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Integrating Project-Based Learning into Innovative Studies in IoT Engineering

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Abstract—**The programme in Internet of Things Engineering, offered by the Faculty of Electronics and Information Technology, Warsaw University of Technology, is presented. To the best of the Author's knowledge this the first attempt in Poland to apply the project-based learning (PBL) throughout the entire engineering curriculum, for both the first-cycle (bachelor's) and second-cycle (master's) studies. This paper is focussed on the first-cycle programme, in particular on the unique structure of its curriculum, the way it was developed and initial observations coming out of its implementation.**

Keywords—**engineering education; Internet of Things (IoT); project-based learning (PBL), interdisciplinarity**

I. Introduction

PROJECT-based learning (PBL) is becoming a new trend in engineering education. Increasingly more universities of technology are experimenting with introducing PBL in engineering curricula. With this approach students are faced with open ended and ill-structured problems, often situated in a real-world context. "To solve the given problem students integrate theoretical and practical knowledge with limited constraints to achieve an end product or artifact that represents their new learning and skills" [1]. Through this process, the responsibility for learning shifts from the instructors to the students. Knowledge and skills are acquired through experiential collaborative learning, social interactions and knowledge sharing – teachers and students work cooperatively to build a learning community. This follows the concept of constructivist pedagogy – an approach that focuses on allowing students to construct their own knowledge of a subject by reflecting on and interpreting their own experiences [2].

Multiple examples of successful application of PBL at all levels and in all areas of education, including engineering education, are reported in the literature. Several surveys of relevant resources and research studies on PBL are published [1],[3]-[6], including those focused on specific areas of engineering, such as electronics [7].

Hundreds of papers, presented at international conferences on engineering education, organised by American Society for Engineering Education (ASEE), European Society for Engineering Education (SEFI), Institute of Electrical and Electronics Engineers (IEEE) and other organisations, and published in journals on engineering education, such as IEEE Transactions on Education, Journal of Engineering Education or European Journal of Engineering Education, describe experience with applying PBL in various undergraduate and graduate engineering courses and degree programmes, including courses and programmes in electronics and telecommunications [8]-[10].

Moving from traditional teaching to PBL brings a lot of benefits to students. Traditional engineering curricula focus on the cognitive domain (foundational knowledge, application and integration), whereas PBL accounts also for the affective domain (human dimension, caring and learning how to learn). Therefore, according to Fink's Taxonomy of Significant Learning, with PBL such significant learning is much more likely to occur [11]. PBL exposes students to diverse perspectives and broadens their thinking. The hands-on nature of PBL supports a deeper understanding of the course materials, leading to increased satisfaction of both students and teachers.

PBL can be applied to an individual course, a specific part of the curriculum – a selected semester or year of study, or as an overarching idea underlying the entire undergraduate or graduate curriculum.

Evidence shows that PBL is particularly useful when it is applied at the very beginning of the study programme, i.e. when a team project, such as the design and implementation of a simple robot, becomes a dominant component of the first-year undergraduate curriculum [12]-[14]. This breaks with the traditional approach to undergraduate engineering education in which students start with learning of fundamentals of engineering science (math, physics, chemistry etc.) which form a basis for courses directly related to their field of study.

One of the key arguments behind such an approach is to provide students with hands-on engineering experience as early as possible and thereby increase their interest in studying engineering and minimise the frustration resulting from learning theory without seeing its practical usefulness. This might lead to a reduction in dropouts. It is also argued that this helps to attract underrepresented groups, such as women, to engineering studies [15].

In an extreme case, PBL can be applied throughout the entire curriculum. There exist higher education institutions for which this has become a dominant pattern of engineering education. Frequently cited examples of such institutions include the Olin College of Engineering (USA) [16],[17] and Aalborg University (Denmark) [18]. Such a fully PBL-oriented approach maximises the earlier mentioned benefits, but generally is still considered a highly experimental and rather costly solution.

In Poland, most universities of technology rely on the traditional model of engineering education where the first year of undergraduate curriculum contains mainly science-related

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courses (math, physics, chemistry etc.) with little, if any, hands-on engineering experience. However, following the global trend, increasingly more institutions or individual faculties introduce innovations, including those that rely on the PBL approach. Nonetheless, to the best of the Author's knowledge, until 2020 no Polish institution of engineering education introduced a complete two-cycle (undergraduate and graduate) study programme dominated by PBL modules.

In this paper, a programme in Internet of Things Engineering, offered by the Faculty of Electronics and Information Technology, Warsaw University of Technology, is presented. It appears to be the first attempt in Poland to apply the PBL approach throughout the entire engineering curriculum for both the first-cycle (bachelor's) and second-cycle (master's) studies. This paper is focussed on the first-cycle programme, in particular on the unique structure of its curriculum, the way it was developed and initial observations coming out of its implementation.

II. Background

The Faculty of Electronics and Information Technology, Warsaw University of Technology, has a long tradition of introducing breakthrough changes in engineering education in Poland. In 1994, a few years before the Bologna Declaration was signed, all the degree programmes offered at the Faculty were restructured in line with the overarching concept of a flexible credit-based two-cycle study system (8 + 4 semesters) [19]. The system provided the students with a large number of diverse opportunities and allowed them to take advantage of the existing diversity. Each student was allowed to design his/her individual study path by selecting courses from the entire offer of the Faculty, but also from the offer of other faculties of Warsaw University of Technology and other Polish higher education institutions. Each student was also allowed to adjust the course load in each semester to his/her background and speed of learning. Some of these solutions were later implemented throughout the University [20].

In 2000, as the next essential step in introducing innovations in engineering education, following an initiative of a group of professors affiliated with the Faculty, a new unit – the Centre for Distance Education was established at Warsaw University Technology. Since then, the Centre offers Internet-based study programmes, based on the original organisational model (referred to as SPRINT) in three fields of study, including Electronics and Telecommunications.

Recently, a series transformations of the educational offer of the Faculty took place. In 2018, members of academic staff affiliated with the Division of Cybersecurity at the Institute of Telecommunications initiated the development of the first-cycle (bachelor's) programme in the field of Cybersecurity. One of the most interesting and unique feature of this programme is the way it was created. A special task force was established with two students as fully-fledged members of this group – real co-creators of the curriculum (and not just reviewers of the work done by academic staff). The involvement of students in designing their own education brings essential benefits [21],[22] and has been recommended as a good practice by several educational experts, including the President of the Olin College of Engineering [16]. Nevertheless, several years ago, this concept was largely unknown in Poland and was even contested by some members of Faculty's community. In addition, regular consultations with high-profile external cybersecurity experts who agreed to support the new programme were conducted.

The resulting study programme, compliant with international standards of engineering education in cybersecurity and interests of key stakeholders (students and employers), was developed and offered for the first time in academic year 2019. It received a lot of appreciation and support from the then Ministry of Digital Affairs which recommended this programme as a solution to follow by other Polish higher education institutions. In 2021, the team who developed and introduced this programme received the award of the then Minister of Education and Science for achievements in education. The most remarkable and unique aspect of this distinction was that among the recipients of this ministerial award intended for academic staff, there were two students – this never happened before and afterwards.

III. Moving forward: First-cycle studies in Internet of Things Engineering

A. *Motivation and key decisions*

Following the rewarding experience with the programme in Cybersecurity, the decision was made to further exploit the entrepreneurial spirit of the team who developed this programme and make another big step forward in transforming the educational offer of the Faculty. The idea was to develop an experimental fully PBL-oriented programme, i.e. a programme where PBL methodology is applied throughout the entire curriculum. This idea became a subject of a successful application for a grant under the Knowledge – Education – Development programme (POWER), coordinated by the National Centre for Research and Development. It might be worth noting that this application, coordinated by the Author, focussed on the innovative model of education (PLB-oriented) without specifying the field of study or even the roughly defined subject area of the programme for which this new approach would be applied.

Originally, it was proposed to redefine the curriculum of some specialisation (area of concentration) within one of the first-cycle degree programmes offered by the Faculty to make it fully PLB-oriented. However, facing several formal problems and potential legal obstacles, it was finally decided to develop a new programme, i.e. a programme in a new field of study.

In discussions on the scope of this new study programme, we proposed to add yet another aspects of innovation – introduce a programme in a new, emerging area of engineering – a programme not offered at that time at any of the Polish higher education institution. This is how the idea of developing a programme in Internet of Things Engineering (IoT Engineering) was created.

There were several arguments behind this decision:

a) Responding to the needs of economy and society

Predictions available in 2019, when the decision on the selection of the subject of the new programme was made, clearly indicated that IoT would grow at a very fast speed, both globally and in Poland (the recent predictions confirm this trend). The outcomes of the survey conducted in 2018 by KPMG – one of the Big Four global accounting organisations indicated that in the next three years (2019-2021), IoT "will drive the greatest business transformation and the greatest benefit to life, society, and the environment” [23].

IoT has become a well-defined area of interdisciplinary research. The editors of IEEE Internet of Things Journal (5-year Impact Factor of 9.0) – a joint publication of IEEE Sensors Council, IEEE Communication Society, IEEE Computer Society and IEEE Signal Processing Society, state: “We currently have enough special issues scheduled to cover all issues up until January 2026. Due to this, we are currently not approving the vast majority of new special issue proposals and suggest prospective guest editors to contact other publications.”

IoT is also explicitly mentioned in Polish national policy documents defining socio-economic priorities in the field of research, development and innovation – the National Smart Specialisations.

One of the most often formulated conclusion regarding the future developments in IoT is that the key barrier hampering the introduction of IoT-based solutions in economy and society is the lack of IoT specialists. It is, therefore, responsibility of the higher education sector to react in order to reduce this competency gap observed in the labour market.

b) Ideal match with the profile and resources of the Faculty

The scope of Internet of Things Engineering perfectly matches the research and education profile of the Faculty which prior to the introduction of this new programme offered the first- and second-cycle studies in:

- Automatic Control and Robotics,
- Electronics,
- Computer Science (Informatics),
- Telecommunications,
- Biomedical Engineering,

and the earlier mentioned first-cycle studies in Cybersecurity, introduced in 2019.

These areas cover almost the whole spectrum of IoT enabling technologies.

This means, in particular, that the costs of the development of teaching and learning infrastructure (dedicated laboratories) could be minimised by exploiting the existing resources, with only minor adjustments, if necessary.

c) Interdisciplinarity

IoT engineering, with its diversified enabling technologies, breaks down the barriers between traditional, earlier mentioned fields of study offered by the Faculty, thereby following the global trend towards making engineering education more interdisciplinary.

Following the decision to introduce the programme in IoT Engineering, the work on the development of its curriculum started. Just as for the programme in Cybersecurity, students actively contributed to this process. Finally, the first cohort of students started their studies in IoT Engineering in October 2020.

It might be worth noting that the new IoT Engineering programme obtained an honorary patronage of the Ministry of Digital Affairs. This decision was made “in recognition of key importance of education of IoT specialists for various branches of the Polish economy and central administration”.

B. Objectives, learning outcomes and contents

The main objective of the new programme is to provide the graduates with competences (knowledge, skills and social competences) that would allow them to understand the benefits and challenges associated with IoT and create intelligent systems and networks based on IoT. Such systems and networks include:

- stationary and mobile smart electronic devices (things), equipped with smart sensors, in many cases able to perform the initial processing of collected data, and actuators,
- network infrastructure (wired or wireless) which connects these devices and servers by means of internet,
- system for collecting and processing data obtained from the network of smart sensors, frequently using AI methods, and integrating them into intelligent products or services, which satisfy the needs of various groups of users.

These components of IoT systems correspond to the three layers of the commonly adopted three-layer IoT architecture (perception layer, network layer and application layer) [24].

It is quite obvious that the 7-semester curriculum cannot cover the full, very broad spectrum of competences of an IoT engineer, presented in the literature, opinions of interested employers and other stakeholders. In one of the most interesting and comprehensive publications on education in cyber-physical systems (conceptually close to IoT) [25], containing an analysis of dozens of degree programmes in this area, it is demonstrated that each of the programmes examined leaves the graduates with some essential gaps in competences needed by industry.

Therefore, an essential step in the development of the IoT Engineering programme was the selection of key learning outcomes and related contents, so that to make it possible to develop an inherently consistent curriculum. In this selection process, the team working on the development of the programme took into account:

- outcomes of the analysis of resources on IoT education (publications, similar programmes at other universities),
- expectations and opinions of employers, formulated in surveys conducted by the dedicated section of the University administration,
- opinions presented during a dedicated meeting organised at the Faculty to address key issues related to the new programme, attended by ca. 20 representatives of leading Polish and international companies and other institutions interested in employing future graduates,
- adequate coverage of different IoT enabling technologies,
- Faculty’s resources (human resources and educational infrastructure – labs etc.).

C. Innovative concept and structure of the curriculum

The IoT Engineering programme is taught in Polish and is offered for a small group of students – each academic year 20-25 students start their education. This creates a good environment for experimentation with highly innovative didactics.

The major innovation introduced in the IoT Engineering programme is a unique structure of its curriculum, characterised by the dominance of teaching methods based on problem solving, project-based experiential learning and other learning activities stimulating the student engagement.

The conceptual framework of this curriculum is shown in Fig. 1. At the heart of it, there are large design courses – six PBL modules, offered in semesters 1-6 (semester 7 is devoted to work on the diploma thesis). Courses that cover „traditional” science-based engineering fundamentals (math, physics), courses in humanities and social sciences and courses on selected topics in the various IoT enabling technologies form a basis for and complement these PBL modules.

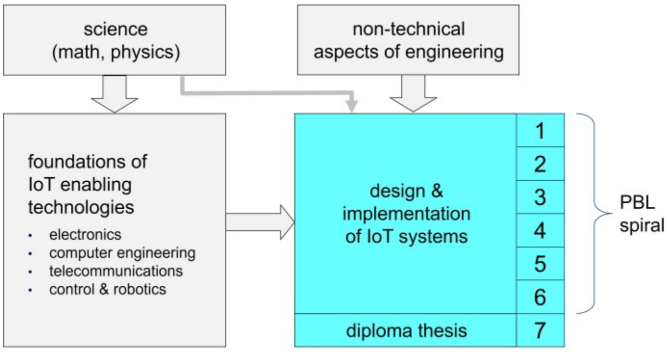

Fig. 1. IoT curriculum structure

The large (10-12 ECTS points) PBL modules starting from the very first semester are a unique feature of the IoT Engineering curriculum which make it different from the other curricula offered by the Faculty, by other faculties at Warsaw University of Technology and by other Polish universities of technology.

Another way of looking at this curriculum is shown in Fig. 2. The term "PBL spiral" means that, within each PBL module, the competences (knowledge and skills) gained within the preceding PBL modules in each of the key subareas of IoT are extended and made deeper – students attach knowledge to their previous knowledge. This can be seen as yet another departure from the traditional engineering curriculum split into courses that are to a large extent distinct silos, only infrequently closely connected to each other.

The IoT Engineering curriculum is shown in Table I. It can be seen that:

- the learning path is quite flexible; students are given many choices regarding the selection of courses (restricted or free electives),

- the number of courses in each semester is relatively low (5-6) which makes it relatively easy to coordinate the contents of these courses; such a solution is typical for engineering programmes offered by universities in many countries, but is infrequently encountered at Polish universities of technology, where the number of courses is usually substantially higher.

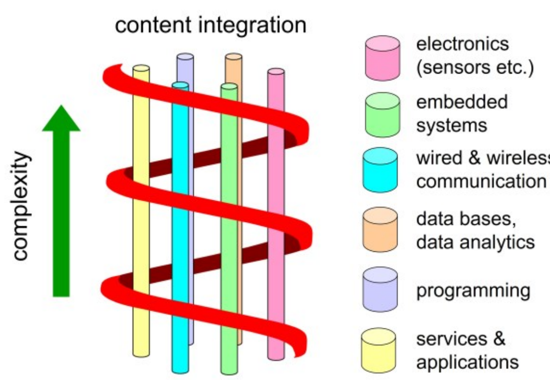

Fig. 2. PBL spiral

D. Teaching methods and verification of learning outcomes

A large variety of well-integrated teaching methods and techniques are applied throughout the IoT Engineering curriculum.

The underlying idea is to change the way engineers are taught, i.e. to depart from teaching based on passive participation of students in classes that focus on transferring of knowledge. Instead, problem solving, designing in teams and other learning activities that engage students become dominant forms of educational provision. Lectures, tutorials, seminars, lab sessions, design projects are integrated in modules/courses where these forms intertwine with each other.

Such an integration takes place primarily within each of the six PLB modules. Learning activities carried out within these modules, especially in semesters 1-4, are based to a large extent on the concept of Double Diamond design process (Fig. 3), rooted in the more general Design Thinking methodology [26].

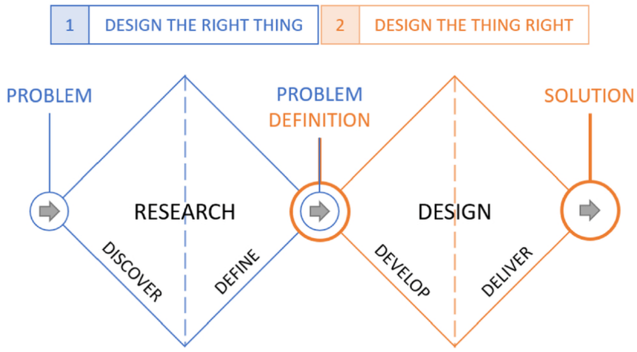

Fig. 3. Double Diamond design process [27]

The learning process is organised into three phases:
- team building,
- formulation of the task (first component of the Double Diamond),
- design and implementation (second component of the Double Diamond).

The student group is divided into 5-6 teams, 3-5 students each. Each team has its individual design task and its own instructor/tutor who supervises the team (each instructor – member of academic staff supervises typically 1-3 teams). Design tasks, often inspired by real problems submitted by external stakeholders, evolve annually to account for the experience gained by the tutors, but also to remove the possibility of students referring to the reports submitted in previous years by their colleagues.

Two basic forms of learning activity take place:

a) Thematic workshops

Four-hour classes are conducted twice a week. At each workshop students solve problems related to the topic of that workshop and their design tasks. These solutions are then discussed and graded by instructors. To make this form of learning activity more effective, the concept of flipped classroom is often applied [28].

b) Designing and prototyping

Students meet regularly, at least once a week, with their tutors to discuss the progress of their work on the design tasks and occasionally also to report and discuss their proposals and solutions with the whole students group. This way they receive

TABLE I
IOT ENGINEERING CURRICULUM – FIRST-CYCLE (BACHELOR) PROGRAMME

[THEMATIC AREA] *course/module*	LTLaP(I)*	ECTS	semester						
			1	2	3	4	5	6	7
[PHYSICAL EDUCATION]		0	0	0	0				
[FOREIGN LANGUAGE]		12			4	4	4		
[ECONOMY & SOCIAL SCIENCES]		6							
Methodological Aspects of Engineer's Work	– – – – (2)		2						
Entrepreneurship in Practice	– 2 – – (–)					2			
ECONOMY & SOCIAL SCIENCES - electives	– 2 – – (–)	2				2			
[MATHEMATICS]		15							
Mathematics 1 – Introduction to Mathematics	1 – 1 1 (–)		4^e						
Mathematics 2 – Calculus	2 1 1 1 (–)		6^e						
Mathematics 3 – Algebra	1 2 – 1 (–)			5^e					
[PHYSICS]		8							
Introduction to Physics	1 1 1 – (–)			4^e					
Physical Foundations of Electronics and ICT	2 1 – – (–)				4^e				
[FUNDAMENTALS OF ELECTRONICS]		19							
Fundamentals of Electronics and Measurements	2 1 1 – (–)		4						
Signals and Systems	2 1 1 – (–)			5					
Electronic Devices and Circuits	2 – 1 1 (–)				5				
FUNDAMENTALS OF ELECTRONICS – electives		5					5		
[COMPUTER ENGINEERING]		23							
Fundamentals of Programming	2 – 2 – (–)		4						
Digital Techniques	2 – 1 1 (–)			5^e					
Microcontrollers and Programmable Circuits	2 – 2 – (–)					5			
Data bases and Big Data	2 – – 2 (–)						5		
COMPUTER ENGINEERING – electives		4						4	
[ICT]		30							
Wireless Transmission	2 – 2 – (–)				5^e				
Architectures of Services & Applications	2 – 1 1 (–)					5			
Fundamentals of Cybersecurity	2 – – 2 (–)						4^e		
Data Analysis	2 1 2 – (–)							6	
Computational Clouds	2 – 2 – (–)							5	
ICT – electives		5							5
[DESIGN OF IOT DEVICES AND SYSTEMS]		69							
PBL1: IoT Components & Systems	– – – 2(7)		10^e						
PBL2: Embedded Systems & Programming	– – – 2(8)			11^e					
PBL3: Wireless & Wired Communication	– – – 4(8)				12^e				
PBL4: Smart IoT Devices	– – – 4(8)					12^e			
PBL5: IoT Services and Applications	– – – 4(8)						12^e		
PBL6: IoT Distributed Applications & Clouds	– – – 4(8)							12^e	
[TECHNICAL ELECTIVES]		8							8
[DIPLOMA THESIS]		20							
Diploma Thesis – Research 1								3	
Diploma Seminar									2
Diploma Thesis – Research 2									15
Diploma Thesis – Writing									
total		210	30	30	30	30	30	30	30
[INTERNSHIP]		4							

^{e} courses/modules with an examination as one of the learning outcomes assessment methods
* the numbers in column LTLaP(I) show the number of weekly contact hours for the various forms of learning activity: lecture (L), tutorial (T), laboratory (La), project (P) and integrated form combining some of the earlier listed forms (I)\

valuable comments and suggestions from their tutors, but also from their peers. A significant part of the work done by students is, however, based on self-directed learning – searching for relevant information/materials, critical evaluation of their usefulness, designing and testing prototype solutions. Towards the end of the semester each team submits a written report and presents their design (in most cases, integrating hardware and software components) in front of the whole group of students and tutors. The quality of the design and the report, but also the way the project is presented and "defended" are major factors that determine the students' grades for the PBL course.

PBL-related learning activities take place in dedicated laboratories, equipped with computers, necessary electronic components and instruments, as well as relevant software tools. Several types of universal development kits and evaluation boards, various sensors and actuators, components of wired and wireless networks, multiple professional instruments, the assembly station for electronic systems, the 3D printer, and the antenna set installed on the roof of the Faculty building, are available. A certain portion of these components and instruments were obtained from commercial companies, such as ST Microelectronics, Infineon, Nordic Semiconductors and Keysight, supporting the programme and participating in the education process (in selected workshops), seeing this as an opportunity to promote their products.

It is worth to mention that during the COVID-19 pandemic times, when most or even all teaching and learning activities were conducted online, students were allowed to take home selected hardware components, including the microcontroller boards, so that to have an opportunity to design and test their prototype solutions without violating regulations concerning their presence at the University premises. This approach is also occasionally applied in post-pandemic times, when prototyping in principle takes place in the Faculty's laboratories, but students can take home necessary hardware and work there on their designs until late evening or during the weekend.

In the PBL modules students attain, besides technical knowledge and skills related to their field of study, also universal (soft) skills and social competences (creativity, entrepreneurial thinking, teamwork, project management and task planning, sense of shared responsibility, communication), which are highly recognised by employers and emphasised in engineering education frameworks, such as the ABET criteria [29].

The PBL modules require a new approach to teaching – a shift from instruction to facilitation. The introduction of the IoT Engineering programme in 2020 was, therefore, preceded by a series of workshops and training session intended for academic staff designated to serve as tutors in PBL modules. These workshops were organised and conducted by other members of academic staff having experience, including international experience, in teaching PBL courses. A toolkit containing guidelines for newcomers in the PBL teaching was also prepared.

The PBL modules – the key components of the IoT Engineering curriculum – are supported and complemented by courses that cover the fundamentals of engineering science and deal with selected areas of the IoT enabling technologies. The curriculum contains also courses that – directly or indirectly – focus on more general non-technical issues relevant for engineering education. In particular, in the first semester, students have to take course "Methodological aspects of engineer's work", which focusses on the development of universal competences useful in their future studies and engineering careers.

Generally, in courses included in the IoT Engineering curriculum, teaching methods that engage students are promoted. Lectures account for only 23.6% of total number of contact hours – significantly less than in other study programmes offered at the Faculty and at the University. But even these lectures are not used for one-directional transfer of knowledge. The concept of flipped classroom, used, as mentioned earlier, in the PBL workshops, is frequently applied, so that to convert the lecture into a questions and answers session.

Another feature of the IoT Engineering curriculum is its flexibility – it offers the students multiple options to select from. These opportunities are available in:

- non-technical courses (electives: 2 ECTS),
- technical courses (electives: 22 ECTS),
- PBL modules (69 ECTS), where students are allowed to select their design tasks or participate in the definition of their design tasks,
- diploma research modules (18 ECTS), where students are allowed to browse through the available offers and select topics of their diploma theses and their supervisors.

Diversified teaching and learning methods and techniques applied throughout the curriculum naturally lead to diversified methods of the assessment of learning outcomes. In particular:

- with the domination of teaching methods that require active engagement of students and „learning by doing", the traditional assessment methods, aimed at the verification of student's knowledge, are replaced with methods that verify student's knowledge indirectly – through the assessment of ability to apply that knowledge during the design process,
- traditional methods of assessment of learning outcomes assume, in some cases, a "non-traditional" form; for example, in some PLB modules, an examination looks more like a team defense of the project rather than a conventional sit-in written exam.
- conventional sit-in written examinations are usually organised as open-book exams, with problems aimed at the verification of ability to apply knowledge rather than the verification of knowledge itself.

E. First experiences and lessons learned

The new programme in IoT Engineering is attracting a lot of attention of candidates for engineering studies. In 2020, when the programme was offered for the first time, 928 candidates applied for admission to these studies. With the enrolment limit of 30, this means that for each place there were more than 30 candidates – the highest number among all programmes offered by Polish universities, as reported by the then Ministry of Science and Higher Education. In the next years, the information about the number of applications in previous years and high admission threshold – the score at the secondary school leaving examination (matura) necessary to get admitted – might have discouraged some candidates. Nevertheless, the number of applicants for each place has consistently exceeded 10.

In this context, It might be worth mentioning that an essential role in promoting of the new programme has been played by members of the student research group dealing with IoT who – among other forms of their activity – have organised several IoT-related workshops for secondary school students, using the same laboratories that are used by the university students.

Some interesting information on the profile of IoT Engineering students come from the survey conducted each year among these students in the beginning of their first semester of education at the Faculty. Of particular interest are answers to the question on different universities to which they applied and were admitted, but rejected that opportunity and decided to study IoT Engineering. In this relatively large group (36% of all IoT Engineering students) besides quite natural and expected choices (Computer Science/Engineering, Automatic Control and Robotics at universities of technology, Computer Science, Mathematics or Physics at comprehensive universities) some unexpected answers were encountered. Students mentioned in particular Medical Studies, Economics, Law, Cognitive Sciences, and Interdisciplinary Studies in Humanities and Social Sciences. Having students with so diversified interests is highly beneficial when dealing with interdisciplinary PBL design tasks.

In the same survey, students were also asked about their motivation for selecting the IoT Engineering programme. The top choices in 2024 are shown in Table II.

The outcomes of another survey conducted in the middle of the first semester indicate that the the first-semester students find the new programme very attractive. More than half of them (55.6%) claim that this programme stands out positively among the programmes offered by the Faculty, the remaining students claiming that it is too early to decide on its attractiveness (Table III). This opinion should be considered taking into account the quality of the Faculty's educational provision – in the national ranking by Perspektywy all the other programmes offered by the Faculty consistently take leading positions – quite frequently being recognised as the best in the country.

Opinions presented by second- and third-year students are also overwhelmingly positive. In addition to pointing out to their significant learning experience, students express feelings of joy. Selected student testimonials, collected by the Student Self-Government, are presented below. They were displayed on the website (in Polish) dedicated to this specific programme (https://iot.pw.edu.pl) on 30 November 2024 (the content of this webpage, including the students' testimonials is updated quite frequently). It should be noted that these testimonials are not anonymous – names and photos of students are given:

- first-year student: "IoT Engineering stands out among other programmes offered at the University – mostly because of a large number of design projects and practical tasks. This is a highly unconventional approach: instead of swotting, every week essential self-directed learning, supervised by a tutor, takes place. …",
- first-year student: "IoT Engineering integrates new technologies with non-typical approach to studying. … If you want to deal with autonomous vehicles, smart homes, artificial intelligence and more, this programme is for you.",
- second-year student: "IoT Engineering is for ambitious persons who look for comprehensive development. PBL allows for attainment of both hard and soft skills …"
- third-year student: "IoT Engineering makes it possible to use tools that others touch only after studies. …"
- third-year student: "Up-to-date programme, highly engaged teachers and working on practical projects make studies a pleasure. … A low number of students and a large number of group projects make us a good team – everybody can count on help from the others.".

Interesting and to some extent unexpected opinions regarding theoretical vs. practical components of the curriculum were

TABLE II
MOTIVATION FOR STUDYING IOT ENGINEERING

option	percentage of students who selected that option[a]
innovative teaching and learning	64.2 %
position in the labour market; high salary	35.7 %
interesting curriculum	28.6 %

[a]each student could select one or two out of 8 options

TABLE III
IOT ENGINEERING VS. OTHER PROGRAMMES OFFERED BY THE FACULTY

option	2020	2021	2022	2023	2024	2020-2024
stands out in a positive way	14	6	11	10	14	55 (55.6%)
stands out in a negative way	-	-	-	-	-	
no difference	-	-	-	-	-	
too little evidence to decide	6	12	8	8	10	44 (44.4%)

expressed by students in less formal conversations. Polish students generally consider engineering programmes they are enrolled in as being too theoretical, complain about that and request more practice-related contents. In this context, it might be worth noting that some IoT Engineering students formulated opposite requests – requests for more theory which would make it easier to overcome difficulties encountered when dealing with their practical PBL design tasks.

Specific requests were formulated for:

- more digital signal processing early in the curriculum; this request was formulated by third-semester students, who in the PBL course encountered difficulties associated with wireless communication in a network of IoT devices,
- more statistics in mathematics courses.

Such valuable suggestions have been taken into account and the contents of selected courses have been adjusted. In particular, in the second-cycle (master's) programme, a dedicated course on statistics has been introduced.

A highly positive assessment of the experimental IoT Engineering programme does not mean that students, but also members of academic staff, do not see shortcomings and opportunities for improvement. The list of recommended refinements includes:

- better cooperation with external stakeholders (industry and public administration) when defining the PBL tasks,
- shift to "more blended" learning – exploiting opportunities associated with synchronous and asynchronous online learning, including flipped classroom,
- fostering the use of AI tools, in particular generative AI tools, by both teachers and learners,
- making the programme more international – including courses taught in English, and encouraging students to take advantage of learning opportunities offered by universities located abroad, in particular by partners of Warsaw University of Technology in the European University ENHANCE Alliance (https://https://enhanceuniversity.eu),
- offering micro-programmes on selected areas of IoT applications, leading to micro-credentials [30].

It should be noted that, for the IoT Engineering programme, teaching students how to use generative AI tools effectively and encouraging them to use such tools does not create problems related to potential „cheating". This is because, as described earlier, the adopted methods of verification of learning outcomes are most frequently based on the assessment of prototypes of real physical systems containing an essential hardware component. This leaves very little opportunity to replace students' work with solutions produced by ChatGPT or similar AI tools.

IV. Second-cycle Studies in Internet of Things Engineering

The first group of students admitted to the IoT Engineering programme (in 2020) completed their first-cycle studies at the beginning of 2024 (actually, taking advantage of the flexibility of regulations at the Faculty, some of these first-cohort students have decided to prolong their education). For these graduates, the second-cycle programme in IoT Engineering was developed and introduced, starting in February 2024.

When developing this programme, the continuation of the experiment initiated several years earlier for the first-cycle studies was assumed.

In particular, like for the first-cycle studies, the students significantly contributed to the development of the programme. However, unlike for the first-cycle programme, where only students from other fields of study could have contributed to the programme development, this time the IoT Engineering students – prospective candidates for second-cycle programme were participating in this process.

Regarding the structure of the curriculum, it was decided to follow the approach applied to the first-cycle programme and include two PBL modules, 12 ECTS points each, in the first two semesters of this 3-semester programme.

To further extend the scope of this educational experiment, new solutions were proposed and implemented. These new solutions include:

- Substantial enhancement of the interdisciplinary character of the programme through cooperation with other faculties. In the first edition of the programme, that started in February 2024, the cooperation with the Faculty of Architecture takes place. Teams composed of students of both faculties work on projects that embrace the idea of universal design, so that to implement the vision of an inclusive society, accounting for the needs of various groups (elderly people, people with disabilities, etc.). The cooperation with the Faculty of Geodesy and Cartography on smart city solutions will be the next step.
- Making studies more suitable for those who try to reconcile full-time work with full-time studying (in the group admitted in 2024 almost all students work full-time) through evolutionary shifting to online learning and appropriate class scheduling. To shift to online learning without degrading the students' learning outcomes, it is necessary to produce high-quality interactive teaching materials for self-directed learning and to provide students with ample opportunity to interact online with tutors. Regarding the class scheduling, the idea is to reduce the percentage of on-campus classes in the morning and early afternoon. In particular, in the first semester, most classes were scheduled for the evening, with Friday and every second Thursday free of on-campus teaching activity.

The second-cycle programme in IoT Engineering is open not only to graduates of the first-cycle studies in the same field, but also to graduates from other fields of study offered by the Faculty of Electronics and Information Technology, other faculties of Warsaw University of Technology or other universities. In fact, only 39% of students admitted to this progamme in February 2024 graduated from the first-cycle studies in IoT Engineering. This seems to indicate that the effort to make the new second-cycle programme better suited to the needs of students, in particular students who work full-time, has brought a visible success.

Conclusion

The development and implementation of a new degree programme in Internet of Things Engineering at Warsaw University of Technology, described in the paper, has been a unique educational experience.

The underlying idea was to change the way engineers are taught, i.e. to depart from teaching based on passive attendance of students in classes that focus on transferring of knowledge and shift towards learning activities that engage students in problem solving and design.

The innovativeness and uniqueness of this initiative has the following dimensions:

- thematic scope: in 2020 when the first cohort of students started their education, no Polish higher education institution offered an undergraduate programme in this area; even today IoT Engineering as a distinct field of study remains unique;
- innovative structure of the curriculum for both the first- and second-cycle studies, with a large team design project (in most cases, 12 ECTS points) in every semester, except for the last one dedicated to work on the diploma thesis,
- involving students in co-designing their own education throughout the entire process of curriculum development.

With the first students graduating from the first-cycle programme and the second-cycle studies underway, first observations regarding this educational experiment can be formulated.

The students are generally satisfied with their selection of the programme – they see and confirm that it differs from other programmes offered by the Faculty and the University. This increases their motivation and willingness to succeed. The drop-out, especially in the first year of studying was substantially lower than in the other programmes. In particular, no failures in PBL courses were reported, which might be attributed, at least to some extent, to an essential competence attained – the sense of shared responsibility for the work done by the team.

We believe that the IoT Engineering graduates have also developed other essential skills and social competences (creativity, ability to work in a team, task planning and effective time management, communication) that would make them successful professionals.

This seems to justify the conclusion that the development and implantation of this highly innovative IoT Engineering programme has been a successful educational experiment which should be continued and, if possible, extended.

This success, however, comes at a non-negligible cost. Running the IoT Engineering programme requires an increased engagement of academic staff (for PBL modules, the student-to-staff ratio is around five-to-one, significantly lower than for other formats of teaching). Costs of non-reusable electronic components used in prototypes designed and implemented in PBL courses also contribute to extra costs. Therefore, there remain doubts about the scalability of this educational experiment and the extent to which it can be applied to the other fields of study where the number of students is substantially higher. This is something that should be discussed in the near future at the level of the Faculty and the University, as the twenty-first century engineering students deserve the twenty-first century engineering education.

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REFERENCES

[1] D. Kokotsaki, V. Menzies and A. Wiggins, "Project-based learning: a review of the literature," Improving Schools, vol. 19, no. 3, pp. 267-277, 2016. https://doi.org/10.1177/1365480216659733

[2] V. Richardson, "Constructivist Pedagogy", Teachers College Record, vol. 105, no. 9, Dec. 2003, Columbia University, pp. 1623–1640. https://doi.10.1046/j.1467-9620.2003.00303.x.

[3] A.C. Reis, S. Barbalho and A.C. Diniz Zanette, "A bibliometric and classification study of Project-based Learning in Engineering Education," Production, vol. 27, 2017. http://doi.org/10.1590/0103-6513.225816

[4] S. Lavado-Anguera, P.-J. Velasco-Quintana and M.-J. Terrón-López, "Project-Based Learning (PBL) as an Experiential Pedagogical Methodology in Engineering Education: A Review of the Literature," Education Sciences, vol. 14(6), 617. https://doi.org/10.3390/educsci14060617

[5] X. Du, E.D. Graaff and A. Kolmos (eds.), "Research on PBL Practice in Engineering Education," Sense Publishers, 2009, ISBN 9789087909307

[6] M. Borrego, M.J, Foster and J.E. Froyd, "Systematic Literature Reviews in Engineering Education and Other Developing Interdisciplinary Fields," Journal of Engineering Education, vol. 103, pp. 45-76, 2014. https://doi.org/10.1002/jee.20038

[7] S. Evanita, Z. Afdal, Rino and Marwan, "Electronic Project Based Learning a Literature Review," Advances in Economics, Business and Management Research, Atlantis Press International B.V., vol. 192, pp. 247-252, 2021. https://www.atlantis-press.com/proceedings/piceeba-21/125963982

[8] H. Hassan, C. Domianguez, J.-M. Martia Nez, A. Perles, J. Albaladejo, and J.-V. Capella, "Integrated Multicourse Project-based Learning in Electronic Engineering," International Journal of Engineering Education, vol. 24, no. 3, pp. 581-591, 2008. https://www.ijee.ie/articles/Vol24-3/s14_ijee2027.pdf

[9] E. Raj and K. Tomalczyk, "Second-cycle Electronics and Telecommunications Program with Project Based Learning Approach", Intl Journal of Electronics and Telecommunications, vol. 68, no. 3, pp. 505-510, 2022. https://doi.org/10.24425/ijet.2022.141267

[10] H. Aliakbarian *et al.*, "Implementation of a Project-Based Telecommunications Engineering Design Course, " IEEE Transactions on Education, vol. 57, no. 1, pp. 25-33, Feb. 2014. https://doi.org/10.1109/TE.2013.2262800

[11] R.M. Paul, Y. Jazayeri, L. Behjat and M. Potter, "Design of an Integrated Project-Based Learning Curriculum: Analysis Through Fink's Taxonomy of Significant Learning, " in IEEE Transactions on Education, vol. 66, no. 5, pp. 457-467, Oct. 2023. https://doi.org/10.1109/TE.2023.3307974

[12] J. Froyd, A. Srinivasa, D. Maxwell, A. Conkey and K. Shryock, "A Project-Based Approach To First-Year Engineering Curriculum Development," Proc. IEEE Frontiers in Education, pp. T3H, 2005. https://doi.org/10.1109/FIE.2005.1611955

[13] M. Kaushik, "Evaluating a First-Year Engineering Course for Project Based Learning (PBL) Essentials." Procedia Computer Science, Elsevier B.V., vol. 172, 2020, pp. 364-369. https://doi.org/10.1016/j.procs.2020.05.056.

[14] H.A. Hashim, C. Tatarniuk and B. Harasymchuk, "First Year Engineering Design: Course Design, Projects, Challenges, and Outcomes," IEEE Frontiers in Education Conference, 2022. https://doi.org/10.1109/FIE56618.2022.9962456

[15] Y. Zastavker, M. Ong and L. Page, "Women in Engineering: Exploring the Effects of Project-Based Learning in a First-Year Undergraduate Engineering Program," Proc. Frontiers in Education Conference, 2006. https://doi.org/10.1109/FIE.2006.322485

[16] R.K. Miller, "Lessons from the Olin College Experiment," Issues in Science and Technology, vol. XXXV, no. 2, pp. 73-75, Winter 2019. https://issues.org/lessons-from-the-olin-college-experiment/

[17] E. Guizzo, "The Olin Experiment," IEEE Spectrum, vol. 43, no. 5, pp. 30-36, May 2006. https://doi.org/10.1109/MSPEC.2006.1628505

[18] F. Habbal at al., "Problem and Project-Based Learning at Aalborg," in: F. Habbal, A. Kolmos, R.G. Hadgraft, J. Egelund Holgaard and K. Reda, "Reshaping Engineering Education: Addressing Complex Human Challenges," Springer, 2024. https://doi.org/10.1007/978-981-99-5873-3

[19] A. Kraśniewski and J. Woźnicki, "Flexibility and adaptability in engineering education: an academic institution perspective," IEEE Transactions on Education, vol. 41, no. 4, pp. 237-246, Nov. 1998. https://doi.org/10.1109/13.728256

[20] A. Kraśniewski, W. Kurnik, "Bologna reforms at the Warsaw University of Technology: Institutional implementation strategies and lessons learned", in E. Froment, J. Kohler, L. Purser, and L. Wilson (eds.), EUA Bologna Handbook, article C 3.1-1, Raabe Verlag, Berlin, December 2008; also in: Implementing Bologna 5 – Best of the Bologna Handbook, vol. 15, Raabe Verlag, 2012.

[21] C. Bovill et al., "Addressing potential challenges in co-creating learning and teaching: overcoming resistance, navigating institutional norms and ensuring inclusivity in student–staff partnerships," Higher Education, vol. 71, 2016, pp. 195-208. https://doi.org/10.1007/s10734-015-9896-4 https://eprints.gla.ac.uk/107084/1/107084.pdf

[22] T. Lubicz-Nawrocka Tanya, "Co-Creation of the Curriculum: Challenging the Status Quo to Embed Partnership," Journal of Educational Innovation, Partnership and Change, vol. 3, no. 2, 2017. https://doi.org/10.21100/jeipc.v3i2.529

[23] "The Changing Landscape of Disruptive Technologies," KPMG International, 2018. https://assets.kpmg.com/content/dam/kpmg/pl/pdf/2018/06/pl-The-Changing-Landscape-of-Disruptive-Technologies-2018.pdf

[24] A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari and M. Ayyash, "Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications, " in IEEE Communications Surveys & Tutorials, vol. 17, no. 4, pp. 2347-2376, Fourthquarter 2015. https://doi.org/10.1109/COMST.2015.2444095

[25] E. Mäkiö-Marusik, "Current trends in teaching cyber physical systems engineering: A literature review, " Proc. IEEE International Conference on Industrial Informatics, 2017, pp. 518-525. https://doi.org/10.1109/INDIN.2017.8104826

[26] D. Gustafsson,"Analysing the Double diamond design process through research & implementation," MA Thesis, Aalto University, 2019. https://aaltodoc.aalto.fi/items/3a6b3fa8-14a4-4b39-809f-cf31ab66c17c

[27] G. Bardaro, A. Antonini and E. Motta, "Robots for Elderly Care in the Home: A Landscape Analysis and Co-Design Toolkit," International Journal of Social Robotics, vol. 14, 2022, pp. 657–681. https://doi.org/10.1007/s12369-021-00816-3

[28] J. Lee, "Flipped Learning," in: O. Zawacki-Richter and I. Jung (eds.), "Handbook of Open, Distance and Digital Education," pp. 1179-1196, 2023. https://doi.org/1179 10.1007/978-981-19-2080-6_69

[29] "Criteria for Accrediting Engineering Programs, 2024 – 2025," Accreditation Board for Engineering and Technology, 2024. https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2024-2025/

[30] "Council Recommendation of 16 June 2022 on a European approach to micro-credentials for lifelong learning and employability," Official Journal of the European Union, 27.06.2022.