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CAPE-based Curricula for the Improvement of Chemical Plants

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Chemical engineering is a complicated combination of skills that depends on the curricula, teachers, and teaching environment and it requires huge resources to prepare skilled personnel for chemical and related industries. Chemical plant specialists face new challenges as digital and energy transition, new products and processes, circularity paradigm, etc. All these need awareness of new trends and the capability to solve related industrial problems. This paper presents a computer-aided process engineering-based (CAPE-based) curricula development that supports continuous improvements of chemical plants and speeds up the application of up-to-date knowledge directly to industrial practice. The approach is based on the interplay of engineers, plant managers and university professors in solving the real industrial problem. The procedure is supported by a cloud-based CAPE environment for teaching, training, and producing the project results. The industrial problems are identified by the plant personnel and appropriate engineers are assigned by managers. The specific structure of the curricula presumes face-to-face, online and hybrid training and consulting in a triangle engineer, plant supervisor, and professor to solve a problem in the chemical and petrochemical industry. The pool of university professors is adjusted to cover all necessary tasks, provide up-to-date knowledge, and give a new paradigm to engineering thinking. The fellows improve in machine learning, data science, communication skills, presentation skills, economic assessment, etc., to increase the importance of the company. As the real results of one of the case studies, the steam consumption of the petrochemical plant was reduced by 64 % and the yield of the production unit was increased. Eleven case studies were solved covering energy and resource efficiency, wastewater treatment, by-product recycling, new product development and other issues. As the final project results the mechanical specification of the equipment, new plant layout and economic efficiency were assessed.

1. Introduction

The chemical industry faces many different challenges that affect its operability and profitability. It deals with process and equipment optimization and operation, energy efficiency, reaction and catalysis, etc. It is also relevant to global challenges of chemical engineering, which are new processes and products, energy and resource efficiency (Heinänen et al., 2012). Besides, the application of new technologies to chemical plants is infeasible without the improvement of the skills of plant personnel to understand and appropriately adopt them. The retrofit of existing process plants is a complicated task and requires a set of interdisciplinary knowledge as reported by Novak Pintarič and Kravanja (2016). Recent advances demonstrated the response to sustainable product design goals in biofuel production (Fedeli et al., 2022), methanol synthesis (Previtali et al., 2020), food production (Raymo et al., 2020) and others. Efficient energy use challenges can be solved by improvement of heat recovery and exchanger network retrofit in chemical (Boldyryev et al., 2021), coke-to-chemical (Kuznetsov et al., 2022), refinery (Boldyryev and Gil, 2021), and other industries. Mentioned above needs to utilize new

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knowledge and trends that can be implemented in disciplines and courses of Chemical Engineering curricula, e.g., virtual reality (Kumar et al., 2021), digitalization (Bodnar et al., 2021), machine learning (Battisti et al., 2021), web labs (Selmer et al., 2007), etc.

All these are important in project-oriented degrees for improved student performance, engineering efficacy, multidisciplinary and retention as was reported by (Ragusa and Lee, 2012). It proves that the use of projects in chemical engineering education is impactful, resulting in students' increased understanding of experimentation and is meaningful, resulting in significantly increased student efficacy. The importance of Chemical Engineering curricula in different countries was proved by scientists in Romania (Onofrei et al., 2016), France (Perrin and Laurent, 2008), India (Gurumoorthy and Smith, 2013) and other countries. This demonstrates that chemical engineering education covers the global market and is important for the world's GDP. However, current advances are mostly oriented toward university students. But young specialists mostly deal with plant operations in the first years of work and are not targeted to operational improvements, which are still complicated and often unsolved problems. Moreover, some knowledge obtained becomes out of date after several years of graduation and needs to be updated soon as reported by (Burkholder et al., 2022). It is shown how the variations both within and across institutions in the specific problem-solving skills students master match with the practice they get. There are new university Chemical Engineering curricula (López-Pérez et al., 2023) that demonstrate employability over 70 % after obtaining the degree, but it presumes full-time engagement of students. There are also specific courses on new trends in Chemical Engineering (Udugama et al., 2022) and related areas (Qian et al., 2023). However, it presumes, in most cases, to take a break from the job to graduate. Besides, the simultaneous studying and solving of the industrial problem are challenging and not described by existing Chemical Engineering courses.

This paper presented the industry-oriented curricula in Chemical Engineering that are based on CAPE-based cloud tools and targeted to solve real industrial tasks. It covers several gaps in Chemical Engineering Education, namely, increase awareness of existing chemical industry employees with new scientific trends, speed-up problem solving and implementation of new technologies in the industry. It performs in an integrated industry-academic environment involving a plant manager and university professor for supervision and to help engineers in problem-solving. The approach can be used to solve industrial problems in other industries and update the knowledge of the industrial personnel.

2. Methods

The teaching approach was developed to ignite solving real industrial problems and bringing up-to-date knowledge to the industry. The curricula are targeted at industry engineers and plant managers of low and medium levels to stimulate the application of new technologies, increase throughput, improve efficiency, etc. At the initial stage, the problems or tasks are identified by plant personnel highlighting the potential operation benefits and debottlenecking. The team of engineers for problem-solving are selected at the specific industrial unit and plant supervisors are appointed. Before the compilation of the curricula, the company applies the list of industrial problems that they are going to solve during the study. Based on this list, the professors are selected considering the specific tasks. The engineers' study in the university environment where the CAPE-based and cloud tool, such as the one proposed by Galeazzi et al. (2021), is used as a key practical instrument allowing solving tutorials and case studies. The curricula utilise the traditional approaches and practical cases in chemical engineering (Pliego and Bloxham, 2023) and new methods, e.g., digital transformation, life-long learning, and individualised education (Meyer et al., 2022) that resulted in successful business examples like Silicon Valley or North-western Europe.

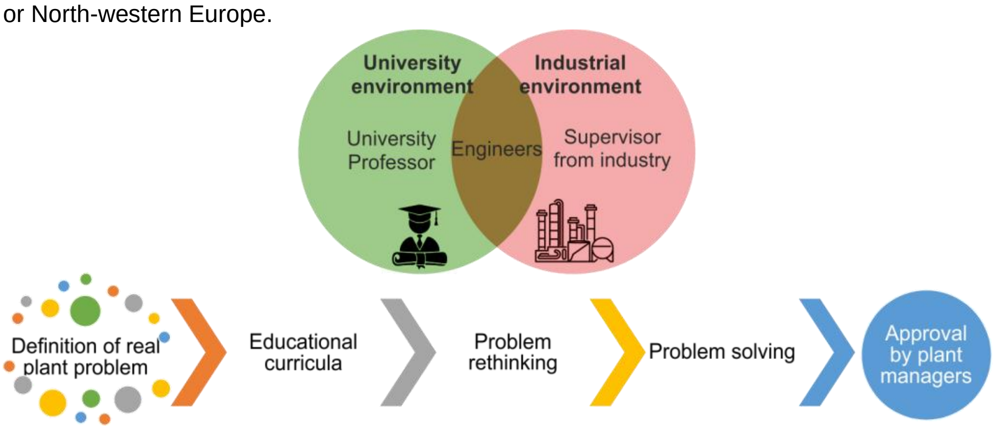

Figure 1: General workflow of problem-solving in integrated industry-academic curricula

The industrial data is analysed by the fellows after absorbing new knowledge and problem-rethinking. The solutions are proposed by providing technical details, risk assessment, and economic and environmental benefits, which are proved by plant managers and the company board. The flexibility of economic indicators is assessed for the different scenarios as presented by, e.g., Boldyryev et al. (2022). The general pattern and the workflow of the fellow pathway along the proposed curricula in a hybrid industry-academic environment are presented in Figure 1.

2.1 Triangle mentor-fellow-professor

Apart from the common teaching schedule for all students, each fellow has an individual studying trajectory related to an individual industrial project. The individual consultation with the professor and plant supervisor is spread along the curricula to meet the tasks of the project timely. The group consultations are also appointed for fellows who have close project topics, it provides additional brainstorming in finding solutions. The target group of considered curricula are all kinds of plant personnel, middle-level managers, research engineers, and plant operators, but entrance testing is performed to get a staff profile, which is capable of delivering necessary results and increasing company value. The fellows have opportunities to move between different online facilities of universities during the whole period of curricula. Additionally, onsite work at the university infrastructure is presumed during several offline sessions. The offline sessions are planned in universities for 2 weeks to immerse students more deeply in studying. The studying is financed by industrial companies interested in the improvement of production culture, efficiency, and strategic development.

2.2 Courses

The specific structure of the curricula presumes face-to-face, online and hybrid training and consulting in a triangle engineer, plant supervisor, and professor to solve an industrial problem in the chemical and petrochemical industry as reported by Kukurina et al. (2021). Apart from chemical engineering, the fellows improve in cloud computing and data analysis, communication & presentation skills, economic and environmental assessment, etc., to bring new thinking and value to the company. The basic part of the curricula provides knowledge in Chemical Engineering, Processes and Equipment, Chemical Process Integration, Environmental Security and Process Simulation. The specific part of the study includes Artificial Intelligence, Machine Learning, Project Management, System Analysis, Data Science, and Economic Analysis. Depending on the branch of industry the specific courses are implemented in petrochemistry, fertilizer, phosphorus compounds, plastics, metal processing, etc.

2.3 CAPE-based tools

In solving the majority of industrial problems, the appropriate tools for the chemical process engineer are the process simulation software for both steady-state and dynamic modelling. The selected software are Aveva PRO/II, Aspen HYSYS, Aspen Plus, and UniSim Design. If the choice of the physical property packages, the unit operation design and other process parameters are close to real plant data then these applications let the user create realistic replicas of the process under study, i.e., digital twins. With such a digital twin developed, it is possible to perform advanced studies and tackle the problem most efficiently. For example, the most common application is process optimization or sensitivity analysis. However, not all industrial problems require performing process optimization. For example, in the task of retrofitting a unit operation or in de-bottlenecking, a process a piece of equipment is usually substituted or added. In this case, the process simulation is still the required tool for performing accurate mass and heat balance calculations. Still, accurate sizing and optimization of units could be required for procurement. For instance, in the case of the heat exchanger design, it is necessary to use accurate sizing tools such as the Aspen EDR or the UniSim Heat Exchangers packages to optimize the technical and economic parameters of the considered item. All such tools are made available to the user for problem-solving by means of a cloud platform, as shown in Figure 2.

2.4 Hybrid learning strategy and mobility

A hybrid learning strategy is implemented. It consists of remote lectures for theoretical aspects and tutorials and in-person dedicated support for industrial problem advances. The approach to the industrial problem requires firstly the mobility of engineers to improve skills and competencies in academic facilities and secondarily the mobility of professors to the real plants. This hybrid approach allows for intensifying the activities, lowering operational costs, and improving teamwork and confidence.

3. Results and discussion

A selection of 11 case studies (and 15 engineers) have been taken into consideration to implement the proposed framework to solve real process decarbonization and circular (waste-to-X) economy issues. Among them, a traditional-technology tubular-reactor large-size polyethylene and polypropylene production plant has been remotely studied, simulated in detail at the host university and, next, progressively implemented as a ready solution on the real plant to target better energy efficiency performances and reduce the environmental impact. The examples of completed projects are presented in Table 1.

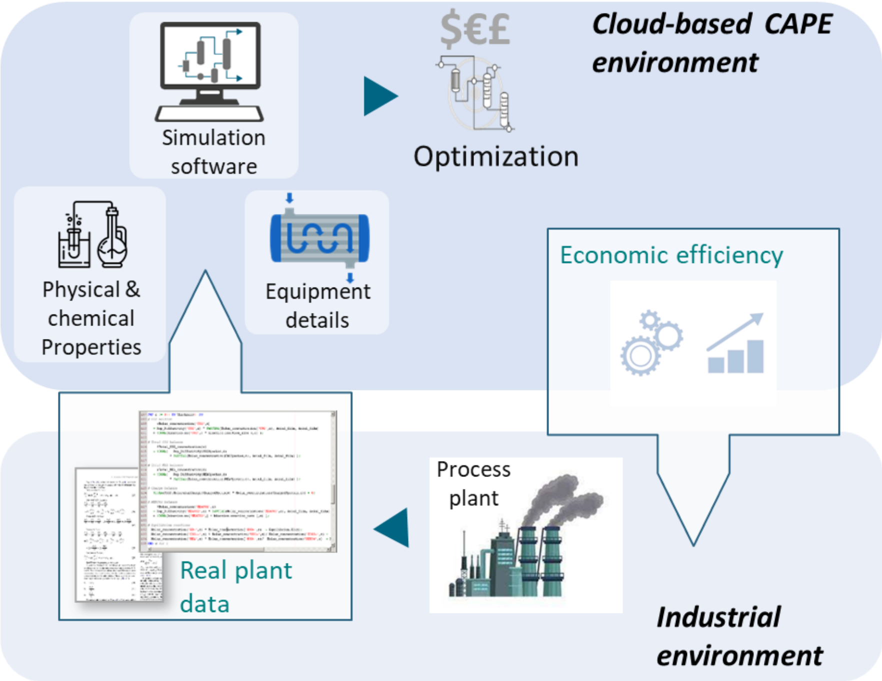

Figure 2: Cloud-based CAPE environment for industrial Chemical Engineering curricula

Table 1: Selected projects that were completed during the education

No	Project name	Features	Saving, EUR	IRR[1], %
1	Reuse of wastewater	Natural gas saving	114,185	30
2	Obtaining high-margin products	Improving the quality and cost of heavy pyrolysis resin	1,097,228	807
3	Increasing the productivity of polypropylene production	• Operation mode and process stream changes. • Equipment retrofit of the granulation section.	4,316,190	21
4	Steam and condensate system optimization	Improving heat recovery and reduction of losses.	230,027	41

[1]Internal Rate of Return (IRR), %

3.1 Energy efficiency improvement

The energy consumption of the polymer production plant was investigated (project 4 from Table 1), and the problem of steam losses was solved. The existing process was simulated in Aspen Plus software, and the energy gap and prospective energy-saving measures were defined. The found solution was analysed in detail and mechanical arrangements of the equipment were selected. At the end of the project, additional recovery heat exchangers and a re-piping were proposed as the most appropriate solutions that were also approved by the plant manager. The annual energy saving was 1,018,545 kWh and an emission saving of 229,570 tCO_2/y. In addition to energy and environmental benefits, the operation of some process equipment was improved, e.g., distillation columns and air coolers. Supplementary energy saving was achieved at air coolers in the cold season. The economic results of the proposed solutions demonstrate the IRR of 41 % and 28 %, accounting for the pessimistic scenario. The total capital investments of Project 4 accounted for around 490,320 euros with a payback period of 4.5 years. More details on energy efficiency projects can be found in the research of Dyudnev et al. (2021). After the case study was accomplished, the results had been set for implementation by the polymer chemical company. The fellows, who were solving the problem, were appointed to co-supervision of the implementation stage.

3.2 Solving industrial problems

This teaching approach let involves the most appropriate professors and consultants from different areas and around the globe for solving a particular industrial problem. Up-to-date knowledge is transferred to the industry fast and purposefully. The problems that are not solved for years may be revisited with new approaches and tools. It also creates additional workflow for engineering companies when the considered projects go to the implementation stage. Besides, the feedback from the fellow during the study may turn on existing models and tools updating with the plant data and empirical coefficients. Restrictions connected with the last pandemic problems, political and other crises may be reduced by the use of hybrid teaching instruments applying distance lecturing and cloud-based lab tools.

3.3 Career development for the fellow

Skills gained by the fellows, which are involved in the curricula, assist in further career development bringing new positions in the company, also improving tutoring skills and preparing a new generation of plant managers. Interpersonal and presentation skills gained during the study allow improving the internal company culture and add its market value.

3.4 Sustainable development goals

Apart from the development of personal skills, the results of the delivered projects let the companies move towards sustainable development goals and improve their production facilities. A new operation strategy allows companies a new product development with special emphasis on the utilization of waste energy and by-products, creating environmentally friendly productions and following resource circularity. All these advancements allow for speeding up the transformation to 4^{th} industry generation and industrial energy transition.

4. Conclusions

In conclusion, an environment for the development of engineers' CAPE skills is presented. This framework addresses and solves several real industrial problems using common CAPE-related tools. The results obtained showed that the integration of academia and consultancy with industry is valuable in creating cutting-edge solutions to industrial problems. The skills gained in this environment by the fellows are decisive in improving the company's best practices in the solution of industrial CAPE problems.

The focus on sustainable development is paramount in shaping the solutions of the future. As further developments, fully immersive and collaborative avatars, including oculus and 3-D realistic and dynamic process digital twins, will be considered, and integrated into the proposed framework to fully support the remote activities, the training of engineers as well as the industrial implementation of final solutions.

The results of several selected case studies of the petrochemical industry demonstrated financial savings of 5.6 million euros annually. Some of the projects have outstanding financial results with a very high IRR index proving the proposed approach's efficiency and curricula. The staff, who was involved in the program and successfully finished their projects, were promoted by the company applying new knowledge on a new level. Apart from the petrochemical industry, the proposed teaching can be applied in other industries improving yield, efficiency and sustainability of wide-class chemical, polymer, food, and other related industries.

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