduled control lines in the Group Project website.

Planning problems result from limited experience in projects, in particular from the lack of ability to estimate time and effort needed for completion of tasks. These problems can be aggravated by limited engineering skills. Surprisingly, in some rather rare cases the Advisor can also be a part of these problems. Inability to assess the complexity of design tasks and properly identify opportunities for working in parallel is probably the most common cause of scheduling problems, along with failure to check delivery times on components and other required items.

Communication problems within the Team can appear in almost every stage of the projects. Lack of clarity, faulty reasoning or simple misunderstanding are leading causes. This type of problems is usually spotted by the Advisor and rectified.
Outside communication problems most often appear in contacts with the Client, especially in the phase of requirement definition, and later in the project, if requirements are modified or changes to the design are requested. In most cases the Project Team members are to blame for not being able to ask right questions, present viable solutions and selecting the proper one with the Client and Advisor. However, cases when the Client cannot formulate his requirements, or where the Advisor is an obstacle in the process, are not unheard of. When transpire, these problems are addressed by the Coordinators. Key factors leading to decision making problems are limited experience of the Team members, inability to quickly exclude non-viable solutions, as well as common procrastination..

Engineering skills of students taking part in the Group Project are fairly limited. As the Design Team consists of rather unexperienced designers, risk of design mistakes is higher than in a company, even in an innovative SME. Additionally, students do not try to take full advantage of technical documents, such as datasheets, application bulletins or design notes. This can cause a host of engineering skills problems.
The most obvious is inability to extract all relevant information from the technical documents caused by lack of experience, especially by not paying attention to what is *not* said or guaranteed in these documents. While using code or circuits developed by others, especially in the form of libraries, design notes or circuit collections, is good, as long as it does not infringe intellectual property of other parties, applying a cookbook approach to engineering without a good understanding can result in problems caused by limitations of published code or circuits. Similar problems may appear when design reuse is attempted. Many problems, especially with hardware, can be avoided by conducting simulation and a careful data assessment. Unfortunately, inadequate simulation quite often appears to be the source of problems with hardware. Last but not least, unforeseen limitations of hardware and software appear sporadically in the Group Project. These are issues that cannot be identified from technical documents, but their existence is often confirmed by Customer Support of relevant suppliers. Microcontroller or CPLD configuration issues are most frequent problems belonging to that group.

Attitude problems in the Group Project result from the simple fact that students taking part in it are normal human beings with different attitudes and priorities. When joining a project team, students may be unaware of the attitudes of the fellow members and unable to quickly and effectively learn about them. When different types of students are mixed in one Team, attitude problems may arise.
For some students a pass grade is enough and they are not interested in putting excessive amounts of their valuable time and energy into this particular subject, as they need them elsewhere. Such 'smart' students employ different effort limitation techniques that result in their workload being at least partially shifted to other Team members more interested in the success. This, as well as simple laziness is almost always noticed either by the Advisor of the Coordinator and punished by lowering the grade of the 'smart' student while slightly increasing the grades of the remaining members of the Team. Especially, the latter action guarantees that such cases are extremely rare.

Different types of problems are inherent part of the Group Project. Most of the Faculty staff involved in the Group Project encourages students to report problems they face and discuss the ideas for solutions. The ‘sweep-under-the-carpet’ approach is actively discouraged by identifying problems by Advisors and Coordinators. These problems are prevented or tackled by supervisors and project coordinators by use e.g. methodology of design thinking. Implementation of design thinking is presented in next part of the paper.

Design thinking introduction

Design thinking has already been introduced in numerous universities including Stanford University and UC Berkeley to support education of engineers (Levine 2017), (Dym 2005), (Kamp 2016), (Kamp 2016a). This method has been also introduced to the Group Project in order also to efficiently address a Conceiving – Designing – Implementing – Operating approach. The CDIO approach is an innovative educational framework for producing the next generation of engineers. The aim is an education that supports students to acquire a deeper working understanding of the technical fundamentals while simultaneously developing the competencies needed for Conceiving – Designing – Implementing – Operating (CDIO) real-world systems, products, and processes.
Therefore, in comparison to the most common workshops from the entrepreneurship courses that are based on standard design thinking subject and kits we are using three stage approach: (1) lectures about design thinking methodology, (2) workshops about typical design thinking subject, and (3) introduction of the design thinking methodology to student activity in real task of the Group Project under supervision of the Advisor.
A series of extra lectures and workshops is offered in frame of the Group Project course. They cover the key aspects of design thinking methodology and skills needed in the group work. Courses are based on methodology from leading universities fit to requirement of IT teaching at the Gdańsk University of Technology. During these classes students analyze main phases of design thinking process: empathy, define, ideate, test, and prototype as it is shown in Figure 1.

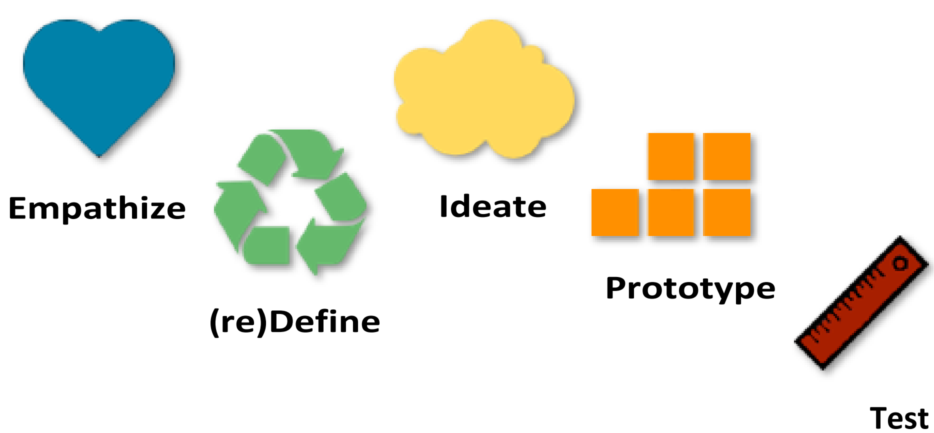

Fig.1. Stages of the creative work according to design thinking methodology.

Following, during the workshop, they train problem analysis and search for possible solutions in groups. They learn how to conduct a brain storm session, use synergy of their abilities and thus enhance the effects of brainstorming (Sutton 1996) in a design team. They also learn different approaches to design process, e.g. *Engineers based on facts* vs. *Designer based on questions* as well as idea generating techniques. Finally, they try to introduce rapid prototyping method to test different possible solutions within limited time and budget. Thus, design thinking session enable students analyse problem, find all possible solutions (including unconventional and not presented during academic course), choose the most promising and begin design work.

EXAMPLES OF PROJECTS

Measurement system for virtual reality environment

A good example of a well-executed Group Project assignment is the development and implementation of a system for measurement of the directional scattering characteristics of the projection screens. When used in a CAVE-type virtual reality laboratory, images on such screens are created by short-throw back-projection and viewed from a broad range of angles and distances, which results in quite demanding requirements.
The description of the project stipulated that the system should use an ISEL-type multi-dimensional scanner with a rotary unit and a Konica Minolta CS-200 luminance and color meter. The measurements were to be performed automatically under control from a PC.
Development and implementation of the measurement system was quite a complex task. It covered both the design and implementation of a dedicated opto-mechanical fixture and design and development of dedicated software. The key stages of the project included: (a) formulation of detailed requirements, (b) discussion of system configuration, (c) analysis of the ISEL and colorimeter Konica Minolta CS-200 driver documentations, (d) selection of software environment, (e) development of a method for mounting a sample of the screen and a colorimeter, ensuring uniform illumination of the examined screen sample, (f) design and development of dedicated software with a user-friendly interface and (g) preparation of project documentation.
This project was well suited the Group Project. A large number of partial tasks of various types allowed the work to be shared by the members of the project team. Moreover, cooperation between the team members was enforced at every stage of the project, requiring good project management and personal responsibility for the person's individual tasks and timely completion of these tasks.
The project has taken by a group of four students of the Faculty of Electronics, Telecommunications and Informatics. Implementation of the project was carried out in the educational-research laboratory of the Department of Metrology and Optoelectronics.
The project group appointed from among themselves a Team Leader, whose task was primarily to coordinate the project, final preparation and submitting of project documentation. The task of the second person was to prepare software with a user interface, based on analysis of the documentation of the system components used. The third person helped in the analysis of the documentation and was responsible for selecting and assembling the optical components, needed to provide uniform illumination of the screen in the measured area. The task of the last person was to design and set up the mechanical part of the system.
The project was finally developed with the use of ISEL rotary module system, Konica Minolta colorimeter CS-200 and the control software prepared in the LabView environment. Implementation of the project has encountered some difficulties, mainly related to incomplete description of remote control of the devices, when the dedicated software is not used. This required additional literature review and additional tests. Minor problems were also caused by non-ideal temporal coordination of the various stages of the project among team members.
Finally, these difficulties were overcome and the project was successfully completed on time. He received an Honorable Mention of the Dean Awards Committee of the Faculty of Electronics, Telecommunications and Informatics.

Optical systems for supporting disabled peoples

Other presented project is based on requirements of professional therapeutics from the rehabilitation and educational center for disabled children (pl. OREW) from Pruszcz Gdański. The aim of the project is the development of optoelectronic devices supporting the functioning and treatment of persons with disabilities in everyday living, and their therapy. One of the elements is simply dedicated electronic / optoelectronic system for marking and identification with voice of selected containers in a household of a disabled person with simultaneous impaired sight and touch. The second element of the support system is the development, practical implementation and testing table - a matrix of light sources used for classes of vision therapy. Important requirements was to develop low-cost and robust solution for home use of disable persons, consider special requirements (e.g. avoiding flashing frequency dangerous to people with epilepsy) and ensure simple use of these devices.

Students (five people team) used design thinking for analysis of the client requirements and development of devices concept. They made a few interviews with the therapeutics and observed therapy with disabled children. Then they conducted a brainstorm and proposed an few solutions based on their own ideas and analysis of the available design solutions. A few iterations enabled collecting possible solutions. For markers they considered radio frequency systems and optical (laser systems), while for light table they considered LEDs, bulbs, fibers, holograms, etc. Simultaneously with analysis of these solutions other team members defined required functionality and developed concept of simple and low-cost control system. Cost, functionality and other features of the solutions were compared. After another brainstorm session RFID and LED based solutions were selected and simply demonstrators were developed. Models were demonstrated to Client – therapists and except general acceptance of the concept, details of functionality and parameters were agreed. Based on feedback students developed low-cost control systems based on Arduino microcontroller boards and selected ergonomic design. Full-size, final systems were integrated, commissioned and delivered to OREW for final testing. As a result of the project and use of design thinking approach the student team developed more flexible device than previous design based in tungsten bulb, optical filters and thick optical fibers, offering better programmable functionality (artificial night sky simulator, education symbols display, light modulation synchronized with music and sounds) and lower cost. Thus the device better fit requirement of professional therapeutics and can be also offered for home use.

Other projects

Many of the projects end implementation of the results in economy or society as well as there were projects that ended in scientific publications. For example there was honoured group of project dedicated to development of applications supporting the treatment and education of children with autism (Jędrzejewska-Szczerska 2015). The aim of these projects was to develop e.g. a mobile application for the Android operating system, which will track the activity of an autistic child who uses applications on the tablet and will write down information about completed tasks and patterns of behavior. The application was prepared based on requirement of and have been applied in rehabilitation practice at professional educational center in Gdańsk. Besides project having applications in economy or social activity, creativity of the students stimulated by researchers from the university enabled use of other projects in support of research activity. Students developed component of innovative measurement systems using Photonics methods. Developed components were introduced into experiments those results were published in scientific journals from the JCR list (Jędrzejewska-Szczerska 2015a), (Jędrzejewska-Szczerska 2012), (Karpienko 2012), (Karpienko 2014)

CONCLUSIONS

In this paper we presented use of methodology of design thinking use in Group projects, analysis of problems that appear during the team work and case study of selected student projects. During 11 years (editions) of the course approximately 1000 projects were carried out by students of our Faculty. It provided significant experience in methodology and evaluation of the course efficiency. The group project is big and successful attempt to educate the students according to the T-model. Use of the design thinking increased creativity of students teams. Moreover, stimulated creativity of the students enabled development of innovating solutions with relatively short budget which is in good agreement with SME environment conditions. The Group Project course shows the students whole complex design process from requirement through ideas to development of dedicated devices and software. Contrary to design thinking based project conducted in companies, the design thinking approach at the university requires strict control of the project progress by the supervisors and intensive tutoring. In comparison to the most common design thinking workshops from the entrepreneurship courses that are based on standard design thinking subject and kits we are using three stages: lecture about design thinking methodology, workshop about typical design thinking subject, and introduction of the design thinking methodology to student activity in real task of the Group Project under supervision of the Advisor. As a result are products introduced into practice or devices used in scientific activity.

Summarizing, there are following experiences achieved by student during activity presented in this paper:

- Work in multidisciplinary teams, including specialists in computer science, biomedical engineering, electronics, photonics, telecommunication, automatics and robotics.
- Contact with clients and their needs investigation (empathize- redefine- ideate)
- Rapid prototyping with limited cost.
- Team work management.
- Basics of budget planning and control.
- Creation of project documentation.
- Product testing and optimization according to Client the needs.

Thus, development of teaching methodology of complex design process is in good agreement with concept of Conceiving – Designing – Implementing – Operating (CDIO) approach for real-world systems, products, and processes.

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BIOGRAPHICAL INFORMATION

Marcin Gnyba is an Assistant Professor at the Department Metrology and Optoelectronics Gdańsk University of Technology. He received Ph.D. in 2006 in Electronics. In 2012 he participated in Top 500 Innovators Course at the University of California Berkeley. Certified manager IPMA (D). He collaborates with universities in Europe in teaching and research areas, e.g. he is responsible for educational co-operation with the Karlsruhe Institute of Technology (Germany). His research interests cover optical, mainly Raman spectroscopy.

Paweł Wierzba is an Assistant Professor at the Department Metrology and Optoelectronics Gdańsk University of Technology. He received Ph.D. in 2001 in Electronics. His research interests cover optical and fiberoptic sensing and measurement methods, thermal infrared detectors and applications of liquid crystalline polymer materials. Dr. Wierzba was a recipient of a year scholarship of the Finnish Academy at the VTT - Technical Research Centre of Finland in 2002-3. Dr. Wierzba has been a Group Project Coordinator for M.Sc. Studies in Optoelectronics since 2005 and has served in the Group Project Dean Award Advisory Committee since 2007. He has been an advisor to 35 M.Sc. students and 9 E.E. students

Adam Mazikowski is an Assistant Professor at the Department Metrology and Optoelectronics Gdańsk University of Technology. He received Ph.D. in 2003 in Electronics. His research and educational activity concentrates on virtual reality systems and optical systems. Moreover, he is active in promotion of science outside university under the Pomeranian Science Festival.

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