

Interconnecting Education and Research through International Partnership: IoT Case Study

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Abstract—The university attempts to meet two basic needs for society: education and research. In most cases these roles are separated. Undergraduate (Bachelor) and graduate (Masters) students are focused more on education while the research is designated for post-graduate students. This paper shows how education and research can be interconnected through students' engagement in research carried out at the university. Such activity can be funded by various national, EU and non-EU grants that support international partnership and encourage universities to improve student competencies through student research. The paper discusses the gap between research and education in the universities, and provides a case study showing how this issue can be tackled using student research teams participating in scientific projects. The study is demonstrated with the joint IoT research project realized by two universities in the Czech Republic and South Korea from 2016 to 2018.

Index Terms—technical education, learning outcomes, IoT, Internet of Things, network security, remote lab, internship

I. INTRODUCTION

One of the major challenges in technical university education is how to endorse students' interest in the research. The university stands on the highest rank of the educational system. Its primary roles are providing the education and training for the students and also participating in research and innovation. This concept comes from Wilhelm von Humboldt's vision *Einheit von Lehre und Forschung* (the unity of teaching and research) that saw teaching and research as two inseparable missions [1]. This is especially important for technical universities which play a key role in the production of new knowledge, technologies and development.

Unfortunately, students of technical universities are not given many opportunities how to participate in university research and development during their studies. It is true that most students are focused on immediate results as passing the courses rather than on searching for new opportunities and intellectual growth that goes beyond the standard curriculum. The university often lacks a systematic approach how

to engage searching undergraduate or graduate students and redirect their effort and enthusiasm towards the research and innovations.

This is partially because of political push towards mass tertiary education as stated in the Europe 2020 Strategy [2] which aims to increase the percentage of European population who have completed their tertiary education to at least 40% by 2020. The serious weakness of this goal is that without adding a quality, it is not possible to meet the requirements that are so crucial for future labor markets. On the other hand, the European Commission's 2020 strategy names research and innovation among the five key targets of the European priorities [3]. This intention seems to be opposite to the mass tertiary education request which focuses more on quantity than quality of the education and which gives teachers less space for individual guidance of the students in the research area.

This paper tackles the issue and shows how education and research can be interconnected through student research teams which promote students' higher cognitive skills as described by Bloom's taxonomy [4]. It builds upon the successful project *TeamIT - Building Competitive Research Teams in IT, 2009-2012*¹ that supported junior research teams at BUT. This paper extends the idea through international partnership.

The paper presents a good practice of co-operation between two universities: Brno University Technology (BUT), Czech Republic and University Hallym, South Korea. It also gives an overview of available funding that help establishing international partnership between universities and involving students in joint research projects. Of course, some practices mentioned in section III are country-dependent and, thus, generally non-transferable. Despite of that, we believe that this study helps universities to utilize available programmes to foster interconnection between education and research.

¹See <http://www.fit.vutbr.cz/~matousp/grants.php.en?id=442> [June 2018]

A. Towards Higher Learning Outcomes

The quality of university education can be measured by various criteria [5]. We can evaluate the quality by the number of graduate students, by an amount of the university budget received from research agencies, by a number of published research papers with high IF score, etc. These criteria evaluate the university from the institutional perspective.

When moving our perspective from the institution to students, the quality of the university can be assessed by measuring the learning outcomes reached by students during their study programme. The *learning outcomes* define what an individual knows, understands and is able to develop. The level of mastery in reaching these outcomes can be expressed using six categories of the revised Bloom's taxonomy [4], see Table I. Each category represents what the learner should be able to achieve at the end of a learning period. The taxonomy defines skill levels of increasing complexity, progressing from simple ones—remember, understand, apply—to more complex ones—analyze, evaluate, create. The complex outcomes can

TABLE I
BLOOM'S REVISED TAXONOMY OF THE LEARNING OUTCOMES IN THE COGNITIVE DOMAIN

Cognitive Level	Description
Remember	Retrieving relevant knowledge from long-term memory: recalling, recognizing.
Understand	Construct meaning from instructional messages, including oral, written, and graphic communication. It includes interpreting, exemplifying, classifying, and summarizing.
Apply	Carrying out (executing) or implementing (using) a procedure in a given situation.
Analyze	Breaking material into its constituents parts and determine how the parts relate to one another and to an overall structure of purpose. This activity includes differentiating, organizing, and deconstructing.
Evaluate	Making judgments based on criteria and standards. It includes checking and judging (evaluating).
Create	Putting elements together to form a coherent or functional whole, e.g., a new pattern or structure. It includes hypothesizing, designing, and constructing.

be partially met by diploma project (or MSC. theses) when an individual student analyzes a non-trivial problem, proposes a solution, designs and implements the system, and evaluates the result with respect to existing systems. The work is supervised by a professor who motivates and directs the student during his or her activity.

A diploma project is often a short-term activity, limited to one year. After successful finishing the project, a student usually leaves the university with the degree. Unfortunately, the student mostly leaves the area of research.

B. Student Research Activities

One way how to motivate students towards the life-long research is to involve them in ongoing university research projects during their studies. Even undergraduate students can

employ their enthusiasm, skills and ideas in the research under the supervision of matured researchers. From the perspective of the university, such process requires a good and systematic strategy that is not focused on immediate results only but is a part of a long-term strategy that interconnects researchers and students. Implementation of the strategy may include the following activities:

- 1) Finding the relevant and interesting topic for student research.
- 2) Defining scope of the research and challenges to be solved.
- 3) Proposing the strategy for the solution.
- 4) Creating research teams, defining the roles and responsibilities of team members, setting milestones and deliverables.
- 5) Working on the solution, evaluating progress, updating deliverables.
- 6) Presenting the results on a student conference or in a student research journal.

By implementing the strategy, the university offers an additional value for such students. Naturally, such a strategy cannot be applied to every student. However, the university should offer such opportunities for its curious and searching students.

The benefit is obvious. Unlike a diploma project that focuses on individual work of the student, young research teams improve students' competencies as collaboration, team working, responsibility, presentation skills, discussing possible solutions, etc. When implemented in the international environment, language, social and cultural competencies are added.

The following text shows how the strategy is implemented in BUT and Hallym.

II. HOW TO MOTIVATE STUDENT RESEARCH

This section gives an overview of national and international programmes, and other activities that promote the student research, team work, international partnership and mobility. The goal of this overview is to present a way how research and education can be interconnected in practice. Some programmes and activities mentioned here are country- or university-dependent, other programmes and activities are available for EU or also non-EU country.

A. Research Programmes and Activities

The following research programmes and activities in respective countries can be employed in the field of electrical engineering, computer science and informatics.

1) South Korea:

- *The Korea Institute for Advancement of Technology* (KIAT) was established under the Industrial Technology Innovation Promotion Act to efficiently and systematically promote industrial innovations and to support policy development in industrial technology. KIAT focuses on research and development programs with a focus on collaboration and knowledge exchange. KIAT supports research and development through grant project funding.

- *The National Research Foundation (NRF)* provides funding under the Young Researcher Program. Under this and similar funding schemes, the NRF supports young researchers in initial research projects in Korea. The project must be supervised by a senior researcher in a Korean Institution.
- Most Universities in Korea offer research staff internal research funding. These are relatively short-term projects proposed by the research staff. The funding is normally enough to cover the cost of materials, however, funding part-time staff, especially undergraduate level researchers, is possible.

2) Czech Republic:

- *The Technological Agency of the Czech Republic (TA ČR)* is a national organization run by the Czech Government that implements the state policy in the sphere of applied research, development and innovations. It developed a set of subsidy programmes that are thematically specified or unspecified and that focus on system areas and horizontal objectives of research, development and innovation policy.

Programme *Delta*² supports collaboration in applied research and experimental development through joint projects of enterprises and research organizations by promoting bilateral and multilateral collaboration of leading Czech and foreign participants. The projects must respond to the current and future needs of the country defined in the National research priorities.

The call for proposals is announced once per two/three years for specified countries (e.g., East Asia countries and China, Russia, West European countries, etc.). The funding covers junior and senior researchers, equipment and mobility. The maximum duration of a project is mostly 3 years. Projects shall be prepared with industrial partners on both sides and focused on outcomes that are put in production.

- *Specific University Research*³ is a national research programme that encourages student research activities in cooperation with academic staff in the area of research and development. The aim of this programme is to strengthen the quality and efficiency of the research, development of interdisciplinary education for graduate and undergraduate students, and the support of international relations in the research.

The call for proposal is announced by an university every year for one-year PhD. student projects or three-year standard projects. These projects support research of undergraduate and graduate students in the form of internships and research mobility.

B. Mobility Programmes

1) *ERASMUS+*⁴: is an EU programme in the field of higher education that supports mobility of individual, cooperation

²See <http://www.tacr.cz/index.php/en/programmes/> [June 2018]

³See <http://www.msmt.cz> [in Czech only, June 2018]

⁴See <https://ec.europa.eu/programmes/erasmus-plus/> [June 2018]

for innovation and the exchange of good practices. The programme includes student mobility (studying or training) for 3 to 12 months and academic staff mobility (teaching or training) at a partner institution abroad for 5 days to 2 months.

Unlike Erasmus programme, Erasmus+ is not limited to EU countries only but it also supports mobility in partner countries outside EU. An university that wishes to participate in the programme submits an online application to the National Agency of the relevant country. Duration of a mobility project shall be between 16 to 26 months. The funding covers mobility expenses including traveling and living costs.

2) *ASEM DUO Fellowship Programme*⁵: is a mobility program that supports exchanges of professors and students in tertiary education field between Asia and Europe under ASEM (Asia-Europe Meeting) domain. In this case, *DUO-Korea* programme offers student exchanges between Korea and EU for one semester (4 months). Participants shall be national students enrolled at the home institution who will move for one semester to a host institution. The programme provides funding of 4,000 Euros per student for the semester.

3) *International Mobility of Researchers*: is a Czech mobility programme funded by the Ministry of Education that supports post-doc and senior researchers arriving to the Czech Republic and junior and senior Czech researchers going abroad. Duration of mobility is from 6 to 24 months.

4) *Korean/Hallym Mobility*:

- Korea offers a number of research fellowship and visiting researcher programs. Many of these programs are supported by the Korean government in partnership with selected Korean Universities.
- Korean Government Scholarship Program (KGSP)⁶ supports international cooperation by inviting talented international students to conduct undergraduate or graduate studies in South Korea.
- Study Abroad Scholarship Program (SAP)⁷ supports, normally undergraduate, students at Korean Universities to study abroad. SAP programs are offered by the Government as well as within universities. For example, the School of Global Studies at Hallym University has a school-funded, mandatory study abroad requirement for graduation.
- Foreign Government Scholarship Program⁸ is a program to help Korean Nationals experience other cultures through academic exchange. These programs are normally funded by foreign governments and negotiated through the National Institute for International Education (NIIED) in Korea.
- Hallym University also provides researcher and staff exchange on an ad hoc basis. The Legal Informatics and

⁵See <http://www.aseduo.org/index.php> [June 2018]

⁶See <http://www.niied.go.kr/eng/contents.do?contentsNo=78&menuNo=349> [June 2018]

⁷See <http://www.niied.go.kr/eng/contents.do?contentsNo=83&menuNo=354> [June 2018]

⁸See <http://www.niied.go.kr/eng/contents.do?contentsNo=82&menuNo=353> [June 2018]

Forensic Science (LIFS) Institute at Hallym University hosts undergraduate and graduate researchers from a variety of study backgrounds. The goal is to support cross-disciplinary research.

C. Publicity

A part of student motivation towards research can promote the results through publications and awards.

- Student research workshop *Excel at FIT*⁹ is organized by BUT every year. Student involved in research and innovations present their result in the form of presentations, posters, and demonstration. Student learn how to write a paper describing their own research, and how to present the result to others. All student papers are reviewed and top student works presented on the oral presentation. Besides, students demonstrate their result in the form of posters and live demos.
- Another way how to promote student research is through student research awards granted by several institutions:
 - *ACM IT SPY* is a competition evaluating successfully defended diploma projects of university students from IT.
 - *ACM Student Research Competition* sponsored by Microsoft offers undergraduate and graduate students to present their original research before a panel at ACM conferences.
 - *Werner von Siemens Award* for graduate and post-graduate student research in technical field.
 - *ABB University Award* for bachelor project, diploma project or PhD. theses in engineering.
 - University: Dean's Reward, Rector's Reward
- Similar reward systems exist in Korea. For example, excellent students present at student research conferences and seminars. Very motivated students are normally provided additional support in the form of after-school research projects. Often, these projects have a corresponding payment or salary. Korean citizens within LIFS are also provided additional study support to apply for the Korean Government's Best of the Best Information Security Program.
 - Within the LIFS research group we are experimenting with a badge-reward based system for individual accomplishments.
 - Hallym University excellent student award for all around academic achievement.

III. CASE STUDY: IOT SECURITY MONITORING

This part describes a joint research project IRONSTONE¹⁰ where researchers and students of BUT and Hallym participate. The goal of this projects is to provide a novel solution for security monitoring of industrial IoT systems (e.g., SCADA networks) and home IoT networks. The project includes the following activities:

- Create a testing lab.
- Emulate real-life events and communication.
- Gather and analyze monitoring data.
- Implement tools for data analysis and visualization.
- Propose and provide attack scenarios in lab environment. Identify, gather and analyze incident data.
- Identify and collect data relevant to digital investigations.
- Develop scenarios that simulate criminal behavior in IoT networks.

These activities have been transformed to short-term (6-12 months) deliverables that were solved by student research teams of both partner institutions. Solutions and results were shared and discussed among participants via collaborative tools: e-mails, shared document, code repository, Skype meetings, and mutual visits.

A. Examples of Student Research Activities

This section presents several examples of student individual or team projects that were solved as a part of the joint university research. The examples show variability of research activities and a list of competencies acquired by involved students which contribute to the higher learning outcomes as mentioned in Section I.

1) Classifying IoT honeypot data:

- *Goal:* Analyze a large dataset obtained from a IoT honeypot and identify possible attack traces.
- *Duration:* 6 months
- *Description:* A student was given a dataset of 9 GB with captured communication obtained from a high-interaction IoT honeypot within a year. The student processed the PCAP files, extracted suspected communication and applied IDS signatures of known attacks on them. Several attacks has been identified: HTTP bashdoor vulnerability, POODLE attack on SSL, SSH brute-force attack, SMB exploitation, etc.
- *Outcomes:* security report.
- *Acquired competencies:* advanced analysis of network communication, reading security articles, testing IDS sw.

2) Penetration Testing of IoT devices:

- *Goal:* Evaluate security of home IoT gateway using penetration testing.
- *Duration:* 6 months
- *Description:* A student created a testing topology in the lab that included D-Link Smart Home Hub with few IoT devices (PIR motion detector, camera, and alarm). Then he carried out a set of penetration tests on the gateway and communication between gateway and Internet, Fig.1.
- *Outcomes:* A list of discovered vulnerabilities according to CVE¹¹.
- *Acquired competencies:* understanding and using penetration tools, evaluating security threats, testing.

⁹See <http://excel.fit.vutbr.cz/> [in Czech only, June 2018]

¹⁰IoT monitoring and forensics, 2016-2019, see IRONSTONE project

¹¹Common Vulnerabilities and Exposures (CVE) database, see <https://cve.mitre.org> [June 2018]

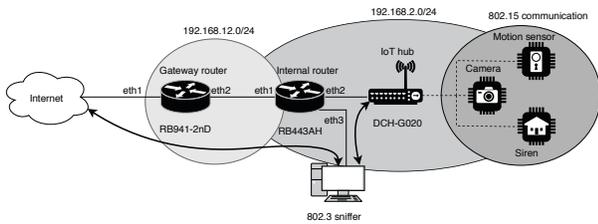


Fig. 1. Penetration Testing.

3) Emulation of Industrial IoT Communication:

- **Goal:** Create a dataset with attacks on SCADA devices.
- **Duration:** 6 months
- **Description:** A student evaluated a set of available software tools of IEC 104 or DLMS communication [6]. Then he created an application that introduced known attack patterns [7] into a captured communication, e.g., changed identifiers, data types, requests. The forged communication was tested against SCADA devices and security violations reported, see Figure 2.

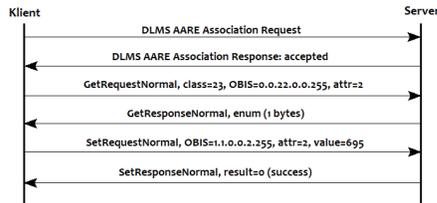


Fig. 2. Emulating DLMS communication.

- **Outcomes:** An software application that introduced attacks and provided penetration tests, an article at student research workshop.
- **Acquired competencies:** advanced data analysis, programming SCADA communication, security testing.

4) Security Monitoring of IoT Communication:

- **Goal:** CoAP security monitoring using IPFIX technology.
- **Duration:** 12 month
- **Description:** CoAP protocol [8] usually transmits data between home IoT gateway and IoT control center in cloud. CoAP communication was monitored using IPFIX. [9] that gathered metadata about the traffic. Students implemented a CoAP extension to the IPFIX probe and installed the probe in home IoT testbed in Hallym. Collected data were transmitted to a IPFIX collector in BUT via a VPN tunnel and analyzed using anomaly detection, see Figure 3.
- **Outcomes:** CoAP plugin, technical report, test report.
- **Acquired competencies:** plugin implementation, CoAP parsing, network configuration.

5) IoT Testbed in Hallym:

- **Goal:** Develop and implement an Internet of Things data collection testbed.
- **Duration:** 6 Months

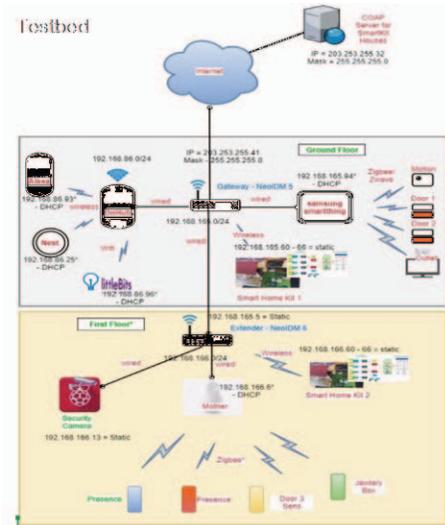


Fig. 3. Monitoring IoT Network

- **Description:** The goal of this project was to build a realistic IoT SmartHome network that allows researchers local access and an ability to simulate action scenarios. The researchers should have the ability to isolate and capture data at each network segment and, where possible, each device.
- **Outcomes:** The students planned and developed an IoT smart home in the LIFS laboratory. After installing and configuring each of the device,s the students created a script to simulate a murder in the IoT smart home. The students simulated the scenario and worked to identify and acquire related data in the IoT network. This scenario was released to the community, and is not a standard IoT dataset.
- **Acquired competencies:** network planning and development, IoT network configuration, IoT feature analysis, network investigation, documentation, device analysis, data acquisition.

B. Collaboration

The above mentioned examples of student research activities are part of the joint research projects between BUT and Hallym university. The project started in autumn 2016 and runs until October 2019. Table II shows how many students and researchers were participating on the project until now.

TABLE II
PARTICIPATION IN BUT-HALLYM JOINT RESEARCH IN 2016-2019

Participants	BUT	Hallym
Undergraduate students	2	5
Graduate students	2	3
Post-graduate students	1	1
Junior researchers	1	0
Senior researchers	3	2
Total	9	11

The following Table III shows number of visits on partner institutes within a duration of the project.

TABLE III
MOBILITY IN BUT-HALLYM RESEARCH BETWEEN 2016-2019

Dates of the visit	Place	Description
11–19 Nov 2016	Korea	Project signature, first meeting
4–11 Nov 2017	Korea	Installing the probe, data analysis
9–14 Oct 2018	Czech Rep.	Project meeting, presentations

IV. CONCLUSION

Universities generally provide opportunities for education and research. However, students often lack motivation. Carefully providing research and collaboration opportunities at undergraduate and graduate levels, allows students more of a sense of ownership in their education experience. By making "real" research projects available, students experience gain valuable insight into how their education can be applied to areas they are interested in.

Our projects have a focus on applied research and also international cooperation. Through exchange or study abroad programs, students have the opportunity to experience the thinking, processes and cultures of other countries. Also, by hosting external researchers and professors valuable experience and perspectives are brought to the laboratory.

Overall, providing funded research opportunities at the undergraduate and graduate level has helped give students additional knowledge and skills that is important in any future work they may do. Further, focusing on international cooperation has been a valuable tool to broaden the perspective of the students.

ACKNOWLEDGMENT

This work is supported by BUT project "ICT tools, methods and technologies for smart cities", FIT-S-17-3964, 2017-2019, and project "IRONSTONE - IoT monitoring and forensics", TF03000029, 2016-2019, funded by the Technological Agency of the Czech Republic.

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