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# Engaging Students in Cross-Disciplinary Research and Education – A Processual Approach to Educational Development

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***Abstract*** The creation of future sustainable and efficient energy systems requires a cross-disciplinary approach in engineering education. In order for energy-related engineering students to be prepared for real-world situations after their studies, it is important that, while they are still studying, they obtain the basic skills for handling different concepts, theoretical frameworks and solution types created in the various disciplines involved. At the Tampere University of Technology (TUT), a cross-disciplinary team was formed from four different departments in three different faculties to create a platform for research and education purposes on the university campus. The purpose was to coordinate research and provide students with a wider picture and a concrete implementation of the different layers and aspects that need to be taken into account when creating innovative solutions for future digital energy systems. The creation of the platform started from a successful student ideation competition that produced many viable solutions. This paper describes the bottom-up incremental process by which the cross-disciplinary platform was created. The innovative solutions created in the student ideation competition convinced the university organization that the cross-disciplinary collaboration should have a more permanent platform on the university campus, allowing researchers and students to incorporate more sustainability and systemic aspects into their work, and having a positive impact on the sustainable energy consumption on the campus.

## Introduction

The transition to renewable energy resources and optimization of energy usage is urgently required in society. This topic needs to be incorporated more effectively into engineering education programs on university campuses with on-site experimentation and research potential. Currently, the trend in the industry is that future graduates will have to work in cross-disciplinary teams and take sustainability into account, and thus it is important for students to obtain the required skills while they are still undergraduates (Aktas 2015). Traditionally, engineering education has focused only on the technical aspects of solutions, and the socially important environmental and human aspects have not been covered. If engineers do not consider the environmental and social impact of their solutions, there are very few professions that have the professional competence to do it for them (Cech 2014). Similarly, more and more students graduating from disciplines other than engineering need to understand engineering-related topics and the systemic changes that technological progression brings about. The role of engineers will be increasingly crucial when society is aiming to achieve the sustainability and energy efficiency targets set by governments worldwide (Tejedor et al. 2018). Finding solutions to reach the UN Sustainable Development Goals is an extensive global effort on which experts from different disciplines need to collaborate effectively. It is thus vital that students are taught effective collaboration and communication skills so that they are able to function in diverse teams and to solve problems by listening to and taking into account the ideas and needs of others, which may differ from their own, in order to create successful sustainable solutions (Savage et al. 2007).

Involving engineering students in projects that focus on solving real societal problems and challenges offers valuable opportunities for students to get practical hands-on learning. Faculties that research sustainability-related issues, and involve their undergraduate students in the projects, are helping the students to develop themselves professionally because, while doing service to the society, the students are finding solutions to problems that they will be facing later in their work life (Aktas 2015). A curriculum that covers sustainability-related issues helps engineering students to develop their communication and project management skills and develop cross-disciplinary solutions (Sharma 2017).

Engineering education should help to produce engineers who can rectify current sustainability problems, and prevent future ones from developing (Guerra 2017). Departments that work in the facilities of university campuses have an important function in promoting sustainability research in technical fields, because they have the required data for research (Aktas 2015). These departments can offer opportunities for students to learn and practice holistic and systemic thinking, to be critical and to work with real-life situations that promote responsible decision-making and professional practice (Guerra 2017). It has been stated that in engineering education there should be a more action-oriented curriculum, where the pedagogic approach is student-centered and experiential. Such learning pedagogies as place-based learning, inquiry-based learning, problem-based learning, discovery learning, case-based learning, and community-based learning have been suggested as good methods for giving students more opportunities to be active learners (Steiner and Posch 2006; Brundiers et al. 2010).

There is a growing demand for education in sustainability and sustainable energy that stems from the increasing awareness in society that universities will provide the future technicians and engineers who will be working within the emerging new technologies, for example in sustainable energy. Those universities that offer more energy-related education will attract the top students and get industry support (Nowotny et al. 2018). When introducing sustainability to university curricula it is important to collaborate with business (Kay et al. 2018). There is also a need for new study programs that cover the challenges posed by the energy transition – the problems are by nature multidisciplinary and complex, and the courses cannot be created in silos presented by single departments or laboratories. The advantages of cross-disciplinary research and studies are raised in the literature on engineering education. However, the cooperation of researchers and students on the same platform as a result of a bottom-up initiative offers a novel way to test and implement a new cross-disciplinary educational approach on a university campus.

This paper introduces the process whereby a cross-disciplinary platform was created for developing energy-related sustainability research. The process could be used as an example when developing a multidisciplinary platform for research projects involving students. At TUT, a Smart Grids Architecture Model (SGAM) framework was developed and implemented as a part of a research platform in the facilities of the university campus. The platform offers an environment for developing and testing different solutions for implementing sustainable energy production and consumption. For example, on the university campus solar panels are installed on the buildings and the production and consumption of energy can be tracked with an integrated control system enabled by Internet of Things (IoT) technology. This paper describes how the platform was developed from an initial collaboration between a few departments and later grew as more departments joined. In particular, the platform was designed to facilitate the boundary spanning competences, i.e., inter- and cross-disciplinary skills, which are increasingly important to engineering students. To date only a few studies have investigated this area (e.g., Prince 2004). In the beginning, the collaborative effort focused on awareness building among the students by arranging a student ideation competition. The paper introduces the very positive results of the competition and concludes with an account of the continuation of the collaboration between the participating faculties. Ultimately, the collaboration resulted in building a more permanent platform that offers multidisciplinary project work for students, together with faculty members and participating companies.

**Methodology**

This paper describes, in the form of a case study, the process of how a set of ideation competitions, arranged in 2013 and 2014 for cross-disciplinary project work among students, led to the creation of a cross-disciplinary research platform. The paper presents the outcome of the ideation competitions and the consequent setting up and organization of a research platform between 2015 and 2018 for cross-disciplinary research on the transition to flexible prosumer-oriented and renewable energy markets. The findings describe the rationale and design used in the development of the research platform and how it deals with various real-world layers and challenges. The conclusions are based on the lessons learned from the challenges faced and successes achieved in the development of the research platform.

**The Fresh Ideas Competition (FIC)**

The student ideation competition at TUT was implemented during two consecutive years, in 2013 and 2014. The idea was to create multi-disciplinary groups from different graduate programs in order to have a number of different approaches to the specific issues. Students were free to create groups, so a group could potentially have students from only one faculty or from several different faculties. Furthermore, all groups were given the same problem, but their focus varied based on the discipline. In the competition, the results of each group were analyzed by a specific jury based on predetermined criteria including, for example, viability of the technical solutions in practice and business opportunities. There were about 15-20 mostly cross-disciplinary groups comprising about four students in each competition.

In 2013, the competition was held in collaboration with a large company. There were three specific cases related to transportation of people and goods: an Electric Vehicle (EV) charging station, a Series Produced Charging e-Bus Stop, and a Multiple Purpose EV. The students were required to define the business concept, cityscape, functional design, traffic and information and energy systems. In this competition, cross-disciplinary groups dominated and the top three groups had students from different faculties including architecture, business, and electrical engineering.

In 2014, the competition was revised based on feedback from the earlier competition. This time the competition concentrated on energy efficiency and ecology in houses, living environments and buildings. Three partnering companies were included in the jury that selected the winner. Similarly to the previous competition, cross-disciplinary groups dominated.

The benefit of the ideas of students is that they are not sufficiently familiar with the current solutions, so they can start afresh and produce completely novel solutions based on totally new assumptions and thinking. This provides companies with new perspectives that help them to develop more innovative solutions. Multidisciplinary collaboration between students and business employees has been found to have a very positive impact on the students and their team cohesion, capability development, satisfaction, and performance, and the company employees also benefit from the collaboration (Kay et al. 2018).

The FIC competitions were considered an effective means for education purposes, and an efficient way for external stakeholders to gain valuable input. With these positive results, the cross-disciplinary group decided to proceed with the development of a research platform that would contain a truly cross-disciplinary group of domain experts.

**Development of the Smart Grids Architecture Model (SGAM)-based Research Platform**

The cross-disciplinary group of experts first held informal meetings after the competitions to coordinate efforts and plan joint activities. In these meetings, it soon became evident that the only way to proceed was to have joint projects, which gathered students and researchers together around research topics. Furthermore, it was considered paramount to have external stakeholders involved in setting the agenda, ensuring the sustainability and overall relevance of the research topics. Therefore, the experts devised a research project that was externally funded and involved key stakeholders from the energy sector.

The four laboratories launched a three-year research project called "Social Energy – Prosumer-Centric Energy Ecosystem (ProCem)" funded by Tekes (the national R&D funding organization). The main aim was to study the role of prosumers and the integration of various kinds of distributed energy resources in the electrical energy system. The IoT-based technology platform has been developed and demonstrated in the Kampusareena at Tampere University of Technology (TUT). The platform enables the study of roles, behavior, needs and requirements of prosumers and new kinds of business models and ecosystems in a new operational environment.

In this project phase, the platform itself was loosely organized to follow a Smart Grids Architecture Model (SGAM), where different disciplines represent different functional layers in the research and education of energy systems (See Figure 1). The SGAM consists of five interoperability layers that help to visualize the business objectives and processes, functions, information models, communication protocols and components (Keski-Koukkari 2018). The SGAM framework eases the analysis of use cases with its graphical representation and enables a detailed and a technology-neutral way to show the design of smart grid use cases for architectural purposes (Keski-Koukkari 2018). The SGAM framework was introduced by the Reference Architecture Working Group for the EU Mandate M/490 (CEN/CENELEC/ETSI, 2012).

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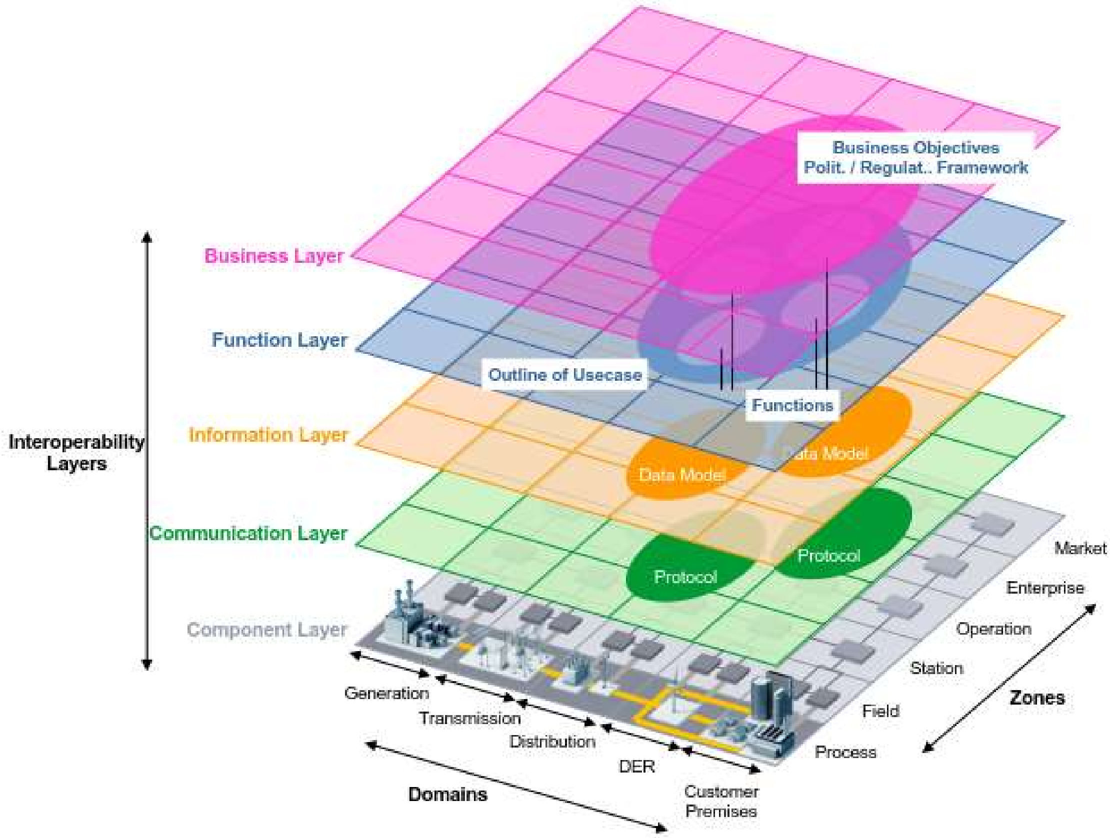


**Figure 1.** Layers in the future energy markets based on the Smart Grids Architecture Model (SGAM) Framework

One task of the project was to add more measurements in a pilot building at the university campus, namely Kampusareena, which represented the electrical network of the component layer of the SGAM model. We used next generation smart meters offering more than 150 measurements over three phases in 100 ms measurement accuracy. The other task was to integrate these measurements into automation and data management systems over the information network and systems layer. A data platform was developed for the purposes of the research. A commercial IoT platform, IoT-Ticket, was selected as the core of the platform. Use of that platform allowed us to create visual dashboards with minimum effort. This visual dashboard could be used to monitor and run various scenarios that were specified in the function and business layers.

The data platform was piloted at the university campus and it was used to collect sensory data from the newest building on the campus. The building was instrumented with a modern building automation system, which provided massively measurement positions. All the areas and rooms are equipped with temperature, $CO_2$ and humidity sensors. The automation system also provides information on the controls of the heating, cooling and ventilation equipment. For research purposes, the building is also equipped with additional sensors that measure the quality of electricity and electricity consumption of some devices, such as elevators and heat pumps for air conditioning. All the mentioned data are collected to the Linux gateway and such data that can be published are also collected to the IoT platform. Only data that are private (there are some companies on the campus buildings) are not published. The arrangement provides an exceptionally comprehensive office building data acquisition, which enables students to study how a building should be controlled and what the characteristics of energy use are in an office building.

Data were collected from several sources and with several sensors, thus we had to develop a gateway system running on a Linux virtual machine. This gateway implemented the necessary protocol conversions, data filtering, buffering and sending to the IoT platform. The data model was a key challenge for us. The design of the data model was driven by the anticipated use, available data and underlying principles of the IoT platform. The design was an iterative learning process with new data sources and needs being invented during the project. The cross-disciplinary nature of the project also added complexity, as the software team did not have prior knowledge about technical details related to electricity or to the modern energy markets.

The usability and applicability of data can be taken to the next level by data visualization and analysis. Data visualization, based on the platform data collection from various sources, was designed to raise public awareness of the use of renewable energy sources, air quality and the economic aspects of energy use at the university campus. Easy-to-read statistics can be displayed on large screens at a central location on the campus. The statistics included, for example, the percentage of solar power of total energy consumption, $CO_2$ levels in the campus meeting rooms, and savings due to self-consumption of solar energy. External information sources such as Nordpool spot energy prices and national weather forecasts, and solar irradiation information can also be added to further enhance the data interpretation.

Centralized data acquisition to an IoT platform is convenient for direct data refining and visualization and for post-processing of data for sustainability analysis. However, real-time analysis, for example for control purposes, has to be implemented on the component layer due to varying response times to queries over the Web. The IoT platform provides comprehensive tools for making visualization dashboards and some tools for data analysis. However, modeling, simulation, control and optimization studies, or deep data analysis based on the centralized data, are not possible in the platform. For this reason, data packages can be imported to external software from the database by using well-defined queries that utilize the Representational State Transfer (REST) Application Programming Interface (API) of the IoT platform. To be able to read data packages over the Web, the reader has to know the URL of the API and the complete data model. To lower the threshold for students in an undergraduate course, an example code in the form of a MATLAB script was written and demonstrated in data transfer. The target software type in this particular course was monitoring and control software, but the structure of the query is similar, independent of programming language. Queries over the Web always result in a varying response time, which implies that this data transfer solution is suitable for post-processing or soft real-time control.

The business layer was not at the center of the platform development process because the system was built within the university campus, mainly for research and education purposes. Therefore, the roles and responsibilities of different potential smart grid actors were conceptually investigated from the point of view of various disciplines, but not experimented with in practice. Instead, the approach of brainstorming and developing business concepts, initiated in the FICs, was continued in two workshops. In addition to researchers and graduate students from the university, members of collaborating companies participated in these workshops. The first workshop involved brainstorming about business opportunities that could be enabled in buildings, virtual power plants and microgrids with blockchain technology. The second workshop looked at harnessing electric vehicles as connected, mobile and flexible storage resources related to the grid. These workshops were useful in the sense that they allowed participants to look to the future and explore the elements and processes that these emerging technologies could bring. The results of the workshops showed that, while there is a lot of potential in using electric vehicles and blockchain technology for value creation, there are many uncertainties and risks related to the monetization of these services. The workshops were designed so that the current regulatory framework did not pose a barrier to the ideation. However, discussions also included how a regulation supporting dynamic pricing and wide participation in energy markets plays an important role in the development of these technologies and a sustainable energy system. These workshops form a benchmark for future workshops to be included in undergraduate courses and projects.

The SGAM model enabled the use of a common language for researchers and students from different disciplines when determining use cases, for example, for realizing the flexibility of prosumers in the electricity market. These use cases were used in determining the architecture for the common platform. Furthermore, SGAM was helpful in directing the efforts of the cross-disciplinary group.

**Issues and challenges of the cross-disciplinary team**

***The challenges of the data model are multidimensional***. This was predicted by the SGAM framework as it highlights the different dimensions involved. Obviously, one of the first challenges was finding a common language and reducing the misunderstandings of existing topics between the experts in different fields. It took time to achieve understanding between the experts on IoT data models (information layer), energy systems (component layer) and energy markets (business layer), before a suitable data model could be designed. The designing of the data model required answers to many questions, such as: What do we need to measure? How precise do the measurements need to be? How often do we need to measure? Where do we need to measure? How do we track physical locations to measurements? How do we need to access the measurement data from the engineering, customer and market stakeholder perspectives? What kind of legislation is there? In addition, the selected IoT platform set a template that the data model had to fit into. This required further discussion between the experts, as the most obvious solutions were not always possible to implement, hence the IoT data model experts were not able, by themselves, to solve the issues between the IoT platform template and the requirements coming from the component and business layers. Therefore, we argue that having a framework such as the SGAM about the field of research, before diving into the cross-disciplinary project, is useful for predicting where and by whom the communication should happen, and where to expect practical problems to rise.

***The virtual research team is distributed across the campus.*** The researchers and post-grad students represented different laboratories from three different faculties. Their work desks were located within their own research groups, which meant that the project was executed in a distributed fashion. The working cultures in different research teams were reasonably similar, but the distribution added clear communication challenges. We addressed these challenges with weekly project meetings, a common mailing list and collaboration tools based on Confluence Technology.

***The cross-disciplinary nature of a project slows its progress.*** The project team included people from five research areas. Although the overall goals of the project required contributions from all teams, research themes – for instance subjects of ongoing doctoral thesis topics – in individual research groups were separate. This meant that a lot of discussion was required just to achieve common ground, understanding and terminology. For example:

- Experts in the IoT data platform did not understand the technical constraints in building automation.

- Experts in embedded systems and building automation did not have experience in the challenges of data modeling required in data platforms used for storing the information.
- Data usage in traditional automation and control is very different from data analysis used in "big data"-style approaches.
- The information technology team did not have any prior understanding about the required measurements or electricity markets in general.

In addition, the cross-disciplinary results are difficult to publish in the typical research forums.

**Conclusions and discussion**

The research platform has created a smart energy system on the university campus, combining energy, automation and IT networks with real functionalities used for simulating the business environment and for research and education purposes. Furthermore, the IoT platform can be used to design open access for students to various sources of sensor data. This can be used in various technical courses, project courses, cross-disciplinary problem solving courses, entrepreneurship courses for developing new innovations, etc.

The cross-disciplinary competitions that resulted in new solutions and innovations used by the companies were the initial trigger for the practical potential of cross-disciplinary research and education. This led to the initial interest of professors from different disciplines in forming a loosely organised group for planning possible activities and getting to know the expertise in different departments and faculties. In these discussions, it became evident that a common research platform was needed to proceed with joint project applications, where the activities of various parties would be aligned. Furthermore, the interest of external stakeholders was also considered vital in these applications. Hence, the platform for cross-disciplinary collaboration has resulted in multiple projects, conference papers, seminar presentations, journal articles, courses and opportunities for students to engage in research and cross-disciplinary teaching.

All this started with a bottom-up process by researchers and teachers in different fields coming together and starting to investigate opportunities for fruitful collaboration. The collaboration is integrated with competence-based curriculum development that is simultaneously accomplished at the university level and that is coordinated as a top-down approach, facilitated by the university's education support team.

When students have the opportunity to participate in cross-disciplinary research initiatives, they acquire a better understanding of the larger context of problems, which are closer to the kinds of problems they may need to solve later in their work life. Furthermore, the student experiences were very positive in terms of learning boundary spanning skills that deal with topical areas outside of the core engineering curriculum of the respective subject matters of educational programs. Sustainable development necessitates the adoption of cross-disciplinary approaches in problem solving, both from the tools perspective as well as having a cross-disciplinary team with members from different backgrounds (Aktas 2015).

The research platform we have created for investigating future energy markets offers an educational environment that provides problem-based learning, inquiry-based learning, discovery learning, case-based learning, and community-based learning, all of which help students to develop the skills to work in cross-disciplinary teams that have complex sustainability-related problems to solve in the energy sector. Naturally, as our empirical context is one case organization, it has numerous limitations that are inherent in all case studies, such as context specificity, a limited amount of data by scope and temporal duration, a limited number of stakeholders involved, etc. Hence, generalization of our findings should be implemented with caution. However, the process of how the research platform was organized exemplifies the power of the bottom-up build-up of new practices: the initial positive results from student competitions; experts in different fields showing an interest and willingness to learn from each other's competences; loose and interest-based initial organization and planning; fluent shifting to the formal project planning phase with the aid of earlier informal organizing; and finally, the execution of projects monitored and verified by external stakeholders to ensure the relevance of the solutions to industry and business.

## References

Aktas, C. B. (2015). "Reflections on interdisciplinary sustainability research with undergraduate students". International Journal of Sustainability in Higher Education, 16, 3, 354-366.

Brundiers, K., Wiek, A. and Redman, C. (2010). "Real-world learning opportunities in sustainability: from classroom into real world". International Journal of Sustainability in Higher Education, Vol.11, No.4, pp.308-324.

Cech, E. A. (2014). "Culture of disengagement in engineering education?" Science, Technology, & Human Values, 39(1), 42-72.

CEN/CENELEC/ETSI (2012). Joint Working Group on Standards for Smart Grids, "CEN-CENELEC-ETSI Smart Grid Coordination Group: Smart Grid Information Security," November, pp. 1–107.

Guerra, A. (2017). "Integration of sustainability in engineering education: Why is PBL an answer?" International Journal of Sustainability in Higher Education, 18(3), 436-454.

Kay, M.J., S.A. Kay, and A.R. Tuininga. (2018). "Green Teams: A Collaborative Training Model". Journal of Cleaner Production 176, 909–919.

Keski-Koukkari, A. (2018). "Architecture of Smart Grid Testing Platform and Integration of Multipower Laboratory". Master's Thesis, Tampere University of Technology.

Nowotny, J., Dodson, J., Fiechter, S., Gür, T. M., Kennedy, B., Macyk, W. and Rahman, K. A. (2017). "Towards global sustainability: Education on environmentally clean energy technologies". Renewable and Sustainable Energy Reviews. June 29.

Prince, M. (2004). "Does active learning work? A review of the research". Journal of engineering education, *93*(3), 223-231.)

Savage, R. N., Chen, K. C. and Vanasupa, L. (2007). "Integrating project-based learning throughout the undergraduate engineering curriculum". Materials Engineering, 1.

Sharma, B., Steward, B., Ong, S. K., and Miguez, F. E. (2017). "Evaluation of teaching approach and student learning in a multidisciplinary sustainable engineering course". Journal of Cleaner Production, 142, 4032-4040.

Steiner, G. and Posch, A. (2006). "Higher education for sustainability by means of transdisciplinary case studies: an innovative approach for solving complex, real problems", Journal of Cleaner Production, 14, 877-890.

Tejedor, G., Segalàs, J., & Rosas-Casals, M. (2018). "Transdisciplinarity in higher education for sustainability: how discourses are approached in engineering education". Journal of Cleaner Production, 175, 29-37.

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