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RESEARCH ARTICLE

A Comprehensive Review of Key Cyber-Physical Systems, and Assessment of Their Education Challenges

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ABSTRACT The importance of cyber-physical systems (CPS) continues to grow today, with AI applications in the CPS design principles that formulate smart cyber-physical systems (S-CPS). These called Extended Cyber-Physical Systems (E-CPS) or Next Generation Cyber-Physical Systems (NG-CPS) are expanding to address more complex problems such as the impact of intellectualization on human roles and the social embedding of heterogeneous systems. The industrial metaverse for smart manufacturing and its novel characteristics require new types of advanced cyber-physical coordinated situational awareness and active defense against cyber-attacks. These new challenges raise the profile of engineering education at the university level, while the addition of new skills requires rigorous preparatory work and the development of tailored requirements for effective knowledge transfer methods that meet the educational needs of the current environment. Students need to be prepared to manage information and influence decision-makers effectively. This article presents a pedagogical approach to teaching CPS as an advanced undergraduate subject by integrating elements of competency and personal development into daily classroom activities. This reflects the circumstances and demands of everyday engineering work, focusing on soft skills such as time management, precision, accuracy, focus, communication, teamwork, and also applying the methods of continuous accountability and reward. The specific tasks and assessment techniques simulate real-life situations in the industry, and R&D activities, where the students became efficient engineers, researchers and later on could fulfil the position of reliable BOSSs. The conclusions are based on individual and group interviews conducted with students in Hungarian and international mechatronics undergraduate programs.

INDEX TERMS Cyber-physical systems, artificial intelligence, cyber and personal security, challenge-based learning.

LIST OF ABBREVIATIONS

CPS	Cyber-Physical Systems.
S-CPS	Smart Cyber-Physical Systems.
E-CPS	Extended Cyber-Physical Systems.
NG-CPS	Next-Generation Cyber-Physical Systems.
R&D	Research and Development.
AI	Artificial Intelligence.
ML	Machine Learning.
XAI	Explainable Artificial Intelligence.
CBL	Challenge-Based Learning.
PBL	Problem-Based Learning.
SBL	Scenario-Based Learning -.
PjBL	Project-Based Learning.
IoT	Internet of Things.
RMFS	Robotic Mobile Fulfillment System.
CLSR4	Classroom 4.0.

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I4.0	Industry 4.0.
E4.0	Education 4.0.
I5.0	Industry 5.0.
E5.0	Education 5.0
SOAM	System Operation Augmentation Module.
CS	Cyber Security.
KISS	Keep it Structured and Simple.
BM	Brain Maintenance.
ST	Small Tasks.
TT	Technical Reports.
TT	Teamwork Tasks.
Pr	Presentation.
TDK	Scientific Students Association.
ChatGPT	Generative Artificial Intelligence Chatbot.
AI-CS	Artificial Intelligence Supported Cyber Security.

I. INTRODUCTION

The term ''Cyber-Physical Systems'' emerged around 2006, when it was coined by Helen Gill at the National Science Foundation in the United States [1]. In this starting phase, embedded computers monitor and control physical processes, usually with feedback loops, where physical processes affect computations. Beyond mechatronics, the discipline of CPSs is a truly open field from many aspects (functional, architectural, cognitive, social, etc.) and its identity transcends the limits of multiple thematic identities [2]. In 2016 Klaus Martin Schwab and his team extended the concept to the Fourth Industrial Revolution, Industry 4.0 (I4.0), which combines emerging technologies in fields such as robotics, artificial intelligence, nanotechnology, quantum computing, biotechnology, the Internet of Things (IoT), the industrial internet of things, decentralized consensus, fifth-generation wireless technologies, 3D printing, and fully autonomous vehicles [3]. The related problem statements formulating every global problem, from cancer to climate change, have an engineering dimension and a growing array of technological tools to master [4]. CPSs represent the interweaving of physical processes such as sensing, actuating such as operating robots, self-driving vehicles while implementing digital controls, and developing synergistic connections with integrated benefits. Communication technologies play a significant role in CPSs by facilitating real-time data exchange, coordination and coherent integration of the processes. New and emerging communication technologies contribute significantly to CPS efficiency growth by facilitating ultra-fast, low-latency connections. They also improve real-time transmission, enabling better control and monitoring of physical processes in a bi-directional manner. Fig 1 shows an overall CPS bi-directional coordination structure that combines, information extraction, processing and the sensor feedback control loops with the actuators. The control processes are algorithm based on simplified cases while the S-PCS are managed by AI-supported solutions as we discuss later.

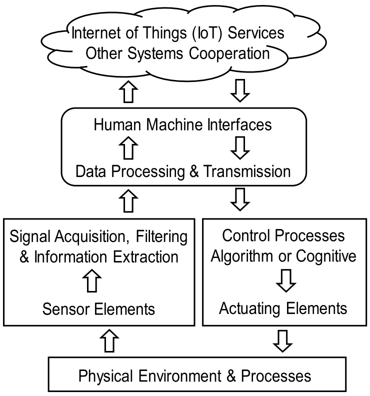

FIGURE 1. Cyber-physical systems' bi-directional coordination structure.

The main challenge relates to the fact that the amount of signal information acquired increases significantly, while the time available for knowledge extraction is limited, frequently shortened, rather than increased. The Robotic Mobile Fulfillment System (RMFS) operational description is a good example to demonstrate in detail the CPS development challenges [5]. This system controls mobile robots, mobile storage racks, put away and picking workstations, charging stations, and wireless communication infrastructure in the context of the robotic-assisted warehouse. The current status of I4.0 adoption from the industry, employees, and training point of view is analysed [6]. The required real-time applicability of the CPS new solutions to be shortened, parallelized and optimised the number of processes that can be implemented within a given correlation time between the expected processes. We need engineers with dedicated expertise to solve and manage these technical challenges.

The general high-level engineering educational requirements, expectations and opportunities, are extracted and summarized in ''A Successful European Training Action of Industry 4.0 for Academia and Business'' [7]. The findings are feasible for our university partially only. The major contribution of this study is to examine the problems and opportunities posed by the incorporation of digital technology in the classroom via the lens of Classroom 4.0 (CLSR4) and Education 4.0 (E4.0) [8]. The I4.0 environment, automated IoT-supported data collection, monitoring, classification and prediction have been observed as a necessity for future development in the education domain [9]. The main reasons are the lack of available qualified educational manpower, shortage of financial resources and limited time for efficient implementation of the required capabilities. A task group was initiated to support engineering training focused on CPS and update teaching methods based on up-to-date literature evaluation, tailored to our in-house capabilities. extended challenge-based learning (CBL) was selected, which is an active teaching methodology that places the student at the core of the teaching-learning process [10].

This manuscript aims to provide a comprehensive overview of the current and emerging state of the art in cyber-physical systems and their education challenges. The literature review methodology was to fit as closely as possible with our university's internal teaching methods, curriculums and the expectations of the surrounding economy using Industry 4.0 technology. A further assessment was to meet the expectations of Education 4.0 and thus fit with modern challenge-based educational expectations. It is hoped that the articles/journals selected based on these criteria, covering a wide range of the publication period under review, will provide us with an opportunity to engage with universities with similar education. We assume that deeper cooperation among different universities could increase our teaching efficiency and gain more credit for our university acceptance worldwide.

Reflecting on the research gaps (see Sections I and II), two research questions are focused.

TABLE 1. Research questions.

Identifier	Description
RQ 1	With the involvement of an extended CBL method, is it possible to create and introduce a modern educational curriculum that can be used effectively and timely to fulfil major faculty and industry requirements?
RQ 2	How the extended CBL assessments can be extracted and displayed?

After this brief overview, Section II presents the technical challenges of implementing S-CPS and NG-CPS in real-world applications. Section III describes, analyses and explains our university's required and realistic educational needs. Section IV introduces the implemented education method specialities. Section V deals with the observations and findings of the implemented method that develops assessments, while Section VI compares the results with a few state-of-the-art case study findings and points out further research directions. Finally, we summarize the key points of the paper.

II. EMERGING CPS TECHNICAL SKILLS CHARACTERIZATION

In 2019 the principles of designing Smart Cyber-Physical Systems (S-CPS) for run-time adaptation were reviewed and the analyses were based on 125 articles [11]. It concludes that S-CPSs are complex engineered systems empowered by cyber-physical computing and equipped with the capability of reasoning, learning, adapting, and evolving by applying Artificial intelligence (AI) support "Smart" solutions in logistics as an example. It synthesizes some general principles that can be taken into consideration when addressing the challenges, first of all, in the context of advanced manufacturing systems. As a further example, a comprehensive survey on the application of AI technologies in logistics cyber-physical systems is conducted [12]. In this paper examples from both academia and industry are studied in detail to illustrate how AI techniques are utilized to provide high-quality solutions and tackle the grand challenges in logistics systems.

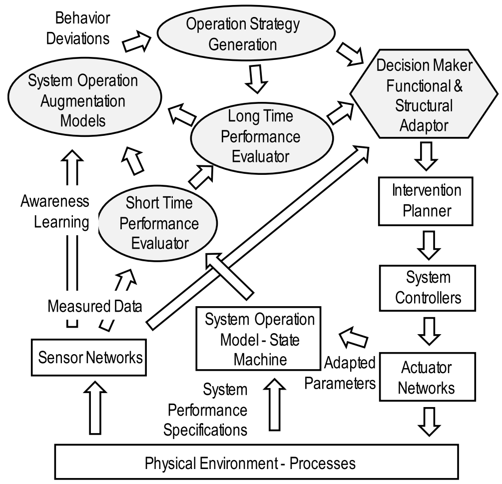

FIGURE 2. The control regime of S-CPSs combines the feedback control loops with those of data-driven reasoning, operational strategy generation, and structural adaptation.

Figure 2 shows the complexity of the S-CPS control structure that determines the present and emerging challenges in the field of education too. All activities and processes are triggered by the physical environment, and their expected effect is also realized here in the physical environment. The data and information provided by the sensors are transmitted in three directions.

The first is the immediate decision-making module, the second is the module for short-time performance evaluators, and the system operation augmentation module (SOAM) is processing recent events. Information from the short-term data processing module is transferred simultaneously to the long-term information processing module and SOAM.

The operational settings of the various modules are determined by the system performance specifications. The SOAM analyse the received data, extracts the pieces of information required for system performance optimization and transfers it to the module responsible for the operation strategy efficiency. Based on incoming information the decision-maker block determines the required real-time intervention, which shall be carried out by system controllers and actuator networks.

A conceptual advancement model of S-CPSs is proposed in [13]. This paper reviews CPSs according to reasoning capabilities and adaptation freedom of systems and recognizes the paradox that a system with a higher level of freedom requires a higher level of self-control, security and resource management according to the overall objective of the operation [14]. The comprehensive review and analyses determine a few general observations such as S-CPSs implementing two recurrent and intertwined cycles of cyber-physical computing [15].

- The basic control cycle comprises: "sensing $\rightarrow$ monitoring $\rightarrow$ adjusting $\rightarrow$ actuating" activities
- The enhancement (self-) cycle comprises "reasoning $\rightarrow$ learning $\rightarrow$ adapting $\rightarrow$ evolving" activities, which is

not Neumann's "making calculations in a predefined way" theory.

The scheme suggests that the fundamental strands of generational evolution of CPS implementations are: (a) self-intelligence and (b) self-organization. In addition, it also proposes that the progression of CPSs happens is a continual basis but through a limited number of generations. The reason is all engineering activities of CPSs start with sensing and end with sensing again for the control process effectiveness checks in modern systems.

The AI control processes are of crucial importance on I4.0 and consequently, their relation to the cybersecurity aspects is a hot topic today. The need for feasible solutions increases with the increase in the importance of cognitive systems. Figure 3 depicts the five levels of S-CPSs, where the starting generation is counted as zero level. These levels combine the feedback control loop complexity according to AI operational requirements.

- *Level 0*: Traditional physical systems and processes only. See Figure 1 for details.
- *Level 1:* The CPS structure and way of default operation are defined in the design phase, and it does not change throughout the system lifespan. The system has conventional control mechanisms and can regulate parameters to a known degree.
- *Level 2:* The system is designed for alternative modes of control and the selection of the optimal mode of control during run-time.
- *Level 3:* Self-learning CPS can adapt predefined control algorithms and quasi-known/unknown changes during the exploitation period. There are serious cybersecurity issues and challenges to be addressed to reduce the risk of intentional and environmental intrusions. The scope and complexity of cybersecurity issues are complemented by human rights and emotional impacts. See Figures 2 and 3 in parallel.
- *Level 4*: The system can control and generate new solutions, in this way, constrain the application and system structure, while the field of adaptation is not restricted to rigid limits. The implications from human rights points of view are still unknown today. Read further details in [15].

The lessons learned during three years of cyber security courses are that the students are enthusiastic about using AI-supported CS applications (AI-CS). We have observed that they are happy to get rid of all boring activities and focus on what they find interesting. However, there are threats to the deterioration of thinking, like orienting with GPS and they give tasks to AI that it is not supposed to do. It is human behaviour to be lazy when it looks convenient.

Based on our findings from the literature and Figure 3, we conclude that autonomous modular control solutions build a strong foundation for CPS modules such as Mechatronics, Robotics, Autonomous Vehicles, and Smart Grids. These advanced modular industrial components, modules and systems need professional, "smart", engineers with specialized knowledge to be prepared for solving or managing further, efficient and permanent engineering tasks in real-time conditions. Based on the author's experience in real-time processing technology Figures 1, 2 and 3 highlight its complexity in the level of freedom and self-control mechanisms with the feasible real-time trajectory determination cases when the implementation of AI control performance levels is increasing.

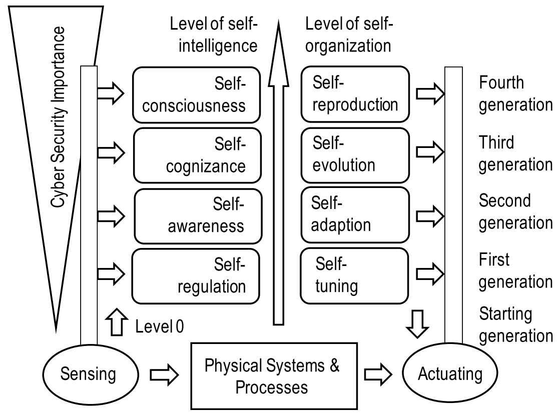

FIGURE 3. Generations of CPSs according to the level of self-intelligence self-organization and Cyber Security requirements.

It could be concluded that the higher level of adaptation freedom requires a higher level of self-control for resource exploitation and setting the operation modes. The complex self-adaptable and controllable systems must be autonomous, system- and environment-aware as shown in [16].

Further expansions are under development in the field of extended CPS for more complex problem-solving such as the influence of intellectualization on human roles, and social embedding of heterogeneous systems [17]. It concludes that NG-CPS paradigms can be identified based on a finite set of indicators, such as (i) the basis of existence, (ii) the objectives of manifestation, (iii) the offered functional spectrum, (iv) the architectural organization, (v) the range of enabling technologies, (vi) the teleology of application, (vii) the possessed problem-solving intelligence, (viii) the doctrine of resource management, (ix) the range of adaptivity, and (x) the apparent operational characteristics.

The review [18], evaluating 162 papers, increasingly advocates the use of distributed, AI-supervised logistics, where the crucial points are Time Efficiency, Cost, Safety and Cyber Security. The review of 77 papers [19], determines a few critical components of AI usage for explainable artificial intelligence (XAI) to be integrated with CPSs.

III. CURRENT AND REQUIRED EDUCATION NEEDS

The essence of the university-level educational applicable solution shall be focused on the engineering way of thinking: What? Why? How? An engineer must evaluate his tasks permanently in real-time, in a reliable and structured manner. They must constantly apply the "What? – Why? – How?"

way of thinking in the analysis of expectations, within which they should focus primarily on the question of Why. Reaching our goal, we concentrate on methods to answer the following questions during the review of state-of-the-art works selected on expectations of engineering lifetime expertise.

What should be considered a basic engineering competence today? For example, which of these should be incorporated into the subject? The main strategic capability package requirements are usually formulated centrally for universities such as:

- Cyber-Physical Systems know-how related skills as basic competencies;
- Usage of artificial intelligence;
- Applications of human rights in smart devices and security questions, including cyber security;
- Knowledge and engineering tasks of space-related technologies.

Why do we need to change our current methods?

- The students' knowledge and general preparation are changing and show great dispersion;
- 70-80% of students have a good ability to use smart devices, but this should be used more effectively;
- Technical report writing and presentation skills must be improved;
- Motivation in learning the engineering way of thinking and principles must be improved;
- The organization's usage of internet-based knowledge must be improved.

How can we achieve the set goal, how should engineering-pedagogical challenges be connected?

- *Current competency requirements:* application of AI in CPS engineering such as "smart" radar and "smart" sensor technology, robots and space engineering activities;
- *Motivation:* continuous, meaningful professional feedback, rewards, and an effective engineering mindset are expected, which can be developed by issuing technical reports;
- *Self-knowledge:* "What are we good at?";
- *Knowing the conditions and expectations:* "How to manage unmanageable situations";
- *Argumentation* and negotiation techniques;
- *Understanding the project* and teamwork expectations, limits, and feasibility framework;
- Exploiting the opportunities provided by modern *mathematical tools* (software).

Other factors such as the structural and cultural transformations of engineering education under the guidance of the new paradigm of engineering education should be an example. Book [20] delves into Chinese solutions. The curriculum includes emerging technologies and interdisciplinary approaches. Invest in training educators to adopt new teaching methods and technologies [21]. Aspects of encouraging students to participate in research projects are highlighted in [22]. The synergistic interconnection of IT, software technology, and mechanical and electrotechnical subsystems that communicate through a "specific infrastructure" such as the,, Internet" is called Cloud-based applications [23]. Promote diversity and tailoring needs in engineering programs to bring different perspectives and ideas evaluated in [24] and [25].

AI technologies in education, Problem-Based Learning effectiveness have posed new and higher requirements for the knowledge system, multi-faceted ability and comprehensive quality of engineering teaching faculty [26]. This is necessary because, in our rapidly developing world, the mathematical background related to digital signal processing, data gathering by IoT methods, the spread of new algorithms and emerging applications of AI requires permanent modernization of university-level engineering education [27]. It is generally accepted that the engineering training requirements of the dominant high-tech companies complement and support the universities' already-in-progress government-approved curriculums. The focal point of study [28] is collaboration with industry to provide internships, research programs, and real-world projects. One of the most popular education methodologies is called "Problem-based learning methodology", which is highly determined by industry needs. Here we focused on the synergy in education: different appearances of a practical problem in different subjects. Usually, the process starts with the definition of the "Engineering problem (or task)". The key here is the second step where we are "Identifying and acquiring the necessary knowledge for the solution". Finally, the "Acquisition of knowledge and skills during problem-solving" gives practice to the students for deepening and consolidating their knowledge. Consequently, engineering skills can be further tuned with prioritization of the needs, by mapping the expectations of company profiles located next to the universities, such as follows:

1. Electric car production and related technologies:
   - 1.1 Robotic production lines based on a Cyber-Physical System's principle;
   - 1.2 Electrical engines, inverters and related components;
   - 1.3 ADAS - advanced driver-assistance system;
   - 1.4 Radar, Lidar, Optical and other sensors' object -detection, -track initialization, track maintenance, and recognition;
   - 1.5 Applications of 5G, 6G, Wi-Fi-related communications networks and Cyber Security;
   - 1.6 Artificial Intelligence/Artificial Reality and Big Data Processing Centre.
2. Advanced Electric Batteries production and related technologies:
   - 2.1 Robotic production lines based on a Cyber-Physical System's principle;
   - 2.2 Batteries, inverters and related components;
   - 2.3 Applications of 5G, 6G, Wi-Fi-related communications networks and Cyber Security;

2.4 Artificial Intelligence/Artificial Reality and Big Data Processing Centre.

3. Advanced measurement systems, networks and related components:

   3.1 Robotic production lines based on a Cyber-Physical System's principle;
   3.2 Phased Array technology and advanced RF signal-data processing;
   3.3 Development of LabVIEW-based applications;
   3.4 Measurement applications to 5G, 6G, Wi-Fi-related communications networks and Cyber Security;
   3.5 Artificial Intelligence/Artificial Reality and Big Data Processing Centre.

From the quality of university technical education point of view, we receive important feedback from the technical managers of the surrounding companies, who are permanent members of the final exams and thesis defences of the students participating in the bachelor's and master's programs. Furthermore, some students with industrial experience in engineering positions and projects are involved in the interviews, we have feedback from the industry. It shows that the educational methodology meets "practice" requirements and helps students start their careers successfully. The feedback from our students confirms the expectation that we need to make our students more resilient to the stress of the first job. It can be seen that the main centrally formulated start-up capability package expectations overlap significantly with industry needs [29] Consequently, industrial demands should be added and prioritized to the minimum required engineering curriculum with the synergy of required capabilities.

The military background of the CPS-related subjects' instructor even at the starting points determines its teaching philosophy. Engineers are shaping the world's development and must take on positions of responsibility. Therefore, engineering education must actively contribute to the development of a well-rounded personality. We need to instil in future engineers, as far as possible, a sense of mission as engineers and prepare them in managed conditions to deal with workplace stress. This is especially important so they can defend their positions with effective engineering arguments in the given work environment, while not over-emphasizing. To emphasize this goal the course starts with the following questions: "What does the word engineer mean?", "What type of people can become the best engineer?" and follows with the idea: "When we were born, no one guaranteed that life would be fair, our environment truthful and honest to us. Your task is to learn, as soon as possible, how to deal with any types of challenges and how to gain the recognition and appreciation of your environment."

People who don't accept the rules, who constantly make excuses, and who lack self-discipline have little chance of succeeding professionally in the engineering field, even if they are brilliant at some things. It is also stated at the beginning of the course that "At home, you can perform the cute child's or grandchild's toothache to the parents and grandparents, if you don't want to do something and the old people are getting emotionally sensitive. I hope you don't think this will work for me, too."

The Problem-Based Learning (PBL) effectiveness evaluation was formulated after reviewing 30 papers related to Computational Thinking of University Students. The PBL applications are efficient, but further research and methodological refinement are required to understand their impact and potential in the educational field [26]. 122 top-quality paper reviews show that ChatGPT's capabilities in natural language processing, text generation, and performance evaluation offer significant opportunities to enhance the educational experience, while concerns about the quality and bias of ChatGPT's responses, plagiarism, and content authenticity pose significant challenges [27]. Based on 85 paper reviews, detailed statistical analyses are given on the extended reality of bridging humans and CPSs in IoT-empowered logistics and supply chain management [28]. 60 journal articles and conference papers reviewed implementing IoT curriculum and associated instructional approaches, educational technologies, and assessment strategies for university students [29]. 152 curriculum, pedagogy, and assessment strategies evaluated in the study focused on the IoT technology paradigm's networking, services, and interface layers. It is concluded, "In IoT education, the predominant form of cumulative activity is a final/capstone project" [30]. The relevance of this observation is confirmed by our new methods implementation findings. Read the details below.

The literature review has proven that AI in education initially took place using computers and computer-related systems then networked forms of web-based and online education platforms. Applications related to embedded systems made it feasible to use robots, in the form of cobots or humanoid robots as teacher colleagues or independent instructors, as well as chatbots to perform teacher or instructor-like functions [31]. The paper [32] proposes a novel supervised learning algorithm, whose method is applied to human-robot interaction for recognizing musical hand gestures based on the work of Zoltán Kodaly. Paper [33] discusses integrating Patient Positioning System safety protocols within the system's architecture, underscoring the practical implications of these advanced measures in augmenting patient safety and treatment effectiveness. A novel deep-learning approach for existing robotic devices that can be applied to future robots without modification was introduced in [34]. Robots equipped with miniaturized sensors extracting industrial process data with high levels of accuracy and robustness, perform tasks and operate in collaboration with humans. Motion control systems have enabled the adaptation of systems to harsh industrial conditions, and all data related to sensing, operation, and control are interconnected using communication networks. Fault diagnosis strategies provide feasible control actions when abnormalities are detected [35]. The next-generation paradigms in smart manufacturing analyses such as Customized Parallel

Simulation Scene Generation; Massive-User Hyper Spatiotemporal Immersive Collaboration; Seamless Human-in-the-Loop Manufacturing Participation; and Digital Assets Circulation and Transactions carried out in 73 papers. It results from a conceptual IMverse Model of the industrial metaverse for smart manufacturing and its corresponding novel characteristics were proposed in [36]. Key technologies for cyber-physical coordinated situation awareness and active defence against cyber-attacks are introduced. An efficient deep learning-based autonomous 5G beam management scheme is characterized and then proposed to predict the most secure beam pair indices between the base station and the user.

The security aspect of the 5G network is modelled and evaluated in [37]. It proposes an approach that models trained using different loss functions to be aggregated. There are two addressed challenges when starting each local training round, the edge entity can check whether it is under attack, and trained models using different loss functions can be integrated through an aggregation process. The tracking control problem of state-constrained high-order nonlinear CPSs with dynamics and external disturbances against malicious attacks performance characterized. The growth of AI and Machine Learning (ML)-dominated applications, and distributed intelligence solutions are gaining momentum with relevant security/privacy challenges addressed for cloud facilities, edge nodes and end-devices in [38]. Examples include a smart grid, a self-driving car, robots, a smart manufacturing plant, an intelligent transportation system, a smart city, and IoT instances connecting new devices for new data streams. To fulfil requirements at least a satisfactory level, learned skills should equip students with the necessary technical expertise to design, develop, and maintain currently in use Industry 4.0, S-CPS, NG-CPS, and Industry 5.0.

We have started our investigation by applying the Karush–Kuhn–Tucker conditions method [39] to identify satisfying solutions for advanced CPS engineering education applications. Unfortunately, during the collected information characterization introduced in [40], we were satisfied that there are no feasible optimal solutions that could be developed and implemented for our needs yet. Figure 4 visually represents the relationships among the three main components extracted from reviewed state-of-the-art literature concerning the newly introduced authors' educational requirements position. The two new blocks, "AI-powered Cyber Security" and "Education" give attention to new required characteristics and connections between AI, Education and advanced NG-CPS engineering.

IV. BRIEF OVERVIEW OF OUR EDUCATION METHOD

Mass education and the decreasing average level of knowledge in higher education, especially in beginner engineering courses, make it difficult even for motivated instructors to keep a high standard of training. The time required to achieve the desired results increases to the point where it becomes unmanageable for trainers.

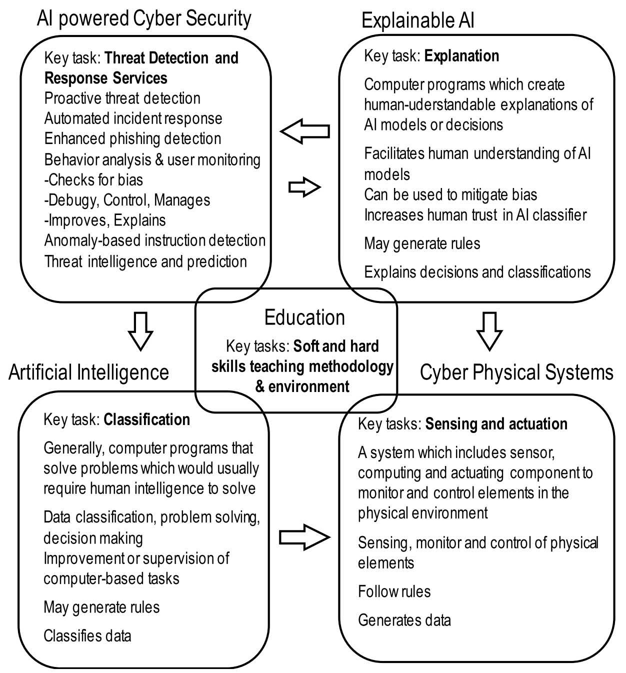

FIGURE 4. Extended classification diagram showing the characteristics and connections between AI and CPSs with Cyber Security and Education.

Our teaching method is traditional in that we are motivated to support students to be successful. To do this we selected the Challenge-based learning method which has gained traction as an active and innovative approach in engineering education, introducing real challenges and open questions to the classroom regarding environmental sustainability and issues faced by Industry 4.0. CBL is related to other active methods, problem-based learning (PBL), scenario-based learning (SBL) and project-based learning (PjBL), all designed to acquire or mobilize knowledge. Among different categories of teaching methods, we start with teacher/instructor-led where we anchor students to be self-motivated engineers. Based on our experience in engineering, we have concluded that excellent engineers will be students *who honestly investigate the causes of their engineering mistakes*.

According to the Keep it Structured and Simple (*KISS*) principle, most systems work best when they are simple, clear, and structured. The application of the KISS principle would be fruitful in engineering pedagogy, supplemented by two new aspects: *Smart and Short* "*Less is More*".

The second stage is the student-centred or learner-directed phase. Students must face the fact that they will be held responsible for the success of the organization on the one hand, and for the accidents and pollution that occur in the technical systems entrusted to them on the other.

It is a basic requirement for an engineer to be able to work in a team, group-oriented cooperative phase, where the team writes and presents technical reports according to the standards, production technology expectations, and customer

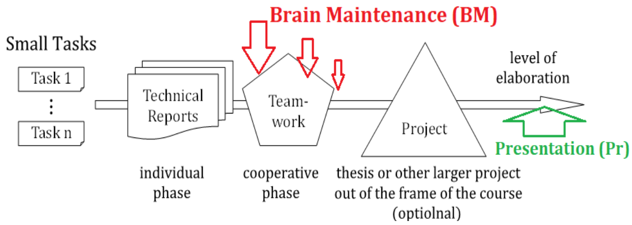

FIGURE 5. Levels of activities.

needs, taking into account the available resources. Engineers believe in the *"Make Things Happen - Let's Make It Together"* principle. Notably, MAKE is used rather than DO. Engineers MAKE things, they leave the creation of theories about how the world could be better for others. We believe that engineering education, or at least its final stage, should be considered part of engineering activity, in the sense that the same rules of knowledge transfer, evaluation, and collaboration apply as in industry. The "new" complex teaching methodology involves the main elements presented.

Following these basic principles, the most important features of our method are reducing the training for real-life expectations ("Small tasks"); developing writing and presentation skills; developing individual effectiveness; regular assessment of general and specific engineering knowledge ("Brain Maintenance"-BM); improvement of the project approach; development of teamwork and negotiation skills. The activity sequences of the CLB-based Brain maintenance and Nobel beer method are illustrated in the Figure 6 flowchart.

A. SMALL TASKS

The activity of students is based on "Small tasks"-ST, which are course-related technical problems or questions that are like what a "Boss" normally submits in industry. Solving them is similar to what engineers do when faced with a new task: they assess the technical, financial, and management requirements and resources needed to solve the task and propose a solution. As a result of the survey carried out in the summer of 2023, MATLAB/Simulink self-learning opportunities have been actively introduced in CPS education. At the ST level, only two basic topics need to be completed and certified, but during the semester, additional topics corresponding to the student's interest shall be developed and certified. Further descriptions of related satisfactory engineering can be found in [41]. An ST must first be developed individually as a Technical Report (TR). In one semester, 3-5 TRs are prepared per person. Later, the solution of some STs is further developed by the students in the framework of teamwork. Complex tasks can later lead to diploma theses or larger student projects.

B. TECHNICAL REPORTS

To the "Boss": Today's people consider writing less and less important, even though technical writing is a crucial professional skill for engineers. When you send a technical report (TR) to the "Boss", who is always busy and has very limited time for "troublemakers", you must be very punctual, short, and well-structured.

C. TEAMWORK TASKS

The Teamwork Tasks -TT is a more detailed elaboration of STs in groups of 3-4 people. Students must learn how to work in teams, they must organize all necessary activities for the fulfilment of the task. It starts with the 4 best student-created teams and ends with the least motivated student teams. This new team organization method increased the quality and efficiency of the teamwork. An article is under development on how the newly developed methodology supports understanding of Applying CPS Framework Security Risk Mitigation Techniques based on the OSI Reference Modell, TCP/IP Reference Modell and Wireshark applications in case of combined Cyber Security and Electronic Warfare Attack.

D. BRAIN MAINTENANCE

The BM test is a written general engineering intelligence test that is only partially subject-specific and represents the basic requirements of the engineering community.

E. THE PRESENTATION

At the end of the semester plays the role of the oral exam. It is a role-playing game where the teacher is the "boss", the student is a "subordinate", and the presentation subject must be "sold" to the group, as an "important client". The usage of any kind of external support such as ChatGPT, Copilot, Tablet, or Smartphone during Brain Maintenance tests and Presentation/oral exams is strongly prohibited.

F. REWARDS

The final mark is determined after the Presentation showing the presentation skills of the future engineers. At most four "Nobel beers" serve as traditional grades, and can be collected in a semester. Here internal motivation and a sense of duty come to the fore, and evaluation is linked to greater accountability.

V. GENERAL OBSERVATIONS

A team of engineers, mathematicians, and experts in human resources management and educational methodology analysed and evaluated the implemented education method for CPS subjects to address the complexity of the educational objectives and findings.

In the 2023 semesters, the new method was applied in three courses related to the topic of CPS including sensor/radar technologies and cyber security. These courses are taught in the 5th and 7th semesters in the Hungarian and international programs. Since its introduction (September 2021), 346 students (193 Hungarian - some in multiple subjects and 163 foreign students, have been involved. The work continued in 2024 with the upgraded method developed on the recommendations made in 2023. Since September 2021,

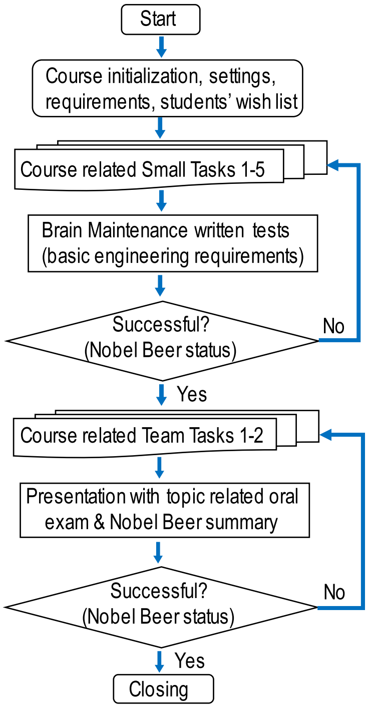

FIGURE 6. Activity sequences of the CBL so-called "Brain maintenance".

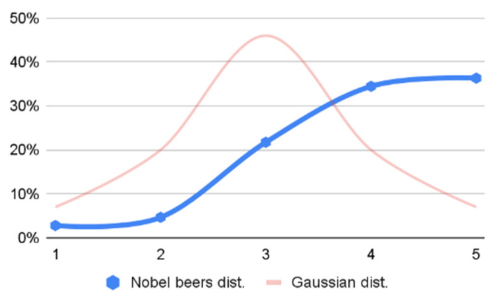

FIGURE 7. Distribution of the grades from 2021 to 2024 (491 cases).

student enrolment increased to 491 students (data collection deadline: 30 June 2024) including 197 Hungarian students and 163 English foreign students. The distribution of grades is very different from the normal distribution as the frequency histogram in Figure 7 shows. The proportion of excellent (5) and good (4) grades is very high compared to the results in other advanced professional subjects in the mechatronics major.

This distribution indicates the student's improved interest and their progress in our teaching method even with the subjective influences of teachers. In future work, more data will be collected on the effectiveness of our methodology to increase the reliability of the statements.

Details of students' efficiency by task group are shown in Table 2. Since our methodology is a special combination of techniques and the lecturer's activity, only a partial comparison would be possible. The analysis reveals that

TABLE 2. Students' performance evaluation by tasks.

BM	ST1	ST2	ST3	ST4	TT1	TT2	Pr	Grade	
1,00	0,31	0,47	0,42	0,45	0,13	0,18	0,53	0,49	BM
	1,00	0,41	0,47	0,37	0,23	0,25	0,51	0,58	ST1
		1,00	0,70	0,55	0,34	0,26	0,53	0,62	ST2
			1,00	0,52	0,22	0,45	0,50	0,50	ST3
				1,00	0,12	0,36	0,45	0,38	ST4
					1,00	0,27	0,23	0,16	TT1
						1,00	0,11	0,34	TT2
							1,00	0,78	Pr
								1,00	Grade

Pr (Presentation) is the strongest predictor of student performance (0.78), followed by ST2 and ST1 with moderate correlations (0.62 and 0.58). While TT1 and TT2 show weak correlations with grades (0.16 and 0.34), student interviews and feedback highlight their importance in developing essential soft skills, such as teamwork and communication, which are crucial for success in the job market. Therefore, emphasis should be placed on enhancing Pr and ST2, while maintaining teamwork tasks for their long-term employability benefits.

The change in student performance can be examined for the 31 and 27 Hungarian students who took a total of three courses using this method in two different semesters. During the period studied (in spring 2022 and spring 2023), using the new method 31 students were assessed in three different (but related) courses.

Although this research is based on interviews, it is notable that during the consequent courses, progress could be observed. Namely, 25% of students could keep the highest grade (grade 5 in the Hungarian system), and 39% achieved a higher grade in 2023 compared to 2022. For the group of 27 students (in spring 2023 and spring 2024), these changes have led to positive consequences.

Figure 8 shows that the combined soft and hard skills improvement was successful, demonstrating the relevance of a qualitative assessment of the improvement in 'skills'. The change in student performance can be examined for the 31 and 27 Hungarian students who took a total of three courses using this method in two different semesters. The effectiveness of the method is proven by the fact that less than 3% of the students failed to complete the course requirements, of those who did successfully, 40% of the students completed the course with an excellent (grade 5).

See Figure 9. There has been a significant increase in the percentage of students with excellent grades and a decrease in the percentage of students with lower grades. This positive change is due to the improvements made to the method, which took into account student abilities and needs, without abandoning the quality standards expected by the faculty.

Note: 29 students in the dataset have completed two similar courses using this method, but their performance changes cannot yet be examined because they were in the same semester for both courses. However, the change in student performance can be examined for the 31 and 27 Hungarian students who took a total of three courses using this method

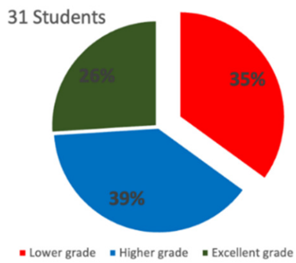

FIGURE 8. Student's improvement based on the ratio of later and earlier grades (31 students).

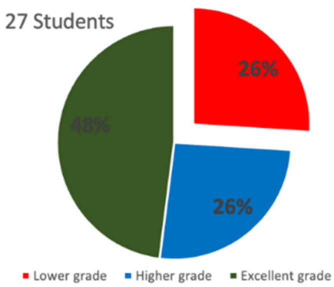

FIGURE 9. Student's performance based on the ratio of later and earlier grades (27 students).

in two different semesters. These changes have led to positive consequences for the group of 27 students (in spring 2023 and spring 2024). There has been a significant increase in the percentage of students with excellent grades and a decrease in the percentage of students with lower grades. This positive change is due to the improvements made to the method, which took into account student abilities and needs, without abandoning the quality standards expected by the faculty.

The task group summarized different aspects of the newly implemented changes that were implemented for the semesters starting in September 2023 and ending on 30 June 2024. During the interviews, several students mentioned the challenges of teamwork. One student's opinion was this: ''The biggest challenge of the method this semester was team building, given the different backgrounds of the team members from different countries. Although this diversity was beneficial, it was challenging in terms of getting to know each other and adapting to different ways of working''. Details of the study on the related soft skills will be introduced in the following manuscript.

The literature review indicates that the proportion of R&D positions importance is constantly increasing, so universities must prepare students for this role. A goal of our method is to increase students' interest in scientific research. We believe that improving soft skills parallel to hard skills in the context of prestigious engineering courses can also lead to high motivation in scientific activity. The number of students presenting new scientific results in a field is a good indicator of the quality of education. We hypothesized that students who were exposed to the new teaching method would be more active in research and be successful when they participated in the work of the Scientific Students Association (TDK) or international engineering conferences. TDK is an essential form of talent management in Hungarian higher education, providing an excellent opportunity to start a research career by joining the research projects of the engineering departments and carrying out independent scientific work. In the frame of the research, we studied the TDK activity of mechatronics students and found that before the introduction of our method in 2021 the average number of theses per year submitted to the mechatronics section of TDK was 3 and only one of them was related to CPSs. The effect of our method was that 5 students submitted their thesis to the mechatronics section of TDK at the faculty level in 2022, and 3 of them attended courses where our teaching method was used. In 2023 these data were 8/7. The rankings were as follows: 1 first, 1 second, and 1 third place in 2022; 1 first, 2 second and 1 third place in 2023; 8 applicants from 10 learned this method: in 2024. The participation graph of the Scientific Student Conference, Figure 10, shows that students taught with this method participate more and more often and successfully in the conference. It can be observed that other educators, sensing the results, accept such challenges and also improve their training.

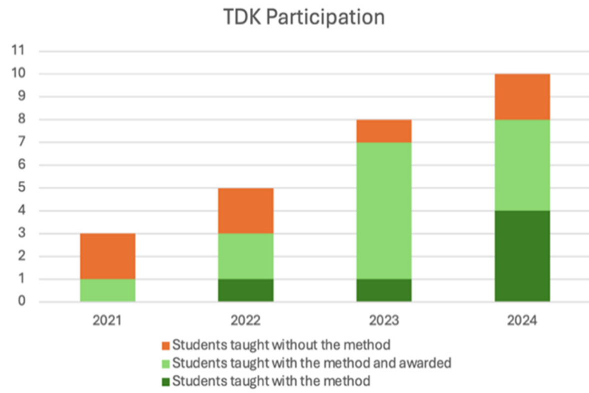

FIGURE 10. Mechanics students' participation in TDK.

Furthermore, it can be observed that alongside the growth in the number of submitted papers, the number of award-winning students has also increased significantly. This indicates that the method facilitates the production of high-quality scientific work.

Another achievement of the mechatronics students was the acceptance of four conference papers at two IEEE conferences in 2022 and six conference papers in 2023. These papers were the result of project teamwork with about 4 student authors each, certainly with the contributions of the faculty staff. Four conference papers were written or contributed by 7 female students. We plan to write a manuscript about the observations and this new method's effectiveness for the ''Women in Engineering'' subject shortly.

Not only the research papers were submitted, but also the students gave presentations at international conferences.

TABLE 3. Mechatronics students' papers in last years.

Student name	Published paper	To whom may useful
A. Masuk	[42] [43] [44] [45] [46][47] [67] [68][69]	CPS Sensors, robotics, AI subsystems
G. Korsoveczki	[48] [49] [50] [55] [56][57][64]	Robotics, CPS, AI subsystems
K. Á. Kis	[50] [51] [57]	Drone, CPS, RF In Situ measurements
O. Kende,	[42] [48]	robots, CPS sensors
K. Illyés,	[47] [52]	AI, CPS sensors
L.S. Lakatos,	[55]	robots, CPS sensors
Z.L. Osváth, A. Kovács,	[53] [62]	LiDAR CPS sensors
Inti Toalombo,	[58] [60]	Smart CPS sensors
Y Elkamshoushy	[64]	robots, CPS sensors
Livia Antal	[65]	AI classrooms, sensors
H H Sayed,	[61]	sensors, AI sensors
Muhammad Umer Jamil	[59] [63]	Smart CPS sensors
Amin Ul Wadud	[66]	ADAS, CPS sensors
A. Jubangaliyeva, E. Shoshi, P. E. Pinto, N. A. Bealallo	[44]	robots, CPS sensors PCB antenna
Mayar A. A. Taleb	[56]	robots, CPS

Note: Paper [55] got the Presentation Award, of the IEEE 28th International Conference ELECTRONICS 2024

Results related to the development of quadcopter drones in a mechatronics project have been published as one of our Engineering Faculty research interests. The realization of different engineering solutions and educational challenges are essential parts of mechatronics studies. Other manuscripts in this area have been submitted to other (non-IEEE) international conferences.

The updated version of the newly developed method increased the student's activities in the 2024 half-year. Many manuscripts were developed and submitted to IEEE-managed conferences in the first 5 months of 2024. Table 3 shows the most successful student papers published in IEEE conferences and internationally recognized journals.

Based on these results, we can conclude that our educational method was fruitful, especially from the point of view of our students' future scientific activities.

VI. OPEN CHALLENGES AND FUTURE DIRECTIONS

Conscious personality development and education with an engineering coaching approach in a professional environment are not typical. In our Extended Challenge-based learning method, there is a definite intention to achieve these goals. The greatest strength of it is that it can create intrinsic motivation in the students through the fact that they understand the purpose of the method and can identify with it. They know what competencies are important for them to be successful engineers in the future, and they gave feedback that they improved in these competencies thanks to the method. Among the elements of the method, engineering reports are considered the most effective, but it is also very beneficial that they can work in a team and learn to present. An advantage of the extended CBL course organization is that the unavoidable stress appears earlier and can be dealt with in time. The grades for "Nobel beers" and the written test "Brain Maintenance" are unusual, but compared to normal methods got positive feedback as students have a great sense of humour. In most courses, the most important exams are scheduled at the end of the semester, causing a high level of stress that is sometimes unmanageable.

We have identified it as a weakness: not all instructors have adequate pedagogical and psychological knowledge to effectively implement the method, and many students are assigned to one instructor. From the student's point of view, due to the constant accountability, there is a constant stress situation to be reckoned with, which both the development of self-awareness and the attitude of the instructors can help a lot in dealing with.

Among the possibilities, we included the inclusion of AI, as it would make the evaluation process much easier for the instructors and would also mean a more objective evaluation method for the students. If more instructors could be trained to use the method, it would be possible to teach with the help of the method on several course evenings. Examining the student side, the inclusion of a self-knowledge block in the method using AI assistants can be formulated as a possibility.

An unfair and fair assessment procedure is considered a source of danger if a uniform system of criteria is not developed in the future. Students are not always able to accept the evaluations received from their peers. Another danger can be if the students experience such a level of stress during the semester that results in a reduction in their performance (distress) and they cannot deal with it effectively. Those group dynamic processes that, if not handled properly, can impair the group's performance should be considered a danger. It is worthwhile to constantly monitor the motivation of the students, and if we find that they perform only to get the reward or to avoid the punishment, then the process must be reviewed the range of motivators must be renewed, and the purpose of the method must be re-outlined so that don't lose sight of the original goal.

VII. CONCLUSION

This study depicts emerging challenges of rapidly growing cyber-physical systems, I4.0, and technology such as AI-supported cybersecurity and education 4.0 during its transformation to I5.0 and E5.0. The study points out that the Extended Challenge-based learning method allows the lecturers with the students to improve engineering educational performance permanently during the semester. The strength of the method is continuous development and learning under permanent feedback. This work emphasizes and demonstrates the applicability and essential successful elements of the synergy of the Technical Reports to the "Boss", individual and team participation, the "Brain Maintenance" test, the assessment with "Nobel beers", and the Presentation skills development at the end of the semester. Assessing competencies before, during, and after engaging with extended

CBL can be crucial for achieving the desired engineering competency development and subsequent challenge solution.

The proposed application's benefits can be drawn from the method's uniformly high level of acceptance such as the increased number of issued and accepted student papers and success in young scientific activities. The literature review results and our findings show that the extended CBL method is well suited to the engineering competencies that students also consider important to their development, which significantly increases the efficiency and value of the training, laying a foundation for their career. Furthermore, the method can also be successfully applied in an international environment, which shows the global nature of our ideas and should be further developed in international cooperation. In this area, engineering creativity is a particularly important factor. The message and experience of the courses is that in the age of AI, ''students should pay special attention to the maintenance of their brains. If they do not do this, their brains will become lazy, and without it, they will not be able to become the good engineers of our time''.

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