Project Work and Project-Based Learning to Support Engineering Education: A Demo on Energy Storage

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***Abstract*—To meet future challenges related to climate change and the ongoing energy transition, the implementation of new energy technology will be needed worldwide. The industry counts on new talents and content for this to happen, which in turn motivates the education in the energy field to be developed. However, the resources available for creating new education are often poor. This puts a lot of stress on the education system, including higher education. Especially those educational programs that require specific environments, technologies, and equipment for practical learning, are dependent on adequate economical support. Consequently, various innovative ways of supporting education are therefore more than welcome. In this work, we show how the result of an energy storage project can be used to support engineering education. Within the same project, the Project-Based Learning (PBL) pedagogy has been implemented for several students in their final studying year. The energy storage project focused on here aims to build up various demos on energy storage technologies that will be available for students and research personnel in the Vaasa region, Finland. The project is discussed briefly as a whole, whereafter the demo on Phase Change Materials (PCM) is presented more thoroughly.**

***Index Terms*—engineering education, project work, project-based learning, demos, energy storage technologies, phase change material**

I. Introduction

The Higher Education (HE) sector has during the last decades been subjected to various mechanisms to make it more cost-effective and productive. Based on numerous discussions in the social, political, and economic arenas, the reshaping of HE has been a focus for improving the welfare of the states. Governments have consequently utilized multiple approaches to increase the quality and improve the performance of their HE system. One method has been to introduce the performance-based financing (PBF) model to regulate the financial resources of the HE sector. In many European countries, PBF mechanisms are utilized to fund the HE sector [1]. This means that the state allocates funding for the universities based on several indicators, achievements, and performance outcomes. The universities in Finland are likewise funded by a PBF model, which is based on the success of various performance criteria. Performance-based elements have been part of the Finnish university system since the early 1990s [2]. A study on how the funding structure has influenced the Finnish universities between the years 1994 and 2005 has been conducted [3]. Here, it was demonstrated that the funding schemes had influenced the Finnish universities in different ways. Some universities had focused on traditional research, others had emphasized applied research, and a third group had focused on education functions. Furthermore, a major finding in the study was that the university research performance had been weakened during that period, probably due to the increased teaching load and the research moving towards applied sciences, etc. The Universities of Applied Sciences (UASs) in Finland faced a change in their funding structure from a cost-based funding scheme to a PBF model during the period 2012 - 2018. This revision increased the productivity and efficiency of the UASs, but the change also emphasized the importance of gaining increased external funding [4]. The present financing models (2021 - 2024) for the Finnish universities and UASs are publicly available. For the universities, 42% of the core funding is based on indicators from education (including degrees), 34% from research (e.g. publications), and 24% from other education and science policy considerations (e.g. strategic funding) [5]. Within the research category, competed external financing (e.g. Academy of Finland and Business Finland) is included as an indicator and consists of 12%. This shows that funding from external sources is a crucial part of the overall governmental resource allocation model in Finland.

A. Projects and Project Work, and Their Implication in Higher Education

A project can be defined as a process that will result in a service, a novel product, or an action. For a project to be regarded as a success, several key factors need to be fulfilled. In short, the project needs to be performed on time, the budget needs to be kept and the promised outcome needs to be delivered. Hence, the definition of

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scope, risk assessment, project scheduling, budgeting, and maintaining momentum are all essential elements for a balanced and lucrative project [6]. There are both benefits and drawbacks to running a project. On one hand, projects can enable additional personnel or other resources for studying original ideas that would never be possible under normal circumstances. On the other hand, since projects often are time scheduled, the continuing of the work done after the project end can be unsure or the project outcome is not possible to implement because of lack of resources after the project period. Even so, governments, municipalities, private organizations, and educational institutes are regularly involved in various projects to address all the challenges and issues that society is facing today.

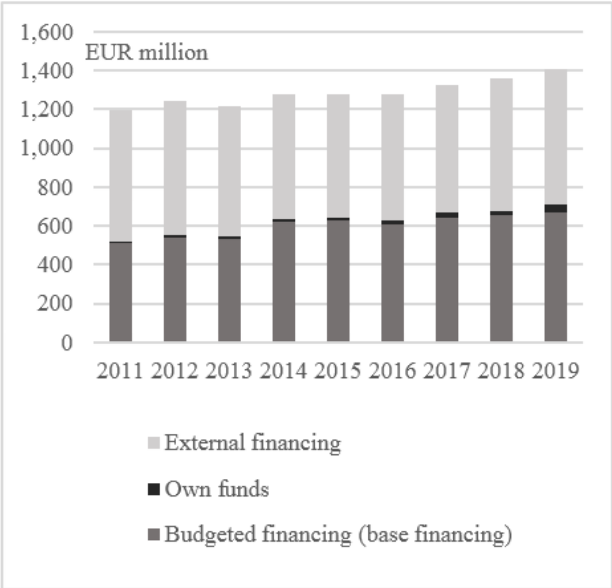

Figure 1. The distribution of research financing at Finnish universities between the years 2011 - 2019, data from [14].

Different kinds of externally financed projects are routine within universities, also in Finland. Through these funding instruments, research is conducted, cooperation between various partners is initiated and novel products are developed. Consequently, the majority of research groups are therefore nowadays continuously applying for new projects and these will function as a means for financing post-doctoral research, but also for scholarships/salaries for Ph.D. students. During the 1990s, the external financing within the universities in Finland showed significant growth [3]. The importance of external funding has continued to apply during the last years. Table I shows the amount and sources of external financing for research at universities and UASs in Finland during 2016. From these data, it is evident that external financing tools are important within the universities and the UASs. For the universities, the Academy of Finland (44.6%) and Business Finland (former Tekes) (15.9%), are contributing to a larger part of external research funds. On the other hand, the UASs are gaining a large share of funds from Ministries and municipalities (36.4%) but also from EU structural funds (32.1%). The volume of funds from EU structural funds within the universities is minimal (2.2%). Fig. 1 displays the distribution of gained research funding for the universities in Finland during the years 2011 - 2019. The total received research financing has increased during the last years and was about EUR 1400 million in 2019. The volume of external financing is marginally higher than the base financing.

In a study performed on six countries in Europe, it was concluded that project-funding has increased from the 1980s and forward and is the second-largest allocation instrument for public research funding [7]. Although external grants are generally gratefully acknowledged in research, dilemmas might arise. The drawbacks of project funding on research have been studied [8]. The authors have analyzed and compared two different types of research funding, prizes and grants, and have looked at how these funds are affecting the epistemic properties of academic research. The results show that research grants, which often are selected from project proposals, are less flexible and have larger constraints on epistemic innovation than prizes that are awards with no explicit plan of how to use the money.

TABLE I. SOURCES OF RESEARCH FINANCING AT UNIVERSITIES AND UNIVERSITIES OF APPLIED SCIENCE IN FINLAND 2016, MODIFIED FROM [9]

	Unit	Universities	Universities of applied science
Direct base financing	M €	626	65
Own financing	M €	20	0
External financing, of which	M €	648	77
Academy of Finland	%	44.6	0.9
Tekes[1]	%	15.9	10.5
Ministries, municipalities, and other domestic, public funding	%	8.5	36.4
Funds; Domestic and foreign	%	8.8	5.1
Companies; domestic and foreign	%	8.5	9.4
EU research funds	%	9.6	4.9
EU structural funds	%	2.2	32.1
Other foreign funding	%	2.0	0.6
Research funding, total	M €	1,294	142

[1] Tekes – the Finnish Funding Agency for Technology and Innovation. Changed its name to Business Finland in 2018.

Project courses or students assisting in projects are regularly utilized in all stages of education. Project-based learning (PBL) is a student-centered educational tool that familiarizes the students with real-life problems in a process that culminates in an end product [10]. With this method, students are believed to gain a deeper conceptual knowledge, be more active, have a higher learner motivation, and develop skills in both teamwork and leadership. Especially in the engineering curricula, projects have been employed by the universities to move towards the industry and their current problems. Implementations of PBL in engineering courses have been demonstrated in several studies and the results are regarded as successful [11]–[13]. Hence, learning through project work, independent of being an employed research assistant, project worker, or an unemployed student working in the project, is enormously rewarding.

External-funded projects, often with a strict plan as well as a budget and a schedule, might find their way into higher education and teaching. On one hand, higher education is obliged to offer the latest knowledge, technologies, and equipment for the graduates. On the other hand, the education sector is cost-sensitive, and the affordance within the HE is often governed by previous degrees and publications [3]. The time limit of projects might pose a problem for the education sector since educational programs are ongoing activities and are required to be like that to contribute to the high and secure quality within higher education. Thus, different ways of using project work as a tool for supporting education can be explored.

B. Industry and Engineering Education Intertwined

The industry, as the major future workplace for Bachelor ́s and Master ́s of technology (BSc and MSc (Tech)) graduates, has historically had a large impact on engineering education, and it still does. However, there have been some concerns raised that the knowledge of engineering graduates is not meeting the expectations of employers in the industry [15]. It is clear that an engineer is expected to possess strong basic skills in mathematics, physics, and chemistry [16] as well as some level of science-based specialization within a field of technology. In addition, personal skills (transferable skills), such as team working; problem-solving; self-learning; information technology (IT), numeracy and communication skills are highly appreciated competencies from an employer ́s point of view [17]. By analyzing two major surveys done on chemical engineering students [17], it was shown that the personal skills needed for employment often are insufficient, both perceived by the graduates themselves and by the employers. A review on how employability can be developed in engineering education has been presented [18]. Analysis of studies published between 2007 and 2017 demonstrates that technical competence is needed to overcome engineering problems and that professional skills including teamwork ability, project management competence, and social and political skills are highly welcome in industrial environments. How these two factors can be balanced and integrated is also further discussed in the review.

One way of accomplishing industry-university cooperation is through an "experience-led learning engineering degree", a concept that refers to the ability of the universities to teach the graduates several skills important for the industry, including operational, technical, and business skills [19]. A study has been conducted based on case studies from several universities in England regarding possible change drivers for improving experience-led learning experiences [20]. The results show that the different natures of the universities often dictate the fallout of the changes. However, several factors are crucial for implementing successful cooperation between the industry and higher education. These cover having academic staff with industrial experience, collaboration with engineers in the industry, and leadership from senior management, and the importance of these factors cannot enough be emphasized. Other successful tools for enhancing the relationship between academia and industry include different forms of industrial training, that is external internship programs [21], professional work placement and engineering research projects [22], and work-related learning [23]. Furthermore, as previously stated, different types of project-based learning approaches are essential in the interaction between the universities and the industry [11]–[13].

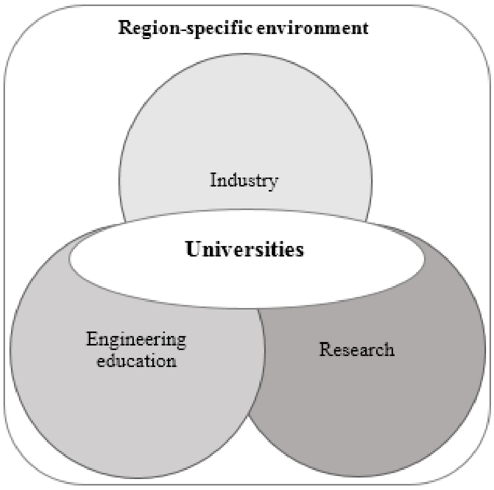

Figure 2. The relationship between research, engineering education, and industry, and the central role the universities possess in such cooperation.

In Finland, industry and engineering education have a long cooperation history. From the 18th century and forward, especially after industrialization, industrial stakeholders have collaborated well with research and natural sciences. This has contributed to a symbiotic relationship of funding opportunities, traineeships as well as completed Bachelor ́s and Master ́s theses [24]. Students at technical universities in Finland usually collect some of their credits from industrial training, and this portion is generally larger within the UASs than within the universities. Hence, the academia and the industry are keen on finding common goals, both regarding improving the necessary transferable skills amongst the graduates, but also from a regional point of view, by offering the students imperative knowledge that is of interest for both regional companies as well as for the educational programs. With this approach, the region would be ensured with enough competence to drive the society in the right direction. Fig. 2 displays how industry, engineering education, and research performed at universities can be interconnected in an environment that may be region-specific.

C. Laboratory and Demonstrations in Engineering Education

In the history of engineering education, there have been five major shifts that have emerged during the last 100 years [25]. These shifts are emphasis on engineering science; outcome-based accreditation; emphasis on engineering design; applying education learning and social-behavioral sciences research, and emphasis on information and computational technologies. Throughout these changes, the importance of practical and laboratory experiences has remained valid and strong. Still today, laboratory work has a central role in engineering education. Sometimes, due to reduced funding or financial resources, demonstrations are considered a good alternative to laboratory experiments [26], [27] or even a complete learning option compared to full-scale laboratory experiences [28]. The value of physical laboratories in science and engineering education is well recognized, and the competence learned from laboratory work and demonstrations are proposed to be multiple. The students learn how to solve a problem, to work in a team, and to communicate [17], but they also learn about unanticipated events and delays within experiments and get familiar with troubleshooting of machinery [29]. Fig. 3 summarizes several skills that can be learned from work in laboratories.

Engineering laboratories can be divided into three basic categories; developmental, research, and educational [30]. In this current work, the focus has been on setting up demo learning environments for educational and research purposes, intending to provide students and research personnel with competence in understanding the concept of different energy storage technologies. This study is a two-fold implementation of a project into the engineering curricula. Firstly, the project outcome will be a long-lasting element in the engineering education curricula. Secondly, the project has offered the students the possibility to work on a project within their engineering studies.

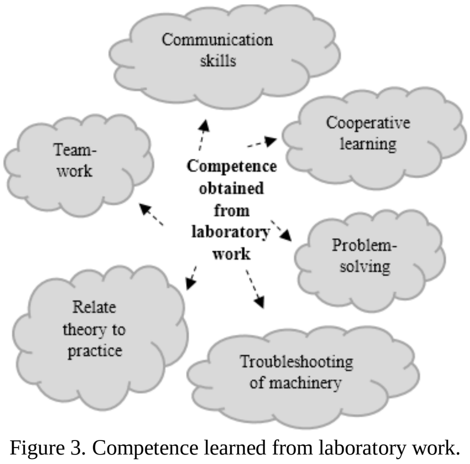

Figure 3. Competence learned from laboratory work.

D. The Ostrobothnia Region in Finland

In the west of Finland, beside the coast, resides Ostrobothnia with Vaasa as the main capital of the region. Ostrobothnia is often mentioned as the leading Energy Technology hub in the Nordic countries due to the possession of a vast amount of energy-based companies. Over 160 companies, with a workforce of about 25% of the employees of the Finnish energy sector, are based in the area [31]. Several large international companies, such as Wärtsilä, Hitachi Energy, and Danfoss Drives are all part of the flourishing environment in this energy sector. The potential of Ostrobothnia to utilize renewable sources in primary energy production has been discussed [32] and it is proposed that the region has a high potential for utilizing renewable energy sources (RES), in particular biomass, solar energy, and wind power. Biomass-to-energy (usually called bioenergy) is the main RES in Finland, and although the biomass potential is not as great in Ostrobothnia as in the central and eastern regions of Finland, a large amount of the energy demand of Ostrobothnia could be met by utilizing biomass from the region. There is high potential for solar energy in Ostrobothnia, especially during the summer months as it is one of the sunniest regions in Finland with over 1900 hours of sunshine annually. The long coastline of the region provides favorable conditions for wind power. As seen in Table II, a significant share (17%) of Finnish wind power capacity is operating in Ostrobothnia, and the region has the second largest number of planned wind power projects. It is thus clear that the region accounts for a large share of Finnish wind power capacity compared to its size, which is only about 2.6% of the area of Finland. The intermittent nature of wind and solar energy generation creates a challenge in matching the supply and demand of energy. The energy system requires more flexibility to integrate these variable RES, which energy storage can provide for, by storing energy when there is excess generation and discharging energy when there is a deficit. Possible storage technologies for this are batteries and storage of gas, via power-to-gas solutions (e.g. hydrogen).

TABLE II. INSTALLED AND PLANNED WIND POWER IN OSTROBOTHNIA AND FINLAND [33]–[35]

	Nominal power of operating wind turbines (MW)	Nominal power of planned wind turbines (MW)	Land area (km^2)
Ostrobothnia	433	N/A	7 752
Finland	2 586	21 408	303 892
Ostrobothnia's fractional share	17%	N/A	2.6%

Thermal energy storage (TES) is a technology that involves heating or cooling a storage medium so that the stored energy can later be utilized for heating or cooling [36]. There are three types of TES: sensible, latent, and thermochemical heat storage. Sensible heat storage relies on the specific heat capacity of a material, the heat that is stored when heating or cooling the storage medium. Latent heat storage relies on the latent heat absorbed or released when a material undergoes a phase change and thermochemical heat storage relies on storing and releasing heat from materials through reversible chemical reactions [37]. Currently, sensible heat storage is a commercially available solution, with water being the cheapest and most commonly used storage medium [36]. Latent heat and thermochemical storage solutions are still mainly in the research and development phase.

In Ostrobothnia, a significant amount of RES have been utilized so far, and their share in the energy mix of the region is set to increase in the future. Actors in Ostrobothnia have realized that there is a need for energy storage. In 2020, the utility companies EPV Energy Ltd and Vaasan Sähkö commissioned Finland's largest TES in Vaskiluoto in Vaasa. The energy storage consists of two caverns with a total volume of 210 000 m^3. The caverns were previously used to store oil but were repurposed into storing thermal energy by cleaning and filling them with water. The water in the thermal storage is heated up with water at 90 °C from the district heating grid of Vaasa and the TES has an energy capacity of 7–9 GWh and a charging/discharging capacity of 100 MW [38]. The recent commissioning of the sensible heat TES in Vaasa shows that TES is a technology relevant for the region. A large advantage TES has over electricity storage is cost. Sensible heat TES is about 100 times cheaper than electricity storage per unit of storage capacity [39]. Latent heat storage with PCMs does not have this cost advantage, it can be more expensive than sensible heat TES by a similar magnitude as electricity storage [36]. However, PCMs have the advantages of being able to store and release energy at almost constant temperature and having a higher energy storage density. PCMs can thus be useful for applications that require a constant temperature and/or a lower storage volume.

The creation and use of a demo environment on PCMs in education can strengthen the knowledge of thermal energy storage for energy technology students at Åbo Akademi University (ÅAU), as well as other students interested in energy storage in the region. One of the most common applications of PCMs is in the building sector [40]. A demo environment on PCMs may thus prove especially beneficial for construction engineering students at Novia University of Applied Sciences in Vaasa. Ref. [20] states that new teaching methodologies often require funding, appropriate learning environments, and supporting equipment and technologies. Hence, this work aims to demonstrate the accomplishment of a demo environment resulting from a project deliverable, which in the future will be considered a permanent element in the engineering curricula.

II. Methodology

A. *Background of the Educational Program and Justification*

The subject (cluster) of Process and Energy Technology at ÅAU in Finland is divided between two different cities, Turku and Vaasa. While the absolute majority of technical courses and the Academic staff reside in Turku in the south of Finland, the Laboratory of Energy Technology is located in Vaasa, about 330 km north of Turku. Hence, the 2-year [MSc(Tech.)] degree program in chemical engineering (specialization in Energy technology) in Vaasa enables a continuation of education for already graduated Bachelors in Technology. Most of the students have a BSc exam from Novia University of Applied Sciences (Novia), also situated in Vaasa. Therefore, the regional universities of applied sciences are a natural development partner for the Energy technology unit.

The subject of Energy technology in Vaasa is quite new (starting in 2011), and has to date around 30 enrolled students and has contributed to about 50 graduates. The need of developing new education, taking into account what kind of employee skills regional companies need in the future, begins to be more obvious. A survey mapping appreciated skills of young engineers was earlier conducted by interviewing several different stakeholders within different energy companies in the Vaasa region [16]. The findings from the survey showed that the regional energy technology companies are looking for technically competent graduates, especially students with an understanding of energy systems, as well as persons with skills in electricity, IT, English, and international communication. Hence, the mutual interest of ÅAU and the regional companies within the energy sector is to educate technically competent persons in the field of energy technology. To be a relatively new and small subject physically distinct from the rest of the engineering program puts some constraints on the subject itself. The possibility to offer the students and the research personnel advanced and modern technical equipment and research facilities is not always optimal. Consequently, innovative strategies regarding financial support, access to various facilities, and cooperation between different organizations, are often required to fulfill the academic responsibilities the university possesses. Therefore, the implementation of an energy storage project, that could be beneficial for educational purposes, was conducted.

In addition to ÅAU, there are several other universities with technical education programs in the Vaasa region. Some of these programs are physically converged in a building called Technobothnia, which aim is to contribute to a high-standard education and research in the field of technology [41]. To broaden the cooperation between the educational partners, and to address the important topic of energy storage in the region, the project "Energy storage in our future low carbon society" was launched and financing was granted by the European Regional Development Fund (ERDF) for 2018 - 2021 [42]. ÅAU, Novia, and Vaasa University of Applied Sciences (VAMK) are copartners in the project and the main aim was to build a demo environment on different energy storage technologies, that later would be open for educational purposes within the different universities, for researchers as well as for the industries in the region. In addition, since energy storage solutions have become more in focus during the last decade, there is a need to create a regional energy storage network and a platform of knowledge between the regional higher learning institutions and the industry. To gain a larger understanding of the need for energy storage solutions of the industry in the region, a steering group consisting of several regional companies and university members, was gathered and inputs were collected. Based on several discussions within the project team and the steering group members the demos were selected based on different criteria:

a) The input from industrial partners on important energy storage methods in the region;

b) Input from universities on methods that could fit the engineering curricula;

c) Taking into account the already available instruments in the Technobothnia building and the expertise within the different universities.

B. The Case Study: A Demo Environment on Thermal Energy Storage

Several different demos were selected within the frame of the project to introduce the concept of energy storage to engineering students. These included Pumped Hydro Storage (PHS), Compressed Air Energy Storage (CAES), battery technologies, flywheels, and TES methods. The project and the various demos have been previously briefly described in a project report [43]. As a form of conceptualization of TES, PCMs were selected since the research interest in PCMs and their potential applications have been increasing in recent years [44]. Solid-liquid PCMs were chosen to be the materials of investigation in the demo environment since they are the most commonly used types of PCMs. Before a latent heat TES system is designed, the thermophysical properties of the chosen PCM, such as latent heat, specific heat capacity, and the melting temperature must be known. Hence, the Temperature-history (T-history) method was selected to be implemented as the demo environment, as it is used for finding out these properties in PCMs using only basic inexpensive laboratory equipment [45]. The T-history method is still being researched and various researchers are still developing the method [44].

The learning objectives of the PCM demo were defined at the beginning of the development process and the following targets were set:

a) To illustrate the working principle of phase change material as an energy storage method
b) To develop a demo environment open for research personnel, companies, and students
c) To develop exercises and instructions for the experiment
d) To have a demo that is easy to run and maintain, is portable, and will not exceed 3 hours
e) To provide a safe environment for the students
f) To provide guidelines for the responsible teacher so it would be easy to instruct students

C. Description of the PCM Demo Environment

The setup of the demo environment's T-history method is largely based on the original method that was presented by [45]. In the method, several PCM samples can be analyzed simultaneously. Glass tubes are filled with PCM samples and one is filled with a reference whose thermophysical properties are well known. Water is used as the reference in this demo [44]. Thermocouples are placed in the center along the horizontal axis of the samples and the reference. The test tubes are placed in a water bath where they are heated to a uniform temperature above the melting point of the PCM, bringing the PCM samples into the liquid state. The test tubes are then removed from the water bath and exposed to an ambient temperature lower than the melting point of the PCM. The PCM samples and the reference cool down to a reference temperature below the melting point of the PCM, bringing the PCM samples back to the solid-state. The phase of the reference remains unchanged during the process. The temperature of the samples, the reference, and the ambient temperature are continuously recorded during the process and temperature-time (T-history) curves are obtained. On the condition of meeting some assumptions as described in [45], thermal energy balances can be formed for the samples and the reference. Since the thermophysical properties of water, the reference, are known, the T-history curves of the PCM samples and the reference can be used to evaluate the thermophysical properties of the PCM samples with the thermal energy balances.

For the demo environment, instructions are provided for three different calculation methods for the T-history method. The first calculation method described is the one used by [45], except with the slight modification of the equations as in [46], to allow for differences in volumes of the reference and the samples. The second calculation method described [46], is an improvement of the first calculation method. The improvements include accounting for the sensible heat during the phase change period and using the inflection point of the derivative of the T-history curve to mark the end of the transition from the liquid to the solid phase for the PCM. The third method described is the time-delay method where the thermophysical properties are calculated using an enthalpy-temperature curve [47].

III. Results and Discussion

A. The Demo Environment at the Technobothnia Research and Education Center

TABLE III. The Demonstration Environments in Technobothnia That Are Available for Educational and Research Purposes

	Energy Storage Method	Responsible organizations
Mechanical energy storage	CAES Flywheel PHS	NOVIA VAMK VAMK
Thermal energy storage	PCM Adsorption heat pump	ÅAU VAMK; ÅAU
Electrochemical energy storage	Batteries	VAMK

It is crucial that there are possibilities for practical laboratory experiences for engineering students since practical work enhances teamwork and communication skills, but also abilities that are necessary when planning experiments [17], [29]. To enable such an environment, a project regarding energy storage was executed within research and education by several educational institutions in Ostrobothnia. The demos in progress and the finalized demos in this project are shown in Table III. The demos on the flywheel, PHS, batteries, CAES and PCMs are finalized, while the demo demonstrating the function of the adsorption heat pump is still under construction.

Before the project started, it was noted that there was a lack of knowledge and relevant courses in the field of energy storage within education in the region. Since Technobothnia is an existing learning environment for collaboration and research in Vaasa where various higher education institutions and partners collaborate, it was decided that a new form of demo environment could be developed there. To our knowledge, this type of demo environment on energy storage, open for several educational institutions and industrial partners, is quite rare, especially in the Nordic countries.

B. The PCM Demo Environment

The setup of the PCM demo environment built at the Technobothnia is presented in Fig. 4. A more thorough description of the PCM demo can be found in [44]. As in the method in [45], a water bath is used for heating the PCM samples and the reference. The PCM materials that can be analyzed with the setup are limited to PCM materials with a melting point within the water bath's temperature range of 25–99.9 ℃. Type T thermocouples 0.2 mm in diameter are wound around metal rods and inserted into the samples through rubber stoppers with holes. The purpose of the metal rods is to keep the thermocouples centered along the horizontal axis of the PCM samples. Temperature data from the thermocouples are acquired using a National Instruments NI 9212 data logger connected to a PC. The NI 9212 has eight channels, allowing for a maximum of 6 PCM samples to be analyzed simultaneously. The other two thermocouples are used for measuring the ambient temperature and the temperature of the reference [44].

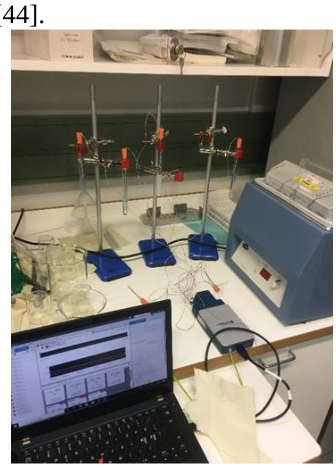

Figure 4. The setup of the PCM demo environment [44].

Fter the PCM samples and the reference have been heated to a uniform temperature above the melting point of the PCM in the water bath, they are removed from the water bath and hung up on stands using clamps to be cooled down by ambient air, as observed in Fig. 4. One of the advantages of using the T-history setup as in [45], is the use of glass tubes. This makes the phase-change process visible when the measurement is taking place, which can enhance the learning experience for students. Instructions for the use of the demo environment have been prepared for students and responsible teachers. The instructions provide detailed steps for analyzing the thermophysical properties of PCMs using the T-history method, from initial preparations to the cleaning of equipment after finishing the measurements. Instructions for the data analysis to be carried out after the measurements using the calculation methods described in [45]–[47] are also provided.

C. Implications of the Project and Project-based Learning in the Case Study

Funding of HE is complex and depends on various criteria and achievements, set up by governments. These achievements include for example the number of degrees and publications produced, and external funding [5]. Although the government has the main responsibility for investments in education and research, external funding is of great importance, and it is estimated that about 40% of the universities income comes from external funding or other public sources in Finland [1]. Since externally financed projects are routine within the universities, the idea of utilizing project work as a tool to develop the engineering curricula is here presented. The ERDF, from which this energy storage project has received funding, belongs to the Structural Funds (SFs) operational programs. SFs are EU-based financing instruments that seek to support the partnerships between various HE institutions, businesses, and other stakeholders on a regional level. Implementation of received SFs projects from 2007 - 2010 within research and development in the University of Latvia has been analyzed [48]. Here it was concluded that both doctoral theses and the number of scientific publications increased, however, the commercialization of inventions was not fully optimized. SFs projects in Finland have been seen as tools to create a platform of collaboration and are essential in delivering the third mission in practice [49]. Especially in remote units in University consortia, that is, units that are physically diverged from their parent university, SF projects have been regarded as an imperative source of funding. In this study, a successful collaboration between three different HE institutions was encouraged with a common goal to create a demo environment on energy storage. Since the ÅA subject, Energy technology, is physically distinct from the main unit that resides in Turku, an SF project was utilized to promote regional development and collaboration with different stakeholders. As can be observed from Table I, the share of received capital from EU structural funds is small within the Finnish universities (2.2%) compared to the part within the UASs (32.1%). Thus, within the universities, there is still room for increasing the volume of funds received from EU structural funds. In addition to enhancing regional development, these externally financed projects can support engineering education. As financial resources occasionally are inadequate and scarce in educational programs, additional investments and new ideas are therefore greatly appreciated.

Within the current project, a survey has been conducted to map the need of the industry and academia regarding energy storage and to promote energy storage competence within the Vaasa region [43]. Based on questionnaires and interviews within both the academic and industrial sectors in the region, data were collected and the results were gathered. The results showed that battery technology was considered the most interesting mode of energy storage by the industrial stakeholders, although it was shown that other forms of storage were likewise appealing, such as sensible and latent TES. From the academic sector, suggestions were put forward on how to create a common platform for energy storage that could be beneficial for the industry and the educational institutions. One suggestion was that long-term projects could be implemented and that student involvement in company projects would be valuable in terms of reinforcing the cooperation between industry and academia.

Ref. [50] has summarized several essential elements in the PBL methodology. These include finding a solution to a problem, the students working in teams (generally), the project being multidisciplinary and non-trivial, the project involving the development of a concrete artifact (e.g. a thesis), a culmination of the project in a written/oral report and the teacher staff taking a more advisory role than authoritarian [50]. From an educational point of view, the project-based learning approach has been widely used in both engineering and chemistry education [10], [51]. This methodology is applied when knowledge for real-world problems is desired and when increased motivation and engagement by students are wished for. The project used in this paper was externally financed by ERDF. In the study, several demo environments have been prepared, and most demos have been finalized to be used in engineering education and by research personnel (Table III). These demos are expected to be a permanent element in the future at the research facilities of Technobothnia. Some students involved in the project have been employed by the project, meaning that they needed to follow the project plan and the requirements therein. Other students made their contributions to the project as a part of their studies, such as a thesis or as a project course. However, in both cases, as a result of PBL in this project, several engineering students have had the opportunity to work in settings that mimic authentic work situations. Teamwork has played a large role when planning some demos, as groups of students have collaborated in the planning- and implementing processes of the demos (e.g. CAES demo). Although the PCM demo has been planned and conducted by a single student, the demo is a result of several discussions and interactions with various stakeholders. Until now, the energy storage project as a whole has enabled project work experiences for both international students (European Project Semester (EPS)) and national students, undergraduate engineering students, and graduate engineering students (about 20) and work in the project on the demos has turned into several completed bachelor ́s and master ́s theses (about 5). Supplementary research work, in addition to work on the demos, has been conducted within the project. For example, students have performed investigations regarding the feasibility of using heat energy storage and Power to-X technologies in the region, as well as looked into energy storage in off-grid systems and the energy storage market from a Finnish point of view.

Soft skills, or personal skills, are imperative within all fields of work situations. Working in projects brings out both the joys and the challenges that might occur during actual work processes. When planning the demo environments, the students have been faced with multiple open questions such as; which components and materials are appropriate for the demo, which technology is favorable to demonstrate the concept of energy storage, how to handle economical and budget issues, and how to solve problems such as breaking of components and instruments. Last, but not least, safety issues must always be assessed and the risks minimized. This has been accomplished by favoring harmless chemicals and utilizing protective clothes/goggles etc. Several of the valuable skills desired from an industrial point of view, including problem-solving and teamwork [17], [18], have been practiced by the students during work in this project. In all these circumstances, the students have been obliged to do a comprehensive literature search to answer several questions and search for technical parameters. This kind of research will help the students to understand the concept of the actual subject, but it also demonstrates how complex real-life problems might be. In the case of the PCM demo, an experimental method was chosen as means for demonstrating thermal heat energy storage. TES is of importance in the Ostrobothnia region, especially after the opening of Finland ́s largest TES in Vaasa 2020 [38]. Furthermore, to take advantage of the competence and special interest within the ÅAU, the PCM was selected for demonstration purposes. The aims and requirements for the demo were in the beginning several. It was seen vital that the demo is safe for the students, that it is not exceeding three hours, that the method is efficiently describing phase change materials and TES, and that detailed instructions of the demo would be available. In terms of meeting these objectives, the PCM demo was planned and conducted, as previously described. Based on the final end product in the case study (the PCM demo), we conclude that the goals for the PCM demo have been accomplished.

In literature, four different laboratory instruction styles can be identified in chemistry education; expository-, inquiry-, discovery- and problem-based instructions [52]. These styles differ in three aspects regarding procedure, approach, and outcome. Still today, the most popular style in laboratory courses is the expository (traditional) style, in which the outcome is predetermined, the approach is deductive and the procedure is given. Because of these characteristics, the expository style is also regularly criticized. One concern is that the students will not be enough engaged in thinking, but rather routinely follow the guidelines [53]. One outcome of the PCM demo was to write an instruction guide for the experiment. These instructions would help responsible teachers/supervisors to demonstrate and teach about the energy storage method correctly. Since the demo was prepared for implementation in education within different educational institutions, it was decided that the instruction would be as detailed as possible. At the moment, the laboratory instructions are created in a traditional way. However, the laboratory instructions could be modified to be more inquiry- or discovery-based and many attempts of introducing new concepts into traditional laboratory activities have previously been demonstrated [54], [55].

IV. Conclusion

This work describes how a project outcome can act as a supporting element in engineering education. Several demos on energy storage methods have been prepared and the majority of them have been finalized, including the demo on thermal energy storage using PCMs. Energy storage, as a tool to store excess energy produced by renewable sources, has gained a lot of interest in the last decades. As an example, the concept of energy storage has lately been emphasized in chemical engineering education in China in response to the urgent need to upgrade from traditional energy sources to renewable ones [56]. Hence, this demonstrates that increased expertise in such areas is necessary to support the development of new technical talents. Especially from a regional point of view, future engineering students must be familiar with various energy storage techniques, to take full advantage of the available resources in the specific region. Learning through practical work cannot be underestimated. Numerous essential skills, such as problem-solving skills and teamwork, are gained when students work in laboratory settings. This SF project has enabled setting up such an important environment and in the process; the project-based learning methodology has been utilized for several students in their final studying year by working in the project.

V. Future Work

Although the project can be regarded as a success in terms of setting up demo environments and offering students to work in a project, there are still things to be improved upon and research to be conducted. To date, the only demo that has been implemented and tested in the engineering curricula is the demo on flywheels. To understand entirely the impact all the demos have on learning and understanding the energy storage concept, further emphasis should be on implementing the remaining demos in engineering education. Evaluation of the new settings by the students should be carried out, and the results analyzed thoroughly. However, this work presents the enabling of several demos on energy storage by work and financial support from an SF project. In the future, external financed projects might be a vital resource for other applications regarding higher education, including doctoral studies.

Conflict of Interest

The authors declare no conflict of interest.

Author Contribution

Jessica Tuuf is the main author of the manuscript. She conceptualized the idea for the article and wrote the majority of the paper. Sami Lieskoski has planned and finalized the PCM demo and wrote a minor part of the article. Margareta Björklund-Sänkiaho suggested the project and acted as PI. She supervised and helped with finalizing the article. All the authors have approved the final version.

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References

[1] E. Adam, "'Governments base performance-based funding on global rankings indicators': A global trend in higher education finance or a global rankings literature fiction? A comparative analysis of four performance-based funding programs," *International Journal of Educational Development*, vol. 76, p. 102197, Jul. 2020.

[2] J. Söderlind, L. N. Berg, J. K. Lind, and K. Pulkkinen, "National performance-based research funding systems: Constructing local perceptions of research?" in *Reforms, Organizational Change and Performance in Higher Education: A Comparative Account from the Nordic Countries*, R. Pinheiro, L. Geschwind, H. Foss Hansen, and K. Pulkkinen, Eds. Cham: Springer International Publishing, 2019, pp. 111–144.

[3] T. Tammi, "The competitive funding of university research: the case of Finnish science universities," *Higher Education*, vol. 57, no. 5, pp. 657–679, May 2009.

[4] A. Eskola and S. Hundal, "The development of funding schemes at finnish universities of applied sciences," *International Journal of Learning and Teaching*, vol. 7, no. 1, pp. 25–31, 2021.

[5] The Ministry of Education and Culture. The ministry of education and culture. Universities core funding from 2021. (2021). [Online]. Available:https://minedu.fi/documents/1410845/4392480/UNI_core_funding_2021.pdf/a9a65de5-bd76-e4ff-ea94-9b318af2f1bc/UNI_core_funding_2021.pdf?t=1608637262540

[6] K. Wells and T. J. Kloppenborg, *Project management essentials*, First. New York: Business Expert Press, 2015. Accessed: Jun. 02, 2020. [Online]. Available: http://proquest.safaribooksonline.com/?fpi=9781631571893

[7] B. Lepori, *et al.*, "Comparing the evolution of national research policies: what patterns of change?" *Science and Public Policy*, vol. 34, no. 6, pp. 372–388, Jul. 2007.

[8] T. Franssen, W. Scholten, L. K. Hessels, and S. de Rijcke, "The drawbacks of project funding for epistemic innovation: comparing institutional affordances and constraints of different types of research funding," *Minerva*, vol. 56, no. 1, pp. 11–33, Mar. 2018.

[9] The Ministry of Education and Culture. Luovuutta, dynamiikkaa ja toimintamahdollisuuksiaehdotus ammattikorkeakoulujen ja yliopistojen rahoitusmalleiksi vuodesta 2021 alkaen. Publications of Ministry of Education and Culture (in Finnish only). (2018). [Online]. Available: https://minedu.fi/documents/1410845/4177242/181024_OKM_rahoitusraportti_web.pdf/44cd4514-8627-1ba7-029f-4ab712f40763/181024_OKM_rahoitusraportti_web.pdf?t=1541165541000

[10] D. Kokotsaki, V. Menzies, and A. Wiggins, "Project-based learning: A review of the literature," *Improving Schools*, vol. 19, no. 3, pp. 267–277, Nov. 2016.

[11] V. Leite, "Innovative learning in engineering education: Experimenting with short-term project-oriented research and project-based learning," in *Porc. IEEE 26th International Symposium on Industrial Electronics (ISIE)*, Jun. 2017, pp. 1555–1560.

[12] D. P. Morales, E. Castillo, L. Parrilla, A. Garcia, and A. Otin, "Towards project-based learning applied to the electronic engineering studies," in *Proc. Conference on Design of Circuits and Integrated Systems (DCIS)*, Portugal, Nov. 2015, pp. 1–5.

[13] R. L. P. Teixeira, P. C. D. Silva, R. Shitsuka, M. L. de A. Brito, B. M. Kaizer, and P. da C. e Silva, "Project-Based learning with industry as a learning strategy for improvement engineering education," in *Proc. IEEE Global Engineering Education Conference (EDUCON)*, Portugal, Apr. 2020, pp. 1–2.

[14] Vipunen. Yliopistojen tutkimusrahoitus (University research funding). (2020). [Online]. Available: https://vipunen.fi/fi-fi/_layouts/15/xlviewer.aspx?id=/fi-fi/Raportit/Yliopistojen%20tutkimusrahoitus%20-%20vuosi.xlsb

[15] E. May and D. S. Strong, "Is engineering education delivering what industry requires," *Proceedings of the Canadian Engineering Education Association (CEEA)*, Aug. 2011.

[16] L. Backa and M. Wihersaari, "Future engineering education: What competences are energy companies looking for when recruiting graduates with a master of science (Technology) degree?" *Engineering Education*, vol. 9, no. 1, pp. 2–17, Jul. 2014.

[17] C. D. Grant and B. R. Dickson, "Personal Skills in Chemical Engineering Graduates," *Education for Chemical Engineers*, vol. 1, no. 1, pp. 23–29, Jan. 2006.

[18] C. Winberg, *et al.*, "Developing employability in engineering education: a systematic review of the literature," *European Journal of Engineering Education*, vol. 45, no. 2, pp. 165–180, Mar. 2020.

[19] D. Sainsbury. The race to the top- a review of government ́s science and innovation policies. HM Treasury, Norwich. (2007). [Online]. Available:https://www.rsc.org/images/sainsbury_review051007_tcm18-103118.pdf

[20] C. Arlett, F. Lamb, R. Dales, L. Willis, and E. Hurdle, "Meeting the needs of industry: the drivers for change in engineering education," *Engineering Education*, vol. 5, no. 2, pp. 18–25, Dec. 2010.

[21] M. A. Martín-Lara, I. Iáñez-Rodríguez, and G. Luzón, "Improving the internship experience in the master of chemical engineering at the University of Granada," *Education for Chemical Engineers*, vol. 26, pp. 97–106, Jan. 2019.

[22] S. Lenihan, R. Foley, W. A. Carey, and N. B. Duffy, "Developing engineering competencies in industry for chemical engineering undergraduates through the integration of professional work placement and engineering research project," *Education for Chemical Engineers*, vol. 32, pp. 82–94, Jul. 2020.

[23] M. Magnell, L. Geschwind, and A. Kolmos, "Faculty perspectives on the inclusion of work-related learning in engineering curricula," *European Journal of Engineering Education*, vol. 42, no. 6, pp. 1038–1047, Nov. 2017.

[24] K. Korhonen-Yrjänheikki, "Future of the finnish engineering education a collaborative stakeholder approach.," PhD thesis, Aalto University, 2011.

[25] J. E. Froyd, P. C. Wankat, and K. A. Smith, "Five major shifts in 100 years of engineering education," *Proceedings of the IEEE*, vol. 100, pp. 1344–1360, May 2012.

[26] S. M. Kresta, "Hands-on Demonstrations: An Alternative to Full Scale Lab Experiments," *Journal of Engineering Education*, vol. 87, no. 1, pp. 7–9, Jan. 1998.

[27] M. Vigeant, *et al.*, "Why not just run this as a demo? Differences in students' conceptual understanding after experiments or demonstrations," in *Proc. 2017 ASEE Annual Conference & Exposition Proceedings*, Ohio, Jun. 2017, p. 29129.

[28] E. McKee, V. M. Williamson, and L. E. Ruebush, "Effects of a demonstration laboratory on student learning," *Journal of Science Education and Technology*, vol. 16, no. 5, pp. 395–400, Oct. 2007.

[29] T. de Jong, M. C. Linn, and Z. C. Zacharia, "Physical and virtual laboratories in science and engineering education," *Science*, vol. 340, no. 6130, pp. 305–308, Apr. 2013.

[30] L. D. Feisel and A. J. Rosa, "The role of the laboratory in undergraduate engineering education," *Journal of Engineering Education*, vol. 94, no. 1, pp. 121–130, Jan. 2005.

[31] EnergyVaasa. 'EnergyVaasa'. (2020). [Online]. Available: https://www.vaasa.fi/uploads/2020/12/116a5ae3-energyvaasa-presentation-short-11-2020.pdf

[32] A. Aslani, P. Helo, B. Feng, E. Antila, and E. Hiltunen, "Renewable energy supply chain in ostrobothnia region and Vaasa City: Innovative framework," *Renewable and Sustainable Energy Reviews*, vol. 23, pp. 405–411, Jul. 2013.

[33] Finnish Wind Power Association. Operating and dismantled wind turbines. (2021). [Online]. Available: https://tuulivoimayhdistys.fi/en/wind-power-in-finland/wind-power-in-production-and-dismantled

[34] Finnish Wind Power Association. Wind power project pipeline 1/2021. (2021). [Online]. Available: https://tuulivoimayhdistys.fi/media/final-16.2-public-wind-power-pipeline-finland-1_2021.pdf

[35] National Land Survey of Finland. Municipalities by area 1.1.2015. (2015). [Online]. Available: http://www.pohjanmaalukuina.fi/assets/10/Pohjanmaa-lukuina/Tilastoaineisto/Kuntien-pinta-alat-2015-taulukko.pdf

[36] I. Sarbu and C. Sebarchievici, "A comprehensive review of thermal energy storage," *Sustainability*, vol. 10, no. 1, p. 191, Jan. 2018.

[37] J. P. da Cunha and P. Eames, "Thermal energy storage for low and medium temperature applications using phase change materials – A review," *Applied Energy*, vol. 177, pp. 227–238, Sep. 2016.

[38] V. S. Oy. (2020). Tulevaisuuden lämpöenergiavarasto otettiin käyttöön Vaasassa. [Online]. Available: https://www.sttinfo.fi/tiedote/tulevaisuuden-lampoenergiavarasto-otettiin-kayttoon-

[39] H. Lund, *et al.*, "Energy storage and smart energy systems," *International Journal of Sustainable Energy Planning and Management*, pp. 3–14, Oct. 2016.

[40] A. Castell and C. Solé, "Design of latent heat storage systems using phase change materials (PCMs)," in *Advances in Thermal Energy Storage Systems*, Elsevier, 2015, pp. 285–305.

[41] Technobothnia. About Technobotnia. (2020). [Online]. Available: https://www.technobothnia.fi/technical-collaboration/about-technobothnia/

[42] Regional Council of Ostrobothnia. Energy storage in our future low carbon society. (2021). [Online]. Available: https://www.obotnia.fi/regionutveckling-och-finansiering/projektregister/energilagring-i-vart-koldioxidsnala-samhalle-energilagring

[43] O. Koskinen, S. Lieskoski, C. Söderbacka, S. Sharma, and J. Tuuf, "Energy storage in our future low carbon society (energilagring!)," Vaasa University of Applied Sciences, Sep. 21, 2021.

[44] S. Lieskoski, "Developing a demo environment on phase change materials," Master´s thesis [English], Åbo Akademi University, 2020.

[45] Z. Yinping, J. Yi, and J. Yi, "A simple method, the -history method, of determining the heat of fusion, specific heat and thermal conductivity of phase-change materials," *Meas. Sci. Technol.*, vol. 10, no. 3, pp. 201–205, Jan. 1999.

[46] H. Hong, S. K. Kim, and Y. S. Kim, "Accuracy improvement of T-history method for measuring heat of fusion of various materials," *International Journal of Refrigeration*, vol. 27, no. 4, pp. 360–366, Jun. 2004.

[47] J. M. Marin, B. N. Zalba, L. F. Cabeza, and H. Mehling, "Determination of enthalpy temperature curves of phase change materials with the temperature-history method: Improvement to

temperature dependent properties," *Measurement Science and Technology*, vol. 14, no. 2, pp. 184–189, Feb. 2003.

[48] L. Muižniece and L. Peiseniece, "EU structural fund investment in R&D and its influence on innovation development - The case of University of Latvia," *European Integration Studies*, no. 6, pp. 31–40, Jul. 2012.

[49] M. Salomaa and D. Charles, "The university third mission and the european structural Funds in peripheral regions: Insights from Finland," *Science and Public Policy*, vol. 48, no. 3, pp. 352–363, Jul. 2021.

[50] S. Palmer and W. Hall, "An evaluation of a project-based learning initiative in engineering education," *European Journal of Engineering Education*, vol. 36, no. 4, pp. 357–365, Aug. 2011.

[51] J. K. Robinson, "Project-based learning: improving student engagement and performance in the laboratory," *Analytical and Bioanalytical Chemistry*, vol. 405, no. 1, pp. 7–13, Jan. 2013.

[52] D. S. Domin, "A review of laboratory instruction styles," *Journal of Chemical Education*, vol. 76, no. 4, p. 543, Apr. 1999.

[53] A. Hofstein and V. N. Lunetta, "The laboratory in science education: Foundations for the twenty-first century," *Science Education*, vol. 88, no. 1, pp. 28–54, 2004.

[54] T. M. Clark, R. Ricciardo, and T. Weaver, "Transitioning from expository laboratory experiments to course-based undergraduate research in general chemistry," *Journal of Chemical Education*, vol. 93, no. 1, pp. 56–63, Jan. 2016.

[55] G. Tsaparlis and M. Gorezi, "Addition of a project-based component to a conventional expository physical chemistry laboratory," *Journal of Chemical Education*, vol. 84, no. 4, p. 668, Apr. 2007.

[56] Y. Tan, K. Liang, and Y. Li, "Connotation and development of energy storage in energy chemical engineering education," *Open Journal of Social Sciences*, vol. 8, no. 3, pp. 522–528, 2020.

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