Article

Cyber-physical Systems Research and Education in 2030: Scenarios and Strategies

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Abstract

Future cyber-physical systems (CPS), such as smart cities, collaborative robots, autonomous vehicles or intelligent transport systems, are expected to be highly intelligent, electrified, and connected. This study explores a focal question about how these new characteristics may affect the education and research related to CPS in 2030, the date identified by the United Nations to achieve the Agenda for Sustainable Development. To this end, first, we have conducted a trend spotting activity, seeking to identify possible influencing factors that may have a great impact on the future of CPS education and research. These factors were clustered in a total of 12 trends – four certainties; namely connectivity, electrification, data and automation – and eight uncertainties; namely intelligence, data ethics, labour market, lifelong learning, higher education, trust in technology, technological development speed, and sustainable development goals. After that, two of the eight uncertainties are identified and used to construct a scenario matrix, which includes four scenarios. These two uncertainties – the so-called strategic uncertainties – are: fulfilment of sustainable development goals and the nature of the technological development, respectively. These two important uncertainties are considered to build the scenarios due to their potential impact on the research and education of CPS. For instance, sustainable development goals are significant targets for many initiatives, organisations and countries. While 2030 is the deadline to achieve these goals, the relationship between the sustainable development goals related to CPS research and education is not studied well. Similarly, the speed of technological development is seen as a driving force behind future CPS. However, the effect of this speed to CPS research and education environment is not known. Different outcomes of the chosen two uncertainties are, then, combined with the remaining trends and uncertainties. Consequently, four scenarios are derived. The Terminator scenario illustrates a dystopian future where profit is the driving force behind technological progress and sustainable development goals are not accomplished. In contrast, The Iron Giant scenario represents the successful implementation of the sustainable development goals where technological development is the force behind the accomplishment of these goals. The scenario called Slow Progress represents a future where gradual technological improvements are present, but sustainability is still not seen as concerning the issue. The Humanist scenario illustrates a future where slow technological development is happening yet sustainable development goals are successfully implemented. Finally, the scenarios are used to initiate discussions by illustrating what the future of research and education could look like and a list of strategies for future CPS research and education environments is proposed. To this end, we invite educators, researchers, institutions and governments to develop the necessary strategies to enable data-orientated, continuous, interdisciplinary, collaborative, ethical, and sustainable research and education by improving digital fluency, advancing digital equality, contributing to new ways of teaching complex thinking, expanding access to learning platforms and preparing next generations to adapt for a rapidly changing future of work conditions.

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... The creation of educational cyber-physical platforms is a challenge, but also a necessity [6] . In these spaces, continuous blended (face-to-face and virtual) learning is possible, tailored to the personal characteristics of each student. ...

... Nevertheless, the crossing of the two marks -the total points together with the points of the open question, denotes the following: He or she belongs to the set μ VeryGood ∩ ν Excellent with 0.79 degree; to μ Good ∩ ν Excellent with 0.21 degree; to the set μ VeryGood ∩ ν VeryGood with 0.005 degree, and to the set μ Good ∩ ν VeryGood with a degree 0.005 of the matrix in Table 1. Consequently, we can assign him or her Excellent (6) . ...

... Now, by way of illustration, let a student have a total test score of 57 points and open question result of 18 points (p = 57 and q = 18). As shown in Table 3, after the fuzzification, the student will be marked with Excellent (6) , which coincides with the traditional evaluation. If we analyze another learner that has received 42 points (which corresponds to Good (4) in the traditional scoring system) and 17 points for the open-ended item, it is seen from Table 4 that after the correction that particular learner should get a higher mark, namely Very Good (5). ...

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... The creation of educational cyber-physical platforms is a challenge but also a necessity [5] . In these spaces, continuous blended (face-to-face and virtual) learning is possible, tailored to the personal characteristics of each student. ...

... He or she belongs to the set of very good marks with a degree of μ VeryGood (49) = 0.79 and to the set of good grades with a degree of μ Excellent (49) = 0.21. Normally, he/she will be assessed as very good (5) . Nevertheless, the crossing of the two marks-the total points together with the points of the open question-denotes the following: according to the matrix in Table 1, he or she belongs to the set μ VeryGood ∩ ν Excellent with 0.79 degree, to the set μ Good ∩ ν Excellent with 0.21 degree, to the set μ VeryGood ∩ ν VeryGood with 0.005 degree, and to the set μ Good ∩ ν VeryGood with 0.005 degree. ...

... When it receives a request from the AA ambient, it selects the requested data and sends it for analysis. The process of this ambient is represented in (5) . ...

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... Gürdür Broo et al. [42] conducted a trend-spotting activity, seeking to identify possible influencing factors and trends that may have a great impact on the future of engineering education and research. According to this article, in total 44 different trends are identified. ...

... These influencing factors are listed in Table I. Interested readers can find all of the trends at the appendix of the earlier work in [42] . ...

... To support the design, development, and manufacturing of the new system of systems in line with the trends that have been introduced in the prior subsection; next-generation engineers are expected to be articulate in different technologies, methods, and methodologies [42] . For instance, intelligence is very much

related to artificial intelligence, machine learning, neural networks, data, and similar concepts. ...

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... In their study, Broo et al. (2020) engaged in a trend-spotting exercise to uncover influential factors and emerging trends that could significantly shape the future of engineering education and research. They identified a total of 44 distinct trends, out of which 12 were chosen as the most influential factors. ...

... In summary, in support of work by Broo et al. (2020) , our findings highlight the interconnectedness of mentorship, technology integration, and collaboration in engineering education. Effective mentorship provides guidance and support, while technology tools supplement traditional learning and offer continuous skill development opportunities. ...

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... Systems thinking is necessary to cope with the complexity and interconnections of today world [1]. For this reason, several system classifications, such as, Cyber-Physical Systems [2] and Socio-Technical Systems [3], exist to focus attention on their main constituent elements and their inter-relations. Among them, Cyber-Socio-Technical Systems (CSTS)s, also known as Cyber-Physical-Social Systems (CPSS)s [4], are socio-technical systems that include interconnected cyber technical artefacts [5], i.e., devices with both computational and physical capabilities. ...

... A knowledge entity represents one of the possible knowledge dimensions referring to the process and pertains to an agent, which plays a role in the process (e.g., sharp-end operator or blunt-end operator). 2 The WAx Framework ontology is available at [48]. ...

Development and measurement of a resilience indicator for cyber-socio-technical systems: The allostatic load

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... Automation and data-driven decisionmaking, hallmarks of CPS, could displace traditional jobs, creating a dichotomy in the workforce [8]. Policy responses and educational reforms are thus imperative to navigate this transition [9] . This paper seeks to elucidate the complex relationship between advanced data capturing, networking technology, and economic security. ...

Cyber-Physical Systems as a New Frontier for Economic Security: The Impact of Advanced Data Capturing and Networking Technology on…

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... This comprehensive review navigates through recent breakthroughs across multiple facets of biomedical engineering, encompassing medical imaging, artificial intelligence, wearable devices, regenerative medicine, and nanotechnology. Each of these domains represents a distinct frontier where engineers, scientists, and healthcare professionals collaboratively push the boundaries of what was once deemed possible (Broo et al., 2021) . ...

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... Our transformation scenario is Cyber Growth. The transformation scenario may refer to the improvements of online learning while we will still be doing hybrid learning for specific areas of studies and social interaction needs [92] . Distinctive hybrid learning incorporated the principle of time, task, and evaluation [93]. ...

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... In the fourth paragraph of the 1945 Constitution, education is also employed as a driving force for culture and habits, signifying that teaching the nation's life is a type of solid burden in reaching virtue for the Indonesian government (International Commission of Jurists, 2022). Education has evolved swiftly alongside the advancement of technology (Gürdür Broo et al., 2021) . This may be attributed to systems and learning techniques that are supported by digital world technology. ...

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... The proposed high-level language goes beyond existing applications of process modeling and represents design models [81], and also allows for IoT process modeling [82] on a single layer of abstraction. Finally, the presented capabilities for digital validation and simulation meet the transformation requirements triggered by technological advances [83] . ...

Digital Process Twins as Intelligent Design Technology for Engineering Metaverse/XR Applications

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... The Cyber-Physical Systems (CPSs) are the novel generation of smart systems with extensive usages in different contexts such as electronic industries, aerospace, transportation, civil substructure, health-care, manufacture, power systems, flight control systems, water distribution systems, intelligent buildings, advanced agriculture, and smart grid systems, which have received impressive attention of the scientific community, especially in recent decade [1] [2][3][4][5]. CPSs have provided the deep integration between the physical space and cyber-space, in which physical world components (i.e., sensors, actuators, and physical systems) are linked with cyber-world components (i.e., controllers /computers) through wired/wireless communication channels for processing information and providing the physical systems suitable performance via the appropriate control. ...

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... blishment of "collaborations" and "partnerships", as well as those that deal with the "interdisciplinary" approach and "health issues". As a highlight, Kuo et. al (2020) analyzes the role of community culture in food product innovation courses considering the SDG agenda. Regarding the interdisciplinary approach, this can be found in the studies by Broo et. al (2021) and Ruiz et. al (2019), among others. As for studies on establishing collaborations and partnerships, we can highlight the papers by Sugandhar & Chaudhary (2017) and Moon et. al (2018). ...

The adoption of the Sustainable Development Goals by the scientific community: a study on the São Paulo Research Foundation (FAPESP)

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... Theoretical approaches make use of novel and non-mainstream methods for engineering education, such as storytelling and future-casting (Gürdür Broo et al., 2021) , scenario-building (Hansen, 2021;Weiss et al., 2021), critical literacy techniques (Lord et al., 2018), and humanist, cultural, or religious readings (Bielefeldt et al., 2021;Laato & Sutinen, 2020). An overarching goal of theoretical approaches is to enhance the awareness and respect for other cultures and traditions, as well as of envisioning culturally relevant strategies for better futures. ...

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... These systems are based on CPS, which integrate physical components, such as machines, robots, and sensors, with software and networked information systems, [82]. CMS are capable of providing a high degree of automation, lexibility, and scalability to the manufacturing process while also reducing costs and improving product quality [24] . They can also provide real-time feedback and data analytics to optimize the manufacturing process [88]. ...

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... Therefore, in Industry 4.0, the application of CPS is continually changing and expanding. Many CPS-based applications have been developed or implemented in a wide range of industries, such as aircraft transportation systems [50], battlefield surveillance [51], chemical production [52], energy [53], agriculture (food supply) [54], healthcare [55], education [56] , industrial automation [57], manufacturing [58], mobile devices [59], robotics [60], transportation [61], and vehicular [62]. Researchers and practitioners may have to reach a compromise among their aims to create a combination of benefits and cost, based on desired CPS and Industry 4.0. ...

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... (iii) integration of cyber and physical world with explicit use of sensors (ii) integration of cyber and physical world with communication technologies (iv) IoT as CPS (i) integration of cyber and physical world [13] [14] [19] [78] - [84] [9] - [12] [85] - [102] [15] ...

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... On the other hand, the adoption of BIM in civil engineering curricula is a matter of survey, debate and systematic scrutiny [2]. When it comes to cyber-physical systems in AEC classrooms, developments are also identified [3] [4] This paper shows the key takeaways of "de las MATES al STEAM". The project resulted on the design of set of activities for embedding Construction 4.0 concepts within a civil engineering curriculum. ...

Learning path for Construction 4.0 based on tinkering and STEAM

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... Organize a series of valuable courses and conferences for employees and cybersecurity workers [26] User Education A

recently discovered security vulnerability operated by a group of hackers that attacks computer systems. This term indicates that a system administrator has just understood the weaknesses of the system but lacks the time to fix or stop the attack [32] Zero-Day Exploit A sophisticated attack that encodes system data and applications and is particularly difficult to detect [33] ...

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... Engineers and scientists should clearly understand the concept of artificial intelligence, machine learning, neural networks, and other modern online technologies to apply CPS [68] . Mohamed et al. [66] proposed to design the CPS system that consisted of several complex software and hardware, with a high-level abstraction of the system. ...

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... Nowadays, CPS are ubiquitous, with different functionalities and capabilities, often supporting critical missions that have significant economic and societal importance. The emerging CPS, such as smart cities, autonomous vehicles, and modern transportation systems are expected to be highly intelligent, electrified, and connected (Broo et al., 2021) . Indeed, major trends in new wireless technologies (e.g., 5G/6G) focus on enabling wide-area connectivity for remote control of previously unconnected assets (Oughton and Lehr, 2022). ...

The State-of-the-Art Survey on Optimization Methods for Cyber-physical Networks

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... The Cyber-Physical Systems (CPSs) are the most eminent emerging systems and modern generation of intelligent systems. The CPSs application field is very immense and includes the aerospace, smart cities, electronic industries, power systems, flight control systems, water distribution systems, environmental monitoring, transportation, civil substructure, health-care, manufacture, intelligent grid systems, smart buildings, advanced agriculture, etc., which has attracted the impressive attention of the scientists and researchers, especially in recent decade [1][2] [3] [4]. The cyber-physical systems have offered the deep integration between physical-world and cyber-world, in which physical space components (i.e., sensors, actuators and physical systems) are connected to cyber space components (i.e., controllers or computers) via wired/wireless network layers for processing information and supplying the physical systems' proper performance through the desirable control techniques. ...

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... In this research, we suggest a strategy for improving the robustness of jamming systems based on DSSS approaches. [2] As many devices, communications channels and media utilized to construct the network, security and privacy are the main issues. Power requirements, media and storage are also necessary. ...

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... As an example, I mention the paper of Törngren and Grogan (2018), which considered complexity as the major challenge of designing next-generation CPSs. Very recently, Broo et al. (2021) identified intelligence, connectivity, and electrification as three main challenging properties of CPSs. They regarded these as rather new dimensions and showed the differences with the systems that our traditional applied research and engineering education are predominantly experienced in. ...

Designing next-generation cyber-physical systems: Why is it an issue?

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... Education is also used as a driving force for culture and habits in the meaning of the 1945 Constitution in the fourth paragraph, implying that educating the nation's life is a form of solid burden in achieving virtue for the Indonesian government. According to Gürdür Broo et al., (2021) , education has developed rapidly, along with the growing technology. This can happen due to systems and learning methods supported by the digital world's technology. ...

The Readiness of Education in Indonesia in Facing The Society Era 5.0

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... Sensors and actuators that interact with the environment are widely used, where smart devices collect data (mostly from sensors) and use cloud computing or similar technologies to make comprehensive and timely decisions (act on actuators) [4]. This phenomenon is depicted in the form of the cyber-physical system (CPS) [5] . Here, the physical systems collect information data from the physical world and send them to the digital twin computing modules residing in the virtual world through communication technology. ...

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... The aggregated decision makers' judgments of alternatives for criteria are aggregated using Equation (7) and as mentioned in Table 7. Apply the three steps for TOPSIS as follows: normalization is applied using Equation (9); results are depicted in Table 8. The positive and negative regions are applied using Equations (10) and (11), with the results presented in Table 8. Compute negative and positive regions using Equations (12) and (13) to achieve the relative closeness using Equation (14), as mentioned in Table 9. Figure 5 shows the final ranking as follows: IBM, Azure DT, oracle, and CISCO. ...

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... As a highlight, Kuo et al. (2020) analyzes the role of community culture in food product innovation courses considering the SDG agenda. Regarding the interdisciplinary approach, this can be found in the studies by Broo et al. (2021) and Ruiz et al. (2019). As for studies on establishing collaborations and partnerships, we can highlight the papers by Sugandhar and Chaudhary (2017) and Moon et al. (2018). ...

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... e Effect of Teaching Reform of Physical Education Industry. A large number of studies show that regression analysis and other

methods focus on controllable objective factors such as the study by Broo et al. [2] , ignoring the correlation between controllable and uncontrollable factors. erefore, there is a large deviation between the theoretical results and the actual results of the teaching reform of sports industry [3]. ...

An Evaluation Model for the Teaching Reform of the Physical Education Industry

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