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The idea of a student research project as a method of preparing a student for professional and scientific work

Krzysztof Nowicki[0000−0002−6574−6263], Mariusz Kaczmarek[0000−0001−6488−7489] and Pawel Czarnul[0000−0002−4918−9196]

Faculty of Electronics, Telecommunications and Informatics
Gdansk University of Technology, Narutowicza 11/12, 80-233 Poland
know@pg.edu.pl markaczm@pg.edu.pl pczarnul@eti.pg.edu.pl

Abstract. In the paper we present the idea and implementation of a student research project course within the master's program at the Faculty of Electronics, Telecommunications and Informatics, Gdańsk Tech. It aims at preparing students for performing research and scientific tasks in future professional work. We outline the evolution from group projects into research project and the current deployment of both at bachelor's and master's levels respectively, management of projects i.e. steps, reporting and monitoring at both faculty and individual project's levels within our custom-built Research Project System (RPS). We further elaborate on adopted formal settings and agreements especially considering the possibility of external clients taking part in the projects. Methodology of conducting and several examples of awarded projects are presented along with statistics on the number of submitted/conducted projects as well as those finalized with actual submitted/published research papers/patents proving actual (inter)national impact of the course.

Keywords: PBL, research student project, university-industry cooperation, Research Project System

1 Introduction

Today's students and skilled workers must learn to function in a climate of constant technological change, innovation and social change. To meet this challenge and prepare them for their future careers, universities need to implement new, attractive and creative forms of education and training. Students are trained to be subject matter experts, highly skilled technology problem solvers. At the same time, they must be team players, be able to work in interdisciplinary teams, identify problems and react to them quickly, and take the role of team leaders. This is especially true for engineering students. Therefore, in order to prepare students for the 21st century environment, academic teachers try to create educational activities that will help students develop substantive knowledge, solve problems and collaborate to meet workplace challenges. One strategy to help students

achieve these skills is project-based learning (PBL), eg. [1]. *Project Base Learning* is a key term in the new learning strategy paradigm. It is a teaching strategy that prioritizes the activity of a student or a group of students whose task is to independently, with the support of a mentor (research supervisor) solve a certain engineering or research problem. The students are the subject in the process of completing the task. The main foundation of PBL is the constant interaction and active participation of all members of the project group and the mentor. Thanks to this strategy, students engage in projects by formulating research hypotheses, defining design assumptions, collecting and analyzing information from various fields of knowledge in order to develop the final product. The main focus of PBL teaching is on allowing students to interact and communicate with their peers while working on their projects and to engage in reflective and critical thinking about what they are learning and doing. Therefore, project-based learning is considered an important approach to learning, which can also support the improvement of students' communication skills during project implementation and the acquisition of so-called *Soft skills*, increasingly required from job candidates by employers[3] [4] and prepare them for life long education [2]. In the article, we present the concept of a mandatory student research project aimed at transferring competences that allow you to work in research and development teams in companies.

2 Literature review

Over the last several years, many articles have been published on the implementation of the practical concept of project-based learning, or more broadly, challenge-based learning. Most of these articles/reports come from universities and concern the education of future engineers in various fields. These are future engineers in the field of ICT, IoT, Machine Learning [5], but we also have energy, civil engineering, environmental engineering and chemical technologies [6] [7]. Summaries of learning outcomes in the PBL system for periods of 10 and more years are already available [8].

An important element of the efficient implementation of the subject of the student project (PBL) is an appropriate IT system for managing and reporting progress in PBL. Many solutions are described, ranging from systems based on the moodle platform, ending with own implementations of CMS systems [9][10][11]. The next step in changing the education system at universities is the challenge base learning concept. Extension of the PBL idea, where we assume even greater interdisciplinarity of projects and the combination of three stakeholders: the design team, a representative of the industry and the end customer who would like to buy such a developed product in the final stages [12]. At Polish universities, student research projects are carried out as projects carried out by student research clubs (SRC) or as special student activity selected as part of special competitions announced by the authorities of individual faculties. An example of research projects carried out by student research clubs and financed by the university are projects carried out at the Wroclaw University

of Environmental and Life Sciences [13]. The conditions for project settlement include: publication of the work in any form; presentation of the obtained results. After completion of the research project, the SRC is obliged to present a final report on the implementation of the research project and the use of the allocated funds. Another approach, giving an opportunity to carry out research projects in self-organizing student groups, selected as part of competitions announced by university faculties, are examples from the Jagiellonian University [14]. The amount of funding and the number of awarded projects are not strictly defined and depend on the Faculty's budget for a given year. There are also thematic competitions, e.g. in 2013/2014 for the best study programs (the so-called One Million for Biochemistry and One Million for Biotechnology). One of the requirements of the competition is that the project is submitted and (if funds are awarded) implemented by a group of students from at least two different fields of study. In this way, student cooperation and interdisciplinary projects are supported. Students prepare and settle projects both in terms of content (e.g. presentation at a conference) and financially. It is a preparation for independent raising of funds for research after graduation. Although undergraduate students can also participate in the projects, the role of initiators and managers of these mini-projects is performed primarily by MSc students. Cooperation with the industry while defining the topics of student research projects and their subsequent implementation was put to the fore at the Institute of Thermal Technology at the Silesian University of Technology [15]. As part of SRP, a student or a team of students (contractor) under the supervision of a researcher (project supervisor) performs a specific research task. The mentor undertakes to properly prepare the contractors for the task. Contractors are obliged to perform the work diligently and to prepare test reports. After completing the project, the contractors receive a certificate confirming their commitment to its implementation. The results obtained as part of SRP should be presented at the seminar of the Scientific Circle, and also be the basis for the implementation of engineering and diploma theses. Student research projects are also carried out at medical universities, for example in Pomeranian Medical University in Szczecin [16]. As part of the research and development subsidy, the Vice-Rector defines a fund for the implementation of student research projects selected in the competition. Unfortunately, the competition is limited to members of scientific circles affiliated with the Student Scientific Society. Projects can apply for funding of up to 5,000PLN, and the implementation time can be up to 12 months. Also at the ETI faculty of the Gdańsk University of Technology, we have experience with learning through the implementation of student team projects in the field of High performance computing (HPC) [17] as well as using underlying ICT infrastructure for teaching HPC [18]. All the examples listed above concern the implementation of projects selected through competitions and are most often addressed to members of scientific clubs operating at the faculty or university. This limits the number of beneficiaries, which is related to the financing provided.

3 Concept of Students Research Project

3.1 Outline

In the years 2004-2019, the ETI faculty conducted a subject called "Group project" for all fields of study. The concept was described in [19]. It was a team student project, obligatory for all students of the 1st and 2nd semester of MSc studies. The project group of students could consist of 3 to 5 people, they selected a leader/manager from among the members of the group, who supervised the implementation of the project. The topics of the projects were more engineering and application than typically research. In all editions we assume that more then 5000 students take part in the project implementation. In the last edition of 2019/2020, several research projects were allowed to be implemented to test the idea of learning through a research project with a research hypothesis.

In line with the research university profile of Gdansk University of Technology (Gdansk Tech), the Research project was designed as a course to teach and prepare students for conducting work in research teams, possibly in R&D teams of high-tech IT companies, institutes or possible careers at universities.

Starting from February 2021, the Research project has been carried out in second degree (master's) studies in a two-semester system. It starts in the first semester and continues in the second semester with a three-semester Master's degree program.

By design, a student or possibly a team of students is expected to verify a research hypothesis defined by a client – either internal (faculty member) or external (company, another university, faculty, institute). Performing required research and tests for the final verification of the hypothesis may require prior development of devices, implementing code, data preparation etc. This is typically known at the project definition phase and stated by the client.

Verification of the hypothesis should be performed in line with a proper methodology and supported by scientifically significant and meaningful experiments and/or tests. Students are expected to finalize the course with preparation of a report formatted as a scientific publication, written in English.

For projects defined by external clients, the scope of the project might alternatively focus on preparation of an application/product in which case the final outcome might be a patent application.

3.2 Steps, reporting and monitoring project execution in the RPS electronic system

Companies are offered both an opportunity to define projects as well as to influence the topics that, in their opinion, students should be interested in, e.g. through competitions for students – see the IHS Markit competition for the "Best Research Project in the Field of Artificial Intelligence" - (https://spb.eti.pg.edu.pl/pages/contest). Projects are implemented on the basis of an agreement signed by the company, students and the faculty, which defines the rules of cooperation and the possibility of acquiring rights to the results of work performed

under the project as outlined in Section 4. Enterprises specify the purpose of the project work and the products expected as its result. The service work such as "maintenance of the network" but also work that does not include research tasks (reproductive, copy of a product already existing on the market) are not allowed for submitting and implementation. In the general scheme of the research project implementation process for companies or the University, it is assumed that they are responsible for ensuring the conditions for project implementation by students (production environment), defining project goals and accepting plans and work results.

It is worth emphasizing that during developing the concept of the Research Project, efforts were made to reflect the typical course of the project implementation process in companies – from the moment of recruitment of employees for the project, through the creation of a project group, project implementation, to its final acceptance [19]. The first stage is collecting offers(topics) from project principals and publishing them in the Research Project System (RPS) (a student finds several hundred proposals for project topics in RPS – this corresponds to hundreds of job offers for ICT engineers and others covered by the Project, which can be found on the Internet and in press advertisements). In the completed 2021/22 edition, over 282 topics were collected, of which 66 came from external companies and additionally 14 from other GUT faculties. In the present edition of 2022/23, 301 topics were proposed to students, including 51 from external companies and additionally 19 from other GUT faculties. In previous editions of the group project also included research topics (over 20, including several from external companies). About 350 students participate in each edition. A student may apply for participation in one or more projects (this is equivalent to applying for a job with multiple employers). At RPS, the student obtains volunteer status. It often happens that course participants apply for even a dozen or so projects, becoming volunteers in each of them (this corresponds to submitting an application for employment in many companies).

The next step involves meeting and an interview. The project supervisor (mentor) organizes individual meetings with volunteers applying for the project and conducts an interview with them (this corresponds to the interview stage). Often, a joint meeting of all volunteers interested in a given project is organized. This allows both parties, the mentor and the students, to get to know each other. The mentor can find out about the skills and knowledge of potential project participants and their aspirations, e.g. regarding team leadership. The scope of work to be performed by individual persons is also determined, as well as the rules of assessment. At this stage, property rights (not only intellectual) are also determined. This is a key topic in projects commissioned by external companies. However, also in the topics offered by academic teachers, the issue of copyright and property rights plays an important role. After these matters have been clarified, final decisions are made by students about staying in or withdrawing from the project group and by the supervisor regarding the selection of group members from among those still declared (this corresponds to hiring an employee). Accepting a student's participation in a given project is possible

only if he/she has not been accepted in another project (and information about this is provided by RPS). In the next stage, the leader of the group is selected from among its members. It is often proposed by students, although the decisive word belongs to the mentor, acting as the principal. Then we have, for the first time, cooperation of the entire team in decision-making and cooperation that allows the group to self-organize (this corresponds to the organization of the project team). Of course, during the implementation of the project, such cooperation of the team, also in technical matters, will occur many times, e.g. when determining the details of the schedule. Setting the schedule consists of adding to the generally imposed deadlines (end of semesters) exact dates of completing individual tasks, participants responsible for these and methods of documenting (companies also know when the project should be completed, and, depending on the method of management, more or less detailed planning of the next stages of its implementation). Of course, in certain circumstances, the schedule may be changed. Always, however, after discussion with the group, it is decided by the mentor. The decision on the choice of a project management methodology (e.g. agile or classic) is made by team members after consultation with the supervisor.

In parallel with the implementation of projects in teams, in order to reduce the gap between the knowledge acquired at university, students' visions and the actual scope and form of engineer's work in a research team, a series of meetings with representatives of enterprises and universities was conducted as a part of the Research Project course. They presented, from various points of view, problems related to the implementation of projects in companies and universities, in particular the research process, expectations that companies have towards students and young employees starting work, required soft skills, etc. Examples of meeting topics include:

- Scientific research and conducting research projects; Systematic literature review; Reporting research and scientific articles; Methods of preparing a presentation.
- Differences between a research project and a non-research project; Where to get money to implement your own ideas and how to use them well; How to prepare a project well to get financing.
- The role of documentation at Intel.
- Project challenges on the example of failures and successes of development projects.
- Management of research projects in an IT corporation.
- Agile in business projects – How not to slip on fashion?; Analyst as an interface between the client and the ICT project team; Testing – "different tests same culture, different cultures same tests".
- Innovative, international R&D projects in the military area – issues of the manufacturing process and its documentation on examples.
- Work in an open source project.

Companies participating in the presentations and offering projects include: Intel, Excento, Vector Technologies, Aiton Caldwell SA, IHS Markit, Radmor

S.A., ADVA Optical Networking, Smart4Aviation. A consultant of The World Bank and the National Center for Research and Development, winner of one of the editions of "Odyssey of Minds", as well as the organizer of the GUT project "Startup School" (https://pg.edu.pl/en/startup) shared their knowledge with students. Thanks to the variety of implemented projects and two-level support for students: by project supervisors and through a package of knowledge provided in the form of lectures, the Research Projects subject meets the requirements of project-based education and team learning.

4 Formal setting and agreements

In the case a research project is performed for an external entity i.e. a company, another faculty of Gdansk Tech, another university, principles of cooperation among the three parties: Students, the Faculty of ETI Gdansk Tech as well as the client is regulated by an agreement of participation in a research project. Specifically, the agreement states that the university appoints Students to carry out a research project on the specific subject and the Students undertake to implement the Project. A project supervisor is a faculty employee whose tasks include supervision designing and implementing the project, its intermediate and final evaluation. It is important that Students declare that they will perform the project personally, will not infringe the rights of other parties. The parties agree they will keep confidential information marked as such.

It an event that a Company acting as a client declares an interest in acquiring the copyrights to the results of a project it will submit a statement to Students or Students and the university, the latter when the university is a co-author of the work. A deadline is declared for such submission after which all the parties agree to conduct negotiations of conditions based on which the copyrights to the results will be acquired by the Company. Formal details of the latter will then be regulated by a separate agreement signed by the involved parties. The vice-dean for cooperation and promotion and the appropriate project supervisor, in consultation with the head of the department, are responsible for negotiating the contract for the implementation of the project. Therefore, students and supervisors have the support of the faculty authorities, and if necessary - the Attorneys' Office for Intellectual Property and Projects or Patent Attorney or Centre for Knowledge and Technology Transfer. If the agreement is not signed, the property rights to the project result remain the property of the students.

From the point of view of the university, it is guaranteed by the first agreement that relevant information may be provided for the evaluation of disciplines within the University and that results might be used by the university based on a free license, either granted by Students or the Company, for research and teaching purposes.

Companies are encouraged to supply a fund for awards granted to the best research projects conducted at the Faculty of ETI as well as organize their own thematic competitions for such.

In an event the university expresses an intent to use outcome (in particular applications and tools) of a Research project in its further research including commercial purposes (primarily the works conducted by a department hiring the supervisor), both the university and the student might agree to sign an agreement on the transfer of property rights.

In an event, the Research project scope realized by the Student(s) is conducted within a project financed by the university, copyrights are transferred to the University based on a respective project agreement.

Based on the Regulations for management and commercialization of intellectual property within the University, the University has the right to use scientific material contained within a scientific work of an author including Students of the University for research and didactic purposes.

5 Implementation of research projects

The way a research project is managed as an academic subject is hierarchical. The responsible person at the faculty is the faculty coordinator who is assisted by department coordinators (16 departments – 16 department coordinators) who manage the course implementation process in the departments. They help supervisors of research projects in formal matters, manage the project presentation schedule. They may also have contact with external clients and students. Project teams composed of any number (in practice up to 10 people) of students undertake the implementation of a topic selected from among the proposals submitted by external companies, academic teachers (supervisors, including those often implementing projects financed from external sources) and students (see Fig. 1).

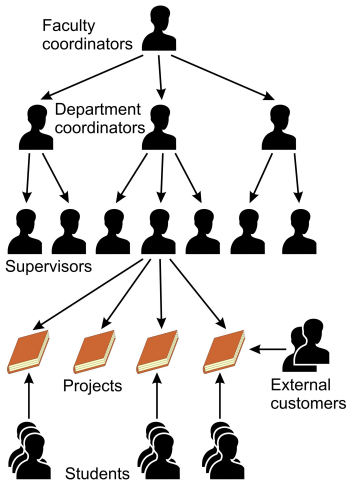

Fig. 1. The process of creating research topics

The result of a year-long work on a selected problem is a product and appropriate documentation, including a proposal for a scientific article or patent application. The course of work is supervised by mentors appointed by the departmental or faculty coordinator (see Fig. 1).

5.1 Methodology of conducting student research projects

The system supporting efficient organization of work concerning the research project is a custom IT system – the Research Project System (RPS) [https://spb.

eti.pg.edu.pl/]. In its creation, experience from the implementation of the system developed in 2010-2020 for running a student group project was used.

The implementation of the student's research project is documented in the RPS informatics system by:

1. Defining by the client (university employee - mentor, external company (external client) or students) the topic and research hypothesis.
2. Defining the schedule including stages with control dates(milestones). The stages should correspond to the tasks leading to the verification of the hypothesis, e.g.: data collection, data preparation/normalization/processing, algorithm/solution design, implementation of the solution, conducting experiments, analysis of results, verification of the hypothesis based on the obtained results, publication/report.
3. Interim reports documenting the achievement of milestones in the schedule.
4. Developing a poster (in Polish and English) after the 1st and 2nd semester informing about the contractors, basic tasks and achieved results.
5. Development of a report in the form of a publication according to a template (IEEE, Elsevier) in English or a report in the form of a patent application.

Subsequent stages of the Research Project implementation are presented in Fig. 2. The whole process begins with the submission of the topic of the research project by the client, i.e. by an external company, a researcher of the ETI Faculty or a researcher of another faculty or university. The author of the project topic from the ETI Faculty automatically becomes a supervisor. On the other hand, for external topics, a faculty member who is willing to lead a given topic is assigned as a supervisor. The next stage is reporting the desire to implement the project by students and forming a project group, after talks and acceptance of group members by the supervisor. All these stages are supported by the RPS system. The members of the project group selects a project leader. Then, the project implementation schedule is set, including milestones and key points that require partial reports to be sent to the system. The schedule must be approved by the supervisor. In contrast to the previously implemented student group project [19], changes in the project implementation schedule are possible. This makes it possible to take into account the more dynamic nature of work in a research project, e.g. problems in conducting experiments with an external contractor, changes in the publishing process - reviewing publications, which are very difficult to define in time in the schedule. The schedule may be changed/updated after obtaining the supervisor's approval. Reports are sent to key stages, which must also be approved by the supervisor. At the end of the second semester of the project, a scientific publication is prepared according to the general IEEE.org template. The project is fully successful when the article is published at a scientific conference or in a scientific journal. It is also allowed to file a patent application as equivalent reporting.

The number of submitted research project topics in the two editions implemented so far is presented in Tables 1 and 2. Table 1 summarizes the number of projects submitted by external clients. Note: RP1-cooperation with companies (projects undertaken by students), RP2-cooperation with other GUT

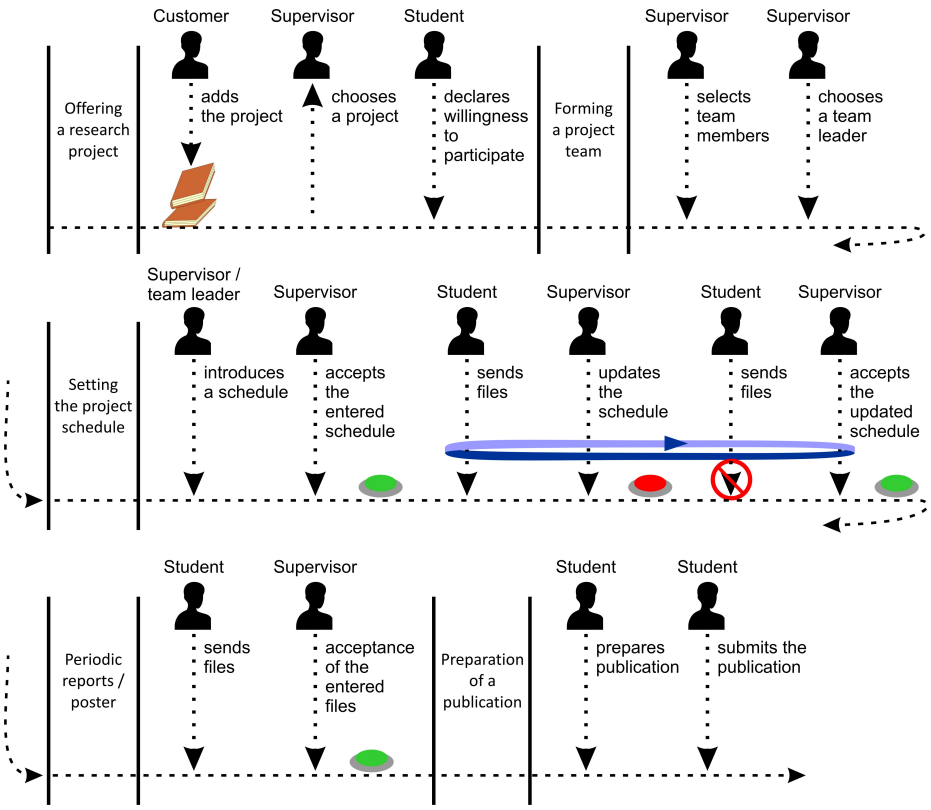

Fig. 2. Research Projects Service – project life cycle

faculties (projects undertaken by students), RP3-cooperation with companies (projects not undertaken by students), RP4-cooperation with other GUT faculties (projects not undertaken by students), RP5-proposed by ETI faculty teachers (projects undertaken by students), PR6-proposed by ETI faculty teachers (projects not undertaken by students); "+"-AI Tech projects - according to grant government program "Digital Poland" [https://www.gov.pl/web/aitech]. The table summarizes all the projects submitted in three editions, divided into projects submitted by employees of the ETI Faculty and by external entities.

Table 1. The submitted research projects in two editions

	Research projects					
Edition	RP1	RP2	RP3	RP4	RP5	RP6
2021	23	5	43	9	13+	15+
2022	10	10	41	9	12+	30+
Summary	33	15	84	18	25+	45+

Table 2. Overview of research projects

	Research projects				
Edition	ETI Faculty	Other Faculty	AI Tech	Industry	Status
2022	189	19	42	51	submitted 301
	60	10	12	10	taken by students 92
2021	174	14	28	66	submitted 282
	43	5	13	23	taken by students 84
2020ˆ	23	0	0	4	submitted 23
	5	0	0	0	taken by students 5

Note: ˆ formally students' group project with partial research aspects

5.2 Awarded research projects

In order to encourage students to implement innovative projects and devote enough time to them, competitions are organized: dean's competition for the best project and competitions sponsored by one of the IT companies – for the best project in the field of artificial intelligence. The awarded student projects' implementations are presented during the inauguration of the first year of second-degree studies at the ETI faculty (400 people in the auditorium). In the completed 2021/22 edition, the following projects were distinguished: "Fast automatic design of planar antennas using optimization algorithms" [22–25], "Implementation of a WBAN radiolocalization system prototype with the use of deep learning"[26], "Supporting the safety of people and car intelligence with the use of automatic pedestrian detection in thermal image sequences"[28, 29], "Analysis of infrared images and segmentation of facial features on thermograms using SI for the purposes of COVID-19 prevention" [30].

Additionally, the research project and awarded projects were picked up and covered by local media TV Gdańsk and Radio Gdańsk [31, 32].

5.3 Published research projects results

Many of the implemented projects ended with a scientific publication in an international journal, at an international conference or a patent [20–30],[33–38]. Table 3 summarizes the publication results in the completed 2021/2022 edition. Out of 80 completed research projects, 11 obtained results suitable for publication in conference materials or scientific journals. There was also one patent application. In total, eight scientific project supervisors published papers as co-authors. In total, 16 papers or conference papers were published. It also happened that two or more articles were written concerning one research project, e.g. [28, 29] or [22–25].

Table 3. Number of publications of research projects results

Published research papers		Under review research papers	
Conference	Journal	Journal	Patent Application
10	4	1	1

6 Conclusions

At the ETI faculty, the idea of PBL has evolved. In the first phase, a student group project was implemented. As part of this subject, engineering/application projects were implemented. Over time, the idea has evolved into the implementation of more research projects (with elements of an experiment that would allow to verify a stated research hypothesis), and ended up as a full-featured research project with a report in the form of a publication for a scientific journal (IEEE style formatted). We have observed that the subject Research Project is a supplement and a certain alternative to Student Science Clubs. There is a relatively small number of students in science clubs and often the projects carried out in clubs are not of a research but rather of an application nature. In our opinion the most valuable elements of the Research project subject are as follows:

- within the class schedule – hours common to all students enabling creation of interdisciplinary groups,
- supported by lectures – theory taught by practitioners from industry,
- students finalize their work in the form of a scientific report/article,
- RPS platform not only supporting the organization of students' work but also enabling external companies to define topics and cooperate with students.

In terms of teaching, computer science serves as a tool allowing to solve research challenges from various domains. Specifically, the following have been frequently and regularly used and applied across various projects:

- Various (programming) languages to solve a research problem e.g. C++, C#, Python, Matlab etc.
- Versioning solutions e.g. svn, git and platforms such as github, gitlab etc.
- Conducting selected projects using commercial technologies.
- The RPS system for definition of phases, milestones, schedules, storage and assignment of documentation, code and results to the phases. A need for a uniform scheme and an environment for conducting and documenting projects using either open or commercial standards has become apparent.
- Modern methods and environments for projects that required AI based solutions. Specifically, the ETI faculty offers NVIDIA DGX systems while selected departments offer advanced resources such as workstations and servers with 2 multi-core CPUs and 2-8 GPUs for time-consuming applications such as training DNN models. Additionally, students have an option to apply for research grants at the Centre of Informatics Tricity Academic Supercomputer and network (CI TASK)[1] and use e.g. the Tryton supercomputer and/or GPU enabled systems.

In terms of universal benefits of the student research project, we shall emphasize the following aspects:

[1] https://task.gda.pl/en/

- Conducting the research project requires and teaches cooperation of both IT and non-IT specialists which is an inevitable necessity in professional work – these skills are not usually subject of the regular university courses,
- Apart from very specialized topics there are those that result in solutions and tools applicable to a variety of contexts, needs and domains. Examples of such projects include: "Comparison of the effectiveness of different types of neural network learning with a small dataset", "Evaluation of performance and energy of DNN training as well as network quality for a selected application in a multi GPU environment under power capping", "Web-based application for automatic checking of exams using neural networks", "Web-based application for automatic exam checking using neural networks and handwriting recognition", "A tool for proofreading research papers", "Automation of application conversion between IT technologies", "Elder's wellbeing analysis system in domestic conditions", "Fake news detection techniques".
- The actual concept of the student research project is not tied to a specific faculty but is rather universal. Consequently, good experiences from the first two editions resulted in the rector's authorities considering extending student projects in this form to all faculties of the university. This would enable even greater interdisciplinarity of projects, as it would be possible to combine issues such as mechanical issues with aspects of electronic control and finally reporting the system status to the IT system. Such an idea fits perfectly into the mission of a research university of the 21st century. Starting with the next edition of the project, the Faculty of Management and Economics as well as the Faculty of Civil and Environmental Engineering will launch the student research project as well.

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