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SURVEY

Digital Tools, Technologies, and Learning Methodologies for Education 4.0 Frameworks: A STEM Oriented Survey

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ABSTRACT The correlation between learning and teaching technologies is multidimensional and complex, thus, the digital tools that can help students turning information into knowledge define the crucial role of pedagogical practice. Open access to hardware and software tools is a focal point for advancing learning. In sciences, lab-based experiments constitute a vital part of curricula that bridge the gap between theory and practice. Access to remote lab tools is possible by pairing simulators, emulators and actual equipment, located in various geographical locations. Under this premise, Education 4.0 defines a new learning framework aligned with the fourth industrial revolution digital requirements. These constitute smart sensors, Artificial Intelligence (AI) and Robotics. In this context, University graduates need to prepare themselves with complex problem solving and interdisciplinary problems. To this end, contemporary Science, Technology, Engineering and Mathematics (STEM) teaching practices should be present along the way. Digitally competent students need to learn from a modern and adjustable curriculum tailored to cover necessary skills related to Internet of Things (IoT). Therefore, the digitization of University campuses, including smart IoT, Information and Communication Technology (ICT) and Fifth Generation (5G) automation infrastructures is necessary. In this work, we carry out an extensive STEM oriented survey which highlights and categorizes all contemporary digital tools and technologies needed to support future graduates. Moreover, we focus on contemporary pedagogical and didactic approaches to support Education 4.0 skills. We match contemporary methods with lab types, expected learning outcomes and open software and hardware tools, as imposed by the Education 4.0 framework. Our scenarios mainly focus on University education and consider smart sensors, IoT, 5G technologies, which are the basic building components for students' digital competencies to meet Education 4.0 requirements.

INDEX TERMS Education technologies, 5G, Industry 4.0, IoT, smart campus, STEM.

I. INTRODUCTION

Learning process should be based on material organized around theoretical principles and experimentation and not on memorizing isolated elements and processes. The majority of teachers focus on how to succeed longer and deeper learning outcomes from their students by involving them to hands on activities. In this work, we provide an extensive and multi – criteria Science, Technology, Engineering and Mathematics (STEM) oriented review, on the state-of-the-art digital tools and technologies, based on IoT and 5G telecommunications, along with their use case correlations to contemporary teaching and learning methods, for University curricula. In the sequel, we discuss and propose ways about how learning is

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aligned to Education 4.0 framework of action – based learning approaches, to support digitally competent future citizens.

Education 4.0 is a learning technique associated with the Fourth Industrial Revolution and focused on transforming the future of education through advanced technology and automation. The goal is to integrate technology into the curriculum, change the learning process, leverage technology and enhance the university experience. The developments in the field of technology with artificial intelligence, machine learning, chatbots, unimaginable internet speeds with 5G and 6G, in a horizon of at least seven years, make it imperative that education adapts to these changes, in order to be able to follow the trend and the needs of students, who are the workers of the future. There is a constant need for jobs in the technology sector, and according to labor market studies, in the future, occupations that do not currently exist will be created.

Remote labs play an important role in shaping the student's learning experience, involved in STEM activities. The way in which labs are set up, as well as the kind of experiments conducted, highly depend on the expected learning outcomes defined by each curriculum and budget. However, learning experience should give equal opportunities to participation in research and exploration processes [1]. According to literature, sensors and acquisition systems, communication networks, data analysis software and systems monitoring are the main pillars to be considered when implementing a tool for effective means of teaching [2], [3], [4].

The increased demand for mobile and broadband services requires higher data rates, lower latency with lower energy consumption [5]. Towards this direction, many global research and industrial initiatives are working on the building blocks of 5G and beyond. 5G supports a heterogeneous network, which integrates many wireless technologies and allows smart devices, machines and robots to act as innovative tools of communication, using applications and services, as well as generating and handling large volumes of data. Emerging IoT – based applications introduce high mobility, high scalability, and low latency requirements that pose new challenges to user services.

This kind of requirements cannot be fully met by existing cloud-based solutions. As a result, the edge-computing paradigm is a candidate technology pillar to provide solutions since it provides data/computing/storage/ application as a service to end users on the network edge [6]. The main features of edge computing are proximity to end users and the mobility support. Along with its application in 5G networks, end-to-end latency is reduced to less than a few milliseconds and Quality of Service (QoS) perceived by mobile users is enhanced. The higher data rates, along with the expected diffuse coverage of reliable networks, will create new opportunities for academia and industry to develop new real time reliable services.

The data burden transition from cloud to the edge results in several challenges, including the need to support custom orchestration and customization of execution time for durable and reliable fog services. This is essential for the success of Internet of Everything (IoE). High-performance boards and microcontrollers / processors, help university students learning to use and program platforms equipped with a range of modules that handle a variety of complex requirements. These platforms are able to allow real time interaction between students and their teachers, utilizing high quality videos to resemble the experience of on–site teaching. Moreover, distant learning solutions based on Augmented Reality (AR) and Virtual Reality (VR) technologies allow students to follow curricula activities from home [7]. Furthermore, the use of 5G leads to adoption of new devices such as Head-Mounted Display (HMD), VR/AR devices and high-definition monitors.

All aforementioned technologies are vital pillars in shaping digital technologies of the Education 4.0 framework. This paper provides the following contributions:

1) We analyze the characteristics of contemporary pedagogical and STEM based didactic approaches that support educational technologies of 5G and IoT and engage students in project-based learning.
2) We provide a multi–dimensional categorization of the available open software and hardware under certain criteria, according to educational approaches and technology clusters.
3) We provide a state-of-the-art listing of appropriate educational scenarios (per scientific field and per didactic approach) and also highlight the trends in terms of digital technologies to support a smart learning– by–doing campus.

The paper is structured as follows: Section II describes fundamental background concepts related to Education 4.0 tools and approaches. Section III provides a categorization of research works related to hardware and software components and according to their educational goals per experiment. Section IV focuses on educational technologies applications scenarios and their correlation to contemporary didactic approaches. Section V draws our conclusions and findings.

Considering the relationship between education and technology is long and complex, the tools that help students turn information into knowledge are at the heart of pedagogical practice. Sharing hardware and software is a key point in research. In the field of science, laboratory-based experiments are a vital part of a curriculum that reinforces the theory being learned and the acquisition of practical skills. This is possible even remotely by pairing simulators/tools located in different laboratories. Existing teaching practices are largely presence-oriented teaching and are based on infrastructure and content that are appropriate in this way. Universities must prevent digitization. In order for students to be able to respond to this system of study, it is necessary for the curriculum to be adjusted to cover the necessary topics and to introduce Internet of Things (IoT) concepts at every step of the student's journey. The transition to digital campus is inevitably based on the campus' ICT and IoT infrastructure. Our research

TABLE 1. List of key acronyms.

Acronyms	Definitions
AI	Artificial Intelligence
STEM	Science, Technology, Engineering and Mathematics
IoT	Internet of Things
ICT	Information and Communication Technology
5G	Fifth Generation
QoS	Quality of Service
IoE	Internet of Everything
AR	Augmented Reality
VR	Virtual Reality
HMD	Head-mounted Display
CT	Computational Thinking
EDST	Engineering Design-based Science Teaching
2D	Two-Dimensional
SDR	Software-Defined Radio
RE	Remote Experiment
SE	Simulated Experiments
RVE	Remote Virtual Experiment
LED	Light Emitting Diode
LCD	Liquid Crystal Display
PDA	Personal Digital Assistant
RFID	Radio Frequency Identification
LabVIEW	Laboratory Virtual Instrument Engineering Workbench
TP	Technical Planning
EDP	Engineering Design Process
STEAM	Science, Technology, Engineering, Arts and Mathematics
DoF	Degrees of Freedom
CPACK	Computational Pedagogical Content Knowledge
PLC	Programmable Logic Controllers
IIoT	Industrial Internet of Things
RoF	Radio over Fiber
MIRACL	Multiprecision Integer and Rational Arithmetic Cryptographic Library
D2D	Device-to-Device
MIMO	Massive Multiple-input and Multiple-output
MEC	Mobile Edge Computing
VM	Virtual Machine
EH-WSN	Energy-Harvesting Wireless Sensor Networks
MISO	Multiple-Input Single-output
FPGA	Field Programmable Gate Array
VHSIC	Very High Speed Integrated Circuit (VHSIC)
VHDL	VHSIC Hardware Description Language
CPS	Cyber-Physical System

focused on pedagogical and didactic approaches that aim to provide students with knowledge that they can use in their future careers. The theoretical part of the approaches is completed by listing the educational technological applications that use IoT and 5G. We will present concepts based on the use of IoT and 5G that aim at the digitization and preparation of a university so that it can meet the requirements of modern society.

Many researchers focus on how to set up a remote lab but only a few of them deal with the educational point of view of the problem, and this is the crucial difference on which we relied for the composition of this paper. In the following sections we will categorize papers according to their educational approach and how the experiments of each paper could stand in the educational process. These papers were selected based on a composition of the following keywords: 5G OR IoT in Education, Remote Labs in University OR Smart Campus, Education 4.0.

II. FUNDAMENTAL BACKGROUND CONCEPTS WITHIN EDUCATION 4.0 FRAMEWORK

Related research has shown that extensive memorization of facts has a negative implication for knowledge cultivation and active research activity. Unfortunately, in several countries, memorization is an inevitable part of the education system, which prevents students from creative thinking. Following this, University students may continue to act this way, by grasping only superficial knowledge and not by deepening into research mentality. In that way, university students reproduce information mechanically, working more like well – tuned storage machines.

Education 4.0 introduces the appropriate flexibility and intelligence that leads to a quality and sustainable education. [8]. In the majority of the cases, when students need to work out a complex solution in real problems, facts memorization, combined with scientific research spirit and contemporary digital tools, lead to stronger and deeper learning outcomes [10].

Contemporary education systems rely on creative learning by involving hands on activities, either individually or in groups. On the other hand, University students need to confront real and disciplinary problems, following a STEM approach. Related literature reveals that learning depth is fully exploited via spontaneous play, research and observation, life experiences and student – teacher interaction [9]. To this end, University students, tend to learn efficiently through exploration and groups interaction. An environment that stimulates and challenges students to work in this way is the ideal one to achieve and cultivate in–depth learning [9]. According to work in [9], active learning:

- Allows students to use their imagination and creativity, learn from their experiences, and develop important skills through research and their own interests.
- Boosts trainees' self-confidence because they feel confident about the knowledge they have acquired.
- Through interaction, trainees learn to handle and solve problems, improve their communication skills, participate actively in the learning process, express their opinion and at the same time respect the opinion of others.
- Creates citizens that are more capable because they can perceive the world in different ways and take an active part in decision-making.

A. COMPUTATIONAL THINKING

Computational Thinking (CT) involves solving problems and designing systems by drawing on fundamental Computer Science (CS) concepts. At the same time, CT is also considered as a universal skill that complements thinking in mathematics and engineering, with a focus on designing systems that help solving complex problems [9]. Therefore, CT concerns not only computer scientists but also other professionals since it can develop a multitude of skills [8]. Additionally, students gain vital skills and experiences, which are academically accredited to enhance future employability. The key features of CT are:

- The construction of concepts.
- The combination of mathematical thinking and engineering techniques.
- The computational way of thinking that results in ideas

Along with the key features, CT fundamental dimensions include [136], [138] 1. *Abstraction and Problem decomposition*2. *Parallelism* 3. *Logical Thinking*4. *Synchronization* 5. *Flow Control*6. *User Interactivity* and 7. *Data Representation*.

B. STEM PEDAGOGICAL APPROACH

STEM pedagogical approaches aim to develop skills that will enable students to succeed and adapt to an ever-changing world. Educational organizations around the world are investing in both the creation of innovative learning spaces (i.e. Maker Spaces) and the implementation of STEM-based educational programs. Since 2009, the Brussels-located *European School Network* has launched a pilot effort to develop new learning and technology activities inside classroom, exploring the use of new pedagogical tools through STEM. STEM has three main objectives [18]:

- The application of the principles of exploratory learning.
- The connection to the real world, where the child asks and / or answers questions related to his/her life and the world in which he/her lives.
- The cultivation of 21st century skills, such as collaboration, effective use of technology, communication, personal and social responsibility, career guidance.

C. INQUIRY BASED LEACHING – EDUCATIONAL INNOVATION

Design research follows a circular pattern in that hypotheses formulated prior to data collection are continually revisited during the teaching experiment, unlike other research approaches where hypotheses are made prior to data collection. This pattern is distinguished in three phases, the preparation, the teaching experiment and the retrospective analysis [9].

The results of the analysis lead to a new cycle. This approach offers students a better understanding of the lesson despite the fact that it is not an easy approach from the teacher's point of view.

D. ENGINEERING DESIGN-BASED SCIENCE TEACHING (EDST) – ENGINEERING DESIGN THINKING

Design is increasingly proving to be an effective pedagogy for the education of Sciences. Students are able to assimilate the content of lectures faster and more efficiently. Another positive aspect of using this pedagogical method in teaching science is the increased performance of the students and their better understanding of the subject. This approach requires knowledge of science as well as the corresponding pedagogies to stimulate the student's interest in science [10].

E. COMPUTATIONAL EXPERIMENTS

Computational experiments provide the implementation of repeated tests with a wide variety of parameter values. Students compare experiment outputs in order to better comprehend phenomena causality. The methodology of computational experiments includes the following phases [11]:

1) The modeling phase: In this phase, an abstract model is developed corresponding to a specific phenomenon or study.
2) The simulation phase: In this phase, mathematical methods are applied to analyze a model. This phase is essentially experimental in order to optimize a system, evaluate its sensitivity, establish a predicting model.
3) The computational phase: This phase refers to algorithms and arithmetic techniques. Writing code for solving and visualizing the simulation.

Work in [11] describes a classification of spaces concerning the design and implementation of computer experiments following this approach:

1) Hypotheses space, in which the trainees in collaboration with the teacher, decide, clarify and formulate the hypotheses of the problem or the scientific area under study.
2) Experiments space, in which the computer experiments are performed, which includes exploration and construction activities, through which the trainees, by utilizing discussion and social interaction (between trainees and/or teacher and trainees), actively construct knowledge and formulate conclusions, generalizations results and solutions to problems or issues under negotiation.
3) Predictions space. In order to check the validity (credibility) of the results, conclusions or solutions formulated in the experimental area, this subject area is created with analytical (mathematical) solutions of the problem.

F. BLENDED LEARNING

Blended learning (a.k.a. hybrid learning) provides to students the opportunity for greater flexibility in their learning experience, as it connects technology and digital media with old fashion teaching inside a classroom [13]. There are four representative blended learning models or categories but the possibilities in terms of educational technologies are innumerable:

- Rotation Model of Blended Learning: Depending on the learning goals, the teacher can alternate between the in-situ and online teaching. Flipped Classroom (FC) is the most representative paradigm of this model.
- Flex Model of Blended Learning: The most common approach is the distance online learning. Similar to the rotation model, the way of teaching can alternate. Students learn mainly on campus but there is a differentiation between online and offline topics.

TABLE 2. Categorization of open software – hardware and applications.

Pillars		Pedagogical Approaches						
		Computa-tional Pedagogy	*STEM*	*Inquiry Innovation*	*Engineering Design*	*Computational Experiment*	*Authentic Problem*	*Blended*
Software								
	Learning Platforms	[39]	[39], [40], [41]	[19],[42]	[32],[43], [44],[45]	[43]	[46]	[47],[48]
	Operating Systems		[49], [50], [51]					
	Programming - Algorithms	[52]	[38], [53]	[54],[55]	[56]	[57],[58],[59]	[60],[61]	[16],[62], [63],[64], [65],[66], [67]
	Databases	[68]	[42]	[69],[70]	[32],[71],[72]	[73]		[21],[74], [75],[76]
Hardware								
	Smart Devices	[77]		[78],[79],[80], [81],[82]			[81],[82], [84], [83],[85]	[86],[87], [88], [89],[90],
	Radio Generators - Receivers	[80],[91]		[92]	[93],[94]	[95],[96],[97]	[95],[96], [98],[99]	
	Robotics		[100], [101]		[102], [103]	[104]		
	Sensors	[28],[29], [30],[105], [106]				[107]		[108], [109], [110]
	Low Cost Boards		[111]	[112]	[113],[114],[115]	[116]	[117]	
	Virtual Reality Devices		[20]			[118]		[20], [119], [120]
Others								
Theoretical								
	Education Reform	[9],[16]	[16], [17], [18]	[19],[20]	[21],[22],[23],[24]			[16],[21], [25],[26], [27]
Workshops								
	Hands On Workshops	[28],[29], [30]	[31]		[32],[33],[34],[35]	[29],[36],[37]		[38]

- A La Carte Model of Blended Learning: In addition to traditional in-situ courses, a learner may also select a variety of one or more online courses. Unlike full-time online learning, students may choose between online and offline courses according to their needs.
- Enriched Virtual Model of Blended Learning: Learning is split between online and offline topics. Students do not necessarily come to campus every day.

III. DIGITAL TOOLS AND TECHNOLOGIES CATEGORIZATION

Over the years, IoT technologies have gained a lot of attention and support a large range of applications, including education. The field of education is considered one of the most promising 5G – powered areas of innovation. Developers and technology users (including tutors and teachers) have the ability to significantly improve digital tools usage and develop new lecture formats beyond the two-dimensional course. However, multimedia education applications require high bandwidth and very low latency, two vital parameters for next generation wireless network experience. Additionally, 5G equipment is at a high cost for large-scale usage among undergraduate courses. This poses difficulties for students to perform experiments with real lab equipment. Virtual tools and simulators offer a way to perform simplified 5G experiments, so that students may study the majority of protocol stack and modules related to 5G. Software – Defined Radio (SDR) technology plays a very important role in experimental teaching of engineering education [15].

The majority of researchers focus on technical details related to remote labs and remote control APIs and only a few of them approach tools usage under the educational prism. In this section we provide an extensive categorization of digital tools and technologies usage, according to multi–parameter logic, related to both technical and pedagogical dimensions. Table 2 illustrates the main technical pillars related to the open software, hardware and applications. The table provides the correlation of these tools

TABLE 3. Technology clusters.

Technology Clusters	Reference
Physics – Chemistry Physical – Natural Sciences	[28],[30],[33],[37],[38],[57],[61] [68],[71],[72],[104], [113]
Industrial Applications	[21],[29],[32],[34],[43],[44],[68], [70],[77],[107],[115]
5G technologies	[19],[20],[21],[25],[26],[35],[45], [52],[58],[63],[73],[77],[80],[86], [87],[89],[91],[92],[93],[94],[95], [96],[97],[98],[99],[102],[105], [119],[120]
MOOCs	[19],[20],[27],[32],[39],[41],[42], [46],[48],[50],[53],[60],[66],[69], [78],[81],[82],[83],[85],[106]
Network Security	[56],[60],[61],[64],[65],[84],[99], [105]
Robotics and Automation	[31],[57],[72],[79],[100],[101], [110],[117]
Construction Activities	[10],[36],[40],[43],[54],[55],[57], [59],[75],[80],[90],[92],[108],[109], [111],[112],[114],[116]
3D Design and Augmented Reality (AR)	[38],[51],[70],[88],[117],[118]

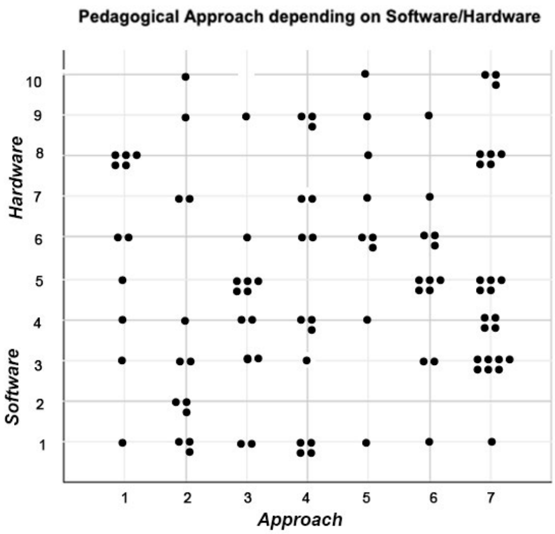


FIGURE 1. Software vs hardware trends according to pedagogical approaches.

to each pedagogical approach, as it was briefly explained in the previous section and is based on the selected references. Therefore, the basic dimension here is the pedagogical approaches. To realize visually, if a trend arises, Fig. 1 gives a scatterplot of tools vs approaches. The scatterplot depicts the frequency based on the categorization of papers at Table 2. On axis X there are the pedagogical approaches and on axis Y the software/hardware that was used in each paper. Each dot represents a paper of Table 2 and according to this figure, someone can find which pedagogical method could be followed in an educational plan depending on hardware or software he has at his disposal.

Specifically, on X - axis we depict the approaches, as: 1. Computational Pedagogy, 2. STEM, 3. Inquiry, 4. Engineering Design, 5. Computational Experiment, 6. Authentic Problems, 7. Blended Learning. On Y-axis, we depict the two

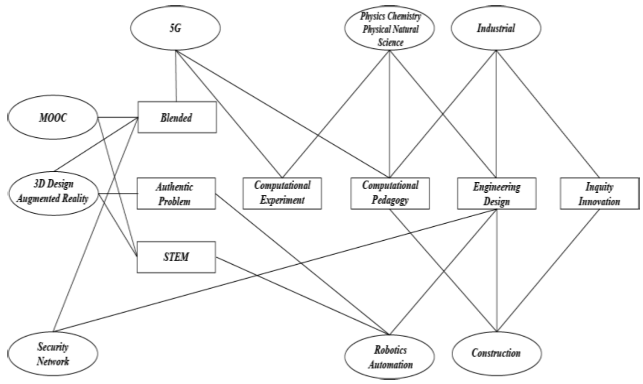


FIGURE 2. Pedagogical approaches correlation with technology clusters.

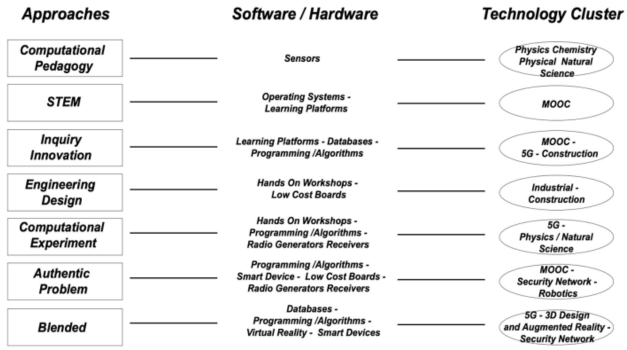


FIGURE 3. Pedagogical approaches correlation with open S/W and H/W and experiments.

basic technical pillars, related to open S/W and H/W. The pillars are shown in Table 2. The dot representation gives the trend in essence that we can relate each approach to tools dimension.

In addition to grouping the files based on teaching approaches, we considered it right to have a clustering based on the teaching unit and the educational goals achieved by each experiment. So, the following table was created where the lines refer to the scientific field/technology cluster of each research. We mainly focus on technology domains and/or applications that are the basic pillars for Education 4.0 framework, as well as essential pillars for Industry 4.0

In this section, the criteria used for the categorization are related to technology, didactic approach and application dimensions. Therefore, as a summary, we make the following remarks:

1. Which pedagogical approaches best suit each digital platform, especially covering the cases of University education. (Table 2 and Fig. 1).

2. Table 3 also gives the trend concerning the technology clusters that literature mostly focuses on.

3. In case we need to unfold the complexity of each cluster, Table 1 provides all related acronyms and definitions, as they appear in literature according to Table 3.

Fig. 2 draws a visual correlation among pedagogical approaches and technology clusters. In essence, this figure works as a conceptual map. For example, if the reader is interested in focusing on 3D design and augmented reality,

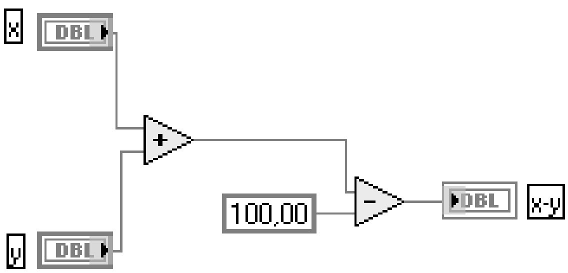


FIGURE 4. LabVIEW graphical commands example.

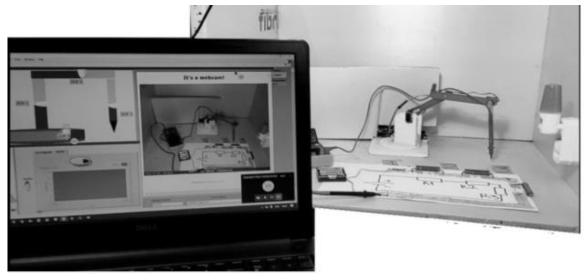


FIGURE 5. Workspace of a remote mechanism according to [128].

the map shows that most preferred teaching approaches to develop should be either blended learning, or authentic problem solving or STEM.Following this, by relying on Tables 2 and 3, the reader will then focus on state-of-the-art literature in order to be inspired from. Overall, Fig. 3 depicts a visual correlation between pedagogical approaches and open hardware/software along with the type of experiments.

IV. EDUCATIONAL TECHNOLOGIES APPLICATIONS

A. PHYSICAL, NATURAL SCIENCES AND TECHNOLOGY APPLICATIONS

Experiments are vital for physical, natural and technology oriented sciences since imagination is never enough to conquer science notions if hands-on activities do not supplement it. Simulations are vital for model design and testing. Authors in [13] refer to five experiments, with the first being a Remote Experiment (RE) for a pulse mode investigation. Students experiment with pumping energy by locating the production limit.

Following, in three Simulated Experiments (SE), students design by gradually building their understanding around motion and mass – force interaction, by working with simpler projects related to simpler concepts. In the second SE, students create electrical circuits. The third SE contains applications related to kinematics, dynamics, wave physics, thermodynamics and circuits. The latter is a Remote Virtual Experiment (RVE) in thermodynamics, where an engine controls the position of a piston in a cylinder, containing air whose temperature may be remotely adjusted by a heater. Sensors are used to measure pressure and temperature.

In [30] a physics lab for RE that analyses oscillations was constructed via a live view through a webcam which frequently checks and plots data, related to forces, acceleration and deflection. Students' experiment with torque is done under two cases: by a bolt when a force is applied to a key and a lifting crane when placing a load. In [68] software is designed for water management and climate control in greenhouses. In [33], a Raspberry Pi board acts as a server and an Arduino UNO board is used as end device for data collection from a live experiment. In particular, the experiments have to do with thermal installation, magnetic suspension and hydraulic tank system. In [113], experiments concerning several electronic dipoles and an Arduino board for data collection is proposed, where a live camera broadcasts the experiment run real time. In the majority of the cases, Arduino platform is used in experiments performed with servomotors, potentiometer, Light Emitting Diodes (LEDs), Liquid Crystal Displays (LCDs) and several other sensors. In [49] a Java oriented application for remote control of a real device is presented. This application is related to the Ball and Hoop apparatus for studying oscillating systems.

In [72] authors present experiments related to flow control, heat transfer, circuit design and LED testing, which allow students to analyze system's performance. In [104] a pilot laboratory for three state organic chemistry (prelab – lab – postlab) course is proposed, which allows students to communicate both synchronously and asynchronously. In the first stage, a remote management virtual lab is presented with remote management functionality of real devices. In the second stage, students perform the experiments both in situ and remotely, via a Personal Digital Assistant (PDA), working in groups. In the last phase, a digital report is sent to the teacher, as a deliverable. Authors in [37] present Radioactivity iLab, which is mainly a workshop for students focused on understanding the factors that influence radiation intensity, such as distance. The participants used a Geiger Miller radiation counter remotely with a sample of radioactive strontium – 90 via a web interface. They obtained data from actual equipment located in Australia.

Work in [57] is related to industrial scale chemical plant treatment. Students conduct experimental research and collect data for statistical analysis. The laboratory is divided into four sections: Development Lab: In this section students answer specific questions based on standards. Research Lab: This is the actual research facility in which the project is conducted. Educational Lab: In this section, students apply theoretical knowledge to gain practical experience. On site Lab, which allows complex and open research that is difficult to develop via online activities. The kind of experiments relates to the study of: Flow control inside tubes and valves, in which the experiment divides into sessions concerning observation and analysis report submission. Heat exchangers, where the original goal of the experiment is to apply the 1^{st} law of thermodynamics, in which students tune the flow rate of hot and cold variables.

Work in [104] describes six benefits and four IoT application on a campus use case. The first benefits are cost and time saving. With IoT applications we can monitor environmental conditions such as humidity, pressure, temperature, etc. by using sensors and then switch off devices if/when it

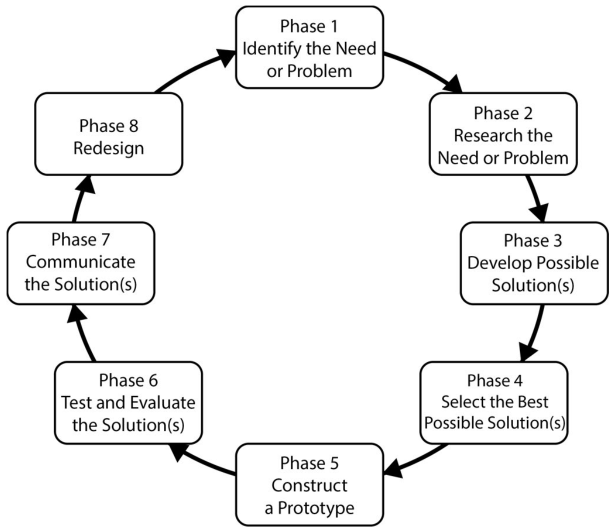


FIGURE 6. Eight phases of the engineering design process (EDP).

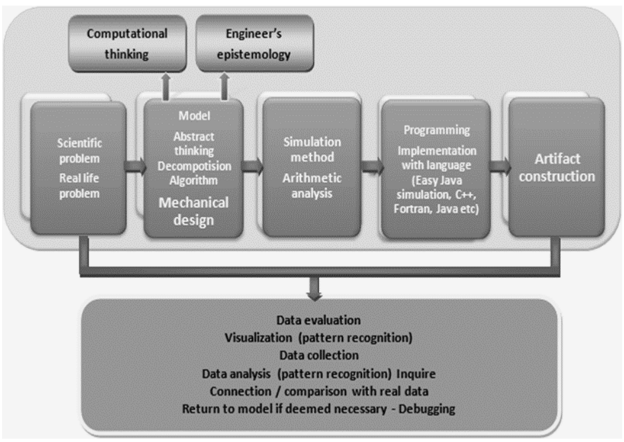


FIGURE 7. The computational STEM pedagogy model [9].

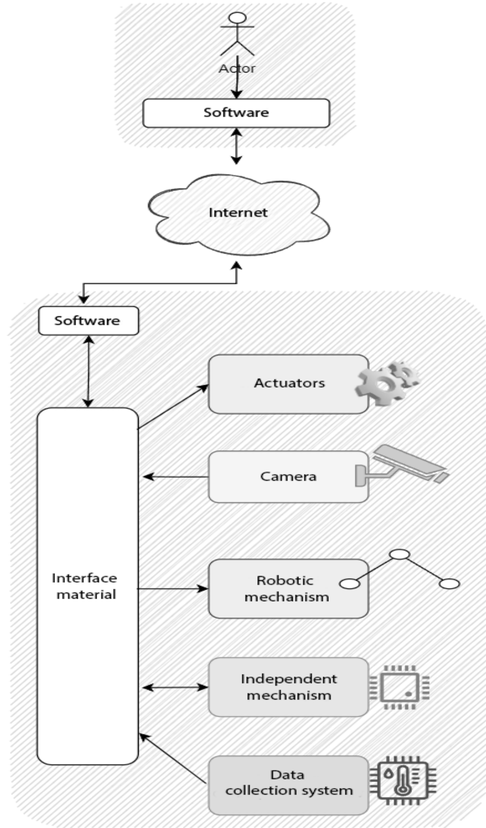


FIGURE 8. Functional diagram of the remote robotic mechanism [128].

is necessary. Another benefit has to do with the automated maintenance, in which campus staff may react only when needed reactively. An additional benefit is related to security since with the use of IoT applications, it is possible to control entrance flow within the campus. Moreover, IoT can effectively control the parking assignments and Radio Frequency Identification (RFID) tags may constitute a low cost distributed monitoring system. Therefore, students may easily navigate inside campus and find classrooms in case of a course change.

Work in [61] introduces an identification system based on biometric parameters and an instructor's evaluation system in which students write comments at the end of each lesson session via a customizable application. According to [129], in majority,the server technologies applied are based on Laboratory Virtual Instrumental Engineering Workbench (LabVIEW), Matlab/Simulink, Java and NetLAB. In the case of the client side, the technologies focus on Java Applets, HTML and Microsoft Silverlight. VRML and Java Script. LabVIEW® software is a powerful object - oriented measurements, control and analysis programming language for data acquisition systems (DAQs) [122]. In the context of physical computing, research work in [130], [131], and [132] supports the design of educational activities by using LabVIEW that has a number of tools for data collection, processing and measurements graphical display. By using LabVIEW, a teacher can design and develop custom control systems for robotic mechanisms, due to the easiness offered by the interface of Maker Hub with the Arduino platform [134]. Fig. 4 illustrates an example of LabVIEW graphical commands.

The following software was used to interface LabVIEW with the Arduino platform, as it is depicted in Fig. 5:

- LabVIEW 2020 (Free Community edition).
- NI VISA Driver for USB port communication
- The Arduino IDE programming environment

According to Fig. 5, through a proposed remote mechanism based on open software and hardware components, it is possible for a student user to perform lab measurements on circuitry. The student logs in the platform via Internet connection and controls the robotic arm in real time. The student then can download and further analyze all measurements. The dynamics of physical computing with open hardware can provide to the instructor the ability to design his/her own remote experiments, and customize robotic mechanisms according to needs. To this end, the design and development of custom

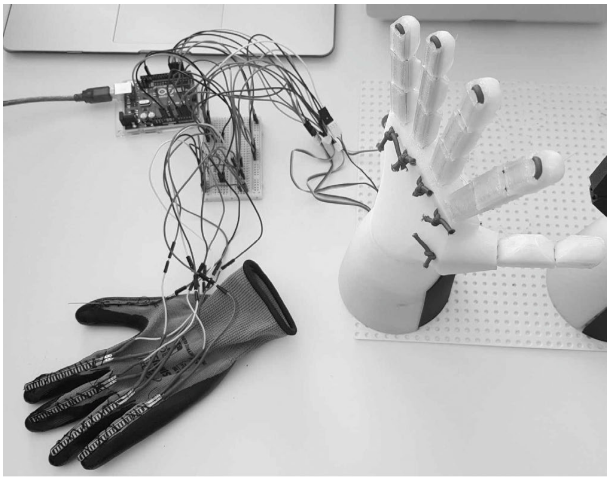


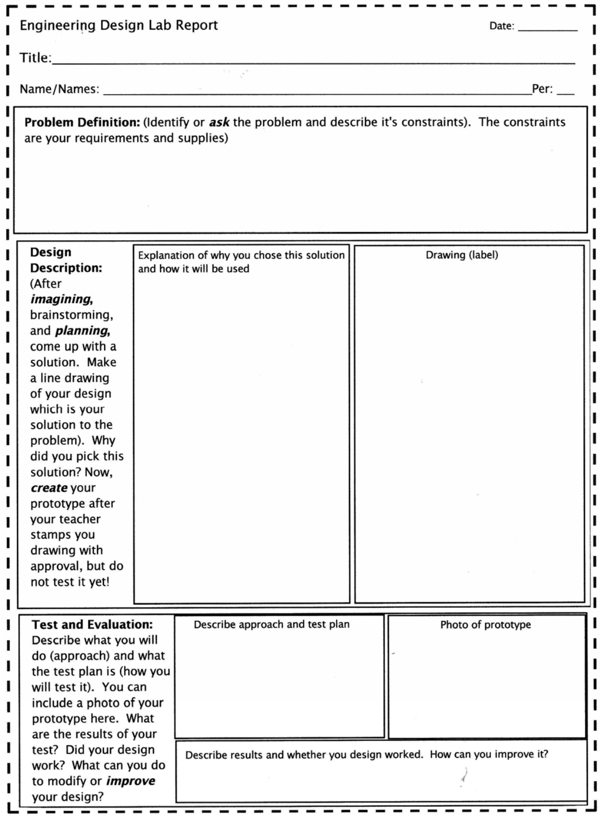
FIGURE 9. **Prototype of the robotic arm developed in our Lab.**

remote lab mechanism relies within the computational thinking and STEM Epistemology framework, according to [135], [136], [137], [138], [139], [140], and [141], as the process follows the model of Technical Planning (TP).

TP is based on eight phases, as proposed by the Massachusetts Department of Education, and constitutes the Engineering Design Process, to solve a real problem, based on the STEM approach.

According to Fig. 6, which depicts the eight phases of Engineering Design Process (EDP), the phases facilitate the solution to a problem that requires lab access. These are P1**:** Identification of the need or problem, in which students proceed with brainstorming around the necessity of a potential solution. P2**:** Research of the need or problem, in which students work on other available solutions or research directions, according to literature. P3**:** Development of possible solutions, in which students work on a prototype. P4**:** Selection of the best possible solution, in which students apply criteria to select the optimal solution, in case of many available. P5**:** Prototyping, in which students work on finalizing their prototype P6: Testing and evaluating the solution, in which students test their solution system response and proceed with evaluation in case of errors. P7**:** Communicating the solution, in which students produce testing reports and inform other students about their prototype functionality and usability P8**:** Redesign, in which students redesign some parts of the prototype, if necessary. That is why EDP works as closed loop.

The functional diagram of the remote mechanism of Fig. 5 is depicted in Fig. 8 [128]. The system's functional requirements are specified by Science, Technology, Engineering, Arts and Mathematics (STEAM) and educational robotics framework. The system has a robotic mechanism with four Degrees of Freedom (DoF). For the visual observation of the robotic movements, a high - definition WEB camera is used. The operational model also incorporates a data acquisition system, including sensors as well as actuators for controlling the experiment's devices (i.e. electric kettle, electric heater, robotic vehicle etc.). Finally, in order for students to engage with the experiment, supplementary external



Engineering Design Lab Report Date: ________

Title: ________

Name/Names: ________ Per: ___

Problem Definition: (Identify or ***ask*** the problem and describe it's constraints). The constraints are your requirements and supplies)

Design Description: (After ***imagining,*** brainstorming, and ***planning,*** come up with a solution. Make a line drawing of your design which is your solution to the problem). Why did you pick this solution? Now, ***create*** your prototype after your teacher stamps you drawing with approval, but do not test it yet!	Explanation of why you chose this solution and how it will be used	Drawing (label)

Test and Evaluation: Describe what you will do (approach) and what the test plan is (how you will test it). You can include a photo of your prototype here. What are the results of your test? Did your design work? What can you do to modify or ***improve*** your design?	Describe approach and test plan	Photo of prototype
	Describe results and whether you design worked. How can you improve it?	

FIGURE 10. **Engineering design lab report.**

systems, such as Arduino, Raspberry Pi [142], [143] and USB DAQ 6008 NI [144] are placed inside the workplace in which the robotic mechanism acts. Inter-systems communication with the main part of the mechanism is implemented as a function by the proposed system in [128].

By pairing computational thinking instruction with STEM s, students can explore and apply computational approaches within more established and accessible STEM context [37]. STEM can enrich computational thinking, by spreading CT skills across STEM spectrum and expose students to interdisciplinary ideas. Therefore, as authors in [9] indicated, CT is an indispensable component of STEM disciplines as they are practiced in the professional world, under Education 4.0 and Industry 4.0 pillars. According to Fig. 8, authors in [9] and [17] propose that for activities related to science and technology, the model integrates in inquiry based teaching and learning approach, with computational experiment and STEM, content transdisciplinary approach. This model is called STEM computational pedagogy. According to the model in Fig. 8, students go through several phases in order to reach artifact construction. In briefly, these phases include: P1**:** Definition of a scientific problem related to real life problems P2**:** Apply a correlated mindset, based on CT's dimensions (i.e. abstraction, pattern recognition, model design etc.) along with mechanical engineering perception P3**:** Simulation of the model P4**:** Programming of the model's logic P5**:** Construction of the artifact.

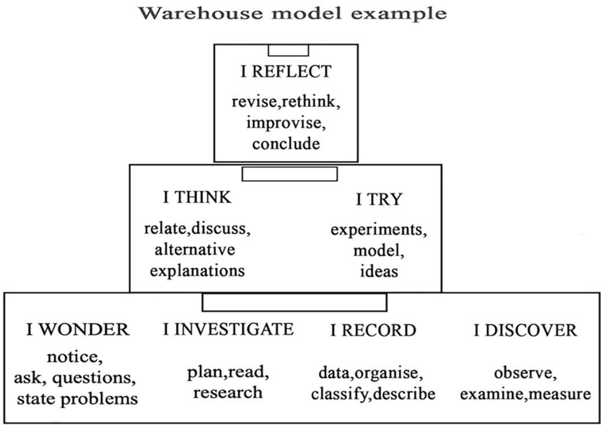


FIGURE 11. Inquiry learning on a warehouse model example [70].

Along with these phases, a feedback loop is present, so that students complete each phase and move to the following one, as soon as analysis, testing and debugging is done.

Additionally, to realize the computational model STEM pedagogy, vertical plane spaces exist and cover all phases, along with the CPACK, the STEM content interdisciplinary approach and the Engineering Education epistemology [9].

This paper is a guide for those who want to associate terms such as Education Technologies, 5G, Industry 4.0, IoT, Smart campus, STEM. In Fig. 9, for example, we developed the following project concerning a robotic arm. First, the students had to design the arm on the computer and then print the 3D model with the help of a 3D printer. The 3D arm was connected via motors and resistors to an Arduino board. The next part of the construction was the installation of the sensors. The sensors were placed in a glove and connected with appropriate wiring to the Arduino board. The last stage was joining the two pieces - 3D replica and glove - by programming. Based on the categorization in the tables of this work, and specifically in table 2, one of the most appropriate teaching approaches was that of Engineering Design. Based on its basic principles, we approached the course by making a lab report, as shown in Fig. 10, where the students answered the basic questions of the phases of Engineering Design.

B. INDUSTRIAL SECTOR AND TECHNOLOGY APPLICATIONS

This sub-section refers to state-of-the-art Industrial 4.0 use cases that may inspire for educational scenarios within the STEM framework. These are related to industrial inspection, virtual assembly of components, digital twins etc. In [29], authors present a system for remote digital holographic microscopy lab, which provides complete infrastructure with graphical user interface and data exchange. 5G technology paves the way for the design of control systems, connected to a digital twin, which is a virtual space implemented in a loop system. The simulator is an excavator that is activated remotely, with tactile control, giving the operator a sense of touch. The operation and processing functions of the considered devices, real and autonomous, semi–autonomous

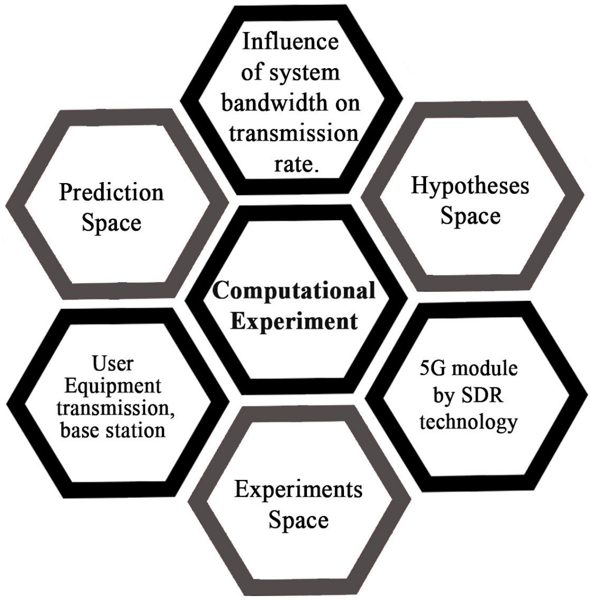


FIGURE 12. Computational experiment in SDR technology [95].

or manual remote control nodes. Due to the usage of public networks for the experiment, significant delay is observed [77].

The term building metaphor is utilized in [68], in which each room or building floor represents a course (i.e. in theory of lab course). In [70], authors present a remote control system for processes using Programmable Logic Controllers (PLC) and the corresponding virtual lab is implemented in Solid Works and LabVIEW. Other works related to the construction engineering and structures control. In the first task, students are asked to construct a building as high as possible with a set of building materials, such as paper, aluminum, wood sticks, etc. Another task related to the prevention of the erosion of a standard beach, by designing a wall and adding materials to the shoreline. In [21] students are asked to find where the right location to build a bridge along a river is. The designed activity guides students to take sample soil, to check if and where there is an erosion and to report it.

In [43], focus is given in understanding control of heating systems and the devices related to controllers, electromagnetic sealing gates and motors, used to control the phenomenon (such an example is the electric oven). In [32] and [34], authors discuss examples concerning remote laboratory experiments, as follows: 1. Controlling a pump and a circuit with a level sensor, 2. Electrical response of an oscilloscope, 3. Temperature, sound, light, current, voltage and power measurements, 4. Motion tests and physics experiments with pendulum friction, 5. Spring and single mass tests, 6. Mass flow wave simulators. Authors in [44] present an industrial robot that intends to include tensile test with integrated power measurement systems and integrates an experimental recording system. The SEPT Learning Factory is presented in [115], providing processes and designs that incorporate Industry 4.0, IoT and Industrial IoT (IIoT)

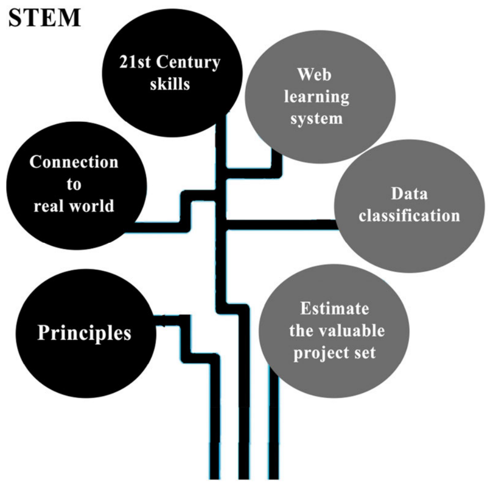


FIGURE 13. STEM approach for the experiment of [39].

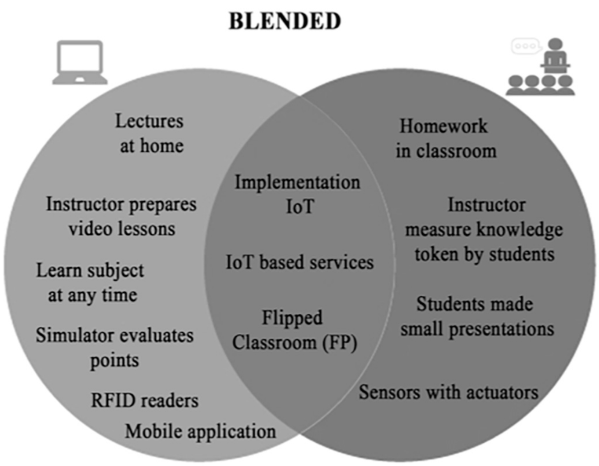


FIGURE 14. Blended learning and flipped classroom [114].

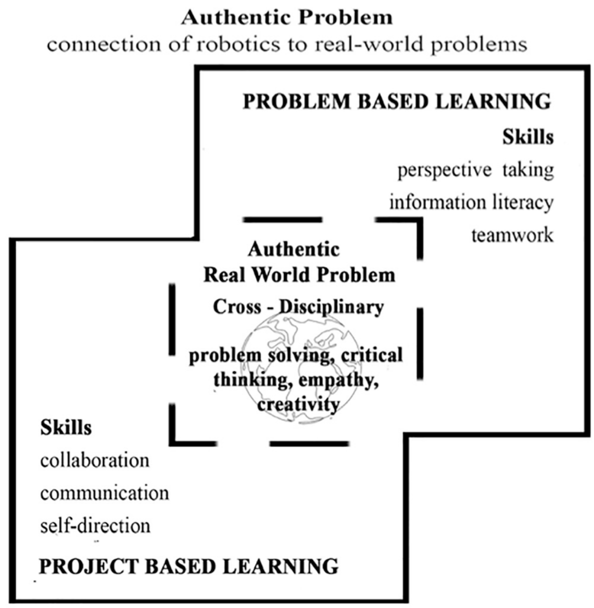


FIGURE 15. Authentic problem definition as a correlation of PBL and project based learning [117].

technologies. The goal is to digitize a production line, such as the process of making a physical object, a series of sensors to collect information from production units. These sensors transmit data to servers in the cloud, using and interacting with a digital twin, controllers and production unit actuators.

In [107] authors create a system that uses simple rules for device access. The goal is to design an optimal production line, so that it manages real-time heavy order traffic and at the same time industrial machines work as efficient as possible. In Fig. 11, we depict a three–layer Inquiry Based Learning experiment. At the first layer students work with ideas, concepts and models. At the second layer students work in a trial-and-error manner, to experiment with their models and at the top layer, students reflect on their models and follow a feedback loop to tweak parameters in case of re–design.

C. 5G TECHNOLOGY APPLICATIONS

In this subsection we refer to hardware and software platforms and solutions with reference to 5G technologies, that may also be used for educational purposes. Initially, we present a number of interesting 5G use cases. Work in [91] presents a 5G signal implementation experiment, based on a SDR platform, which is applied to a RF radio module with signal processing units. In [52] authors consider the Radio over Fiber (RoF) technology in the field of 5G wireless communication applications. The cases of Vehicle-to-Vehicle (V2V) communications, the design and implementation of a reliable and efficient 5G network remains a challenge [19]. Moreover, in [35], a Multiprecision Integer and Rational Arithmetic Cryptographic Library (MIRACL) is proposed, to measure execution time in cryptographic experiments. In [93], authors propose a smart 5G campus and measure the efficiency of their channel point-to-point transmission, between base station and terminals. The signal propagation model in real time experiments in NR 5G systems, is presented in [94]. Authors in [45] upload their code on GitHub to simulate mm Wave cellular systems that also allows testing of various protocols. Work in [102] proposes a hybrid architecture with new technologies such as Device-to-Device (D2D) communication, Massive Multiple-input and Multiple-output (MIMO), etc. This work is evaluated via agent–based simulators that meet blurred volume and latency requirements. Finally, in [73], a review of 5G use cases is given.

Authors in [96] propose a Mobile Edge Computing (MEC) proximity detection architecture based on ground-based technologies such as 5G and IoT, cloud computing, Virtual Machine (VM) network fragmentation. Authors in [97] propose the so-called green algorithm that aims to optimize energy and minimum transmission power with high reliability under a specific time. Finding an optimization algorithm is within the content of [58], too. Comparing algorithms that focus on a specific level. Work in [95] introduces distributed high–performance routing for Energy-Harvesting Wireless Sensor Networks (EH – WSNs), based on low latency and high synchronous operation and provides a performance comparison with the shortest route routing scheme. In the following system, there is a simplified experiment, which consists of a laboratory platform, equipped with the functionality to perform remotely, including also virtual simulation modules. With this platform, students can program a 5G unit. Channel coding and decoding are designed and verified by students. Students can also remotely load modulation algorithm into the software radio device, and transmit the modulated signal via RF. The receiver software radio captures the modulated signal and executes the demodulation algorithm using two oscilloscopes. The experiment in [95] is characterized as computational experiment for a 5G SDR use case. It is therefore related to STEM principles, meaning that students explore a real problem, collect real data, conduct experimentations and try to find optimal models. The experiment is related to the three spaces proposed in [9], which are the hypothesis space (i.e., orienting, asking questions, generating hypothesis), experimental space (i.e., planning, investigating, analyzing and produce models) and prediction space (i.e., making evaluation and predictions).

In [98], a simulator – oriented survey for 5G usage scenarios is proposed. Authors conclude that the complexity of a unified framework that meets the specifications is great and everyone is dealing with a functional subset. Literature also presents some 5G use cases, focused on mobile users of traffic produced after a natural disaster (i.e., flooding, fire, earthquake etc.). These use cases can be easily applied for academic educational scenarios. Work in [21] investigates the use of 5G technologies in education. The AR / VR feature is very important in use cases where students need to understand microscopic (i.e., microscale) phenomena. Additionally, another example is related to music education, in which students have the ability to remotely join a musical performance like in person. The research reveals that students' participation reaches 86%. The combination of VR and IoT technologies can break distance barriers and create a riveting experience for students. However, 4th generation networks still have serious limitation and authors in [119] explore the technical requirements of 5G network in higher education.

D. NETWORKING SYSTEMS FOR EDUCATION – TECHNOLOGY APPLICATIONS

In this subsection, we focus on the design and analysis of educational resources of web mining technology in networking systems for education. We provide some representative use cases. Firstly, in [39], authors describe a platform that keeps student records and referral indexes so that the material is sorted based on recommendations. Indicators are also used to check the accuracy of the recommendations. The goal is to create a scheme of recommendations by creating a classification of educational resources based on students' preferences. Fig. 13 depicts the STEM approach of the experiment, which combines the STEM engineering pedagogy, based on spaces pillars, together with the dimensions of computational thinking and experimentation. In [102], the use of bio signals

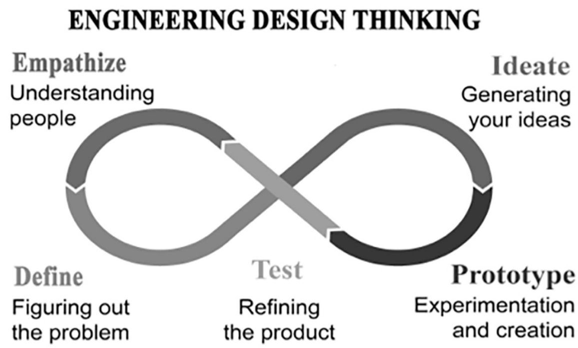


FIGURE 16. Engineering design thinking on integrated systems [114].

to monitor students' progress, productivity and stress levels is presented. Work in [20] proposes a shared platform that allows teacher-sharing material, along with an AR / VR capability for resource sharing.

IoTtalk platform introduced as a vehicle service that allows a center to monitor the location and condition of vehicles in [50]. A monitoring framework is proposed and new technologies facilitate remote users' communication by reducing site load and latency [41]. Authors in [78] design and use a smart bracelet that measures heartbeat and estimates the student's attendance in classroom. Authors in [69] present their students' dropout rate prediction platform, based on social – economic conditions.

Based on cloud technology, students' trend prediction algorithms developed in [19]. Moreover, in [81], a user experience questionnaire for training 4.0 with smartwatch is related to questions for digital skills, hardware competencies and technology acceptance.

A platform where students can present solutions with various platforms provided by the campus for various problems they face within it. Each presentation is graded mainly to keep students motivated and dedicated to their work. It is also emphasized that the role of the instructor is advisory, the students are in groups that decide their own course and arrange their sessions and once a week they meet with the instructor [82]. Creating a platform that creates time slots where students book remote laboratories [32].

In [46] authors propose the creation of a data collection model that uses a sensor to find out whether a student is focused during lesson. The sensor monitors eye movements. Education 4.0 framework imposes the use of real time data acquisition systems, sensors, actuators and automations [81]. In [83], authors propose a system to monitor students stress levels, by comparing normal behavior values with values, which translate to stressful events. In a smart campus, an attempt is made to anticipate the participation in the halls in order to make the best use of them and the organization so that there is no waste of space [85]. Research on which factors teachers should pay attention to in order to enhance students' motivation to learn is performed in [48]. Authors in [66] check the accuracy of a student's entry information by improving the location algorithm so that the student can obtain the information they are interested in. Distance learning solutions through AR and VR allow students to guide their own curricula [27].

E. NETWORK SECURITY APPLICATIONS

This subsection provides certain use cases, highlighting network security and secure communication. Development of cybersecurity algorithms, inspired by nature, such as antiviruses, honeypots, performance intrusion detection, counterattacks and threat behavior analysis, is given in [105]. To improve security in communications, an experimental approach, which enhances IoT applications with Blockchain, is proposed in [56]. A contemporary idea for smart and secure monitoring, alerting mechanism and student movement in schools is given in [60]. Authors propose an ultra-fast Blockchain network (IoST) that uses a GPS tracker. By deploying IoT and high–speed network devices, we may transform campuses as follows: Students can access classrooms remotely and attend lectures real time. Distributed devices and smart sensors may be used to monitor student's movements, behavior, stress levels, fatigue etc. Students will receive reminders regarding their obligations. Smart sensors will also record absences. Finally, this IoT ecosystem may minimize total campus energy consumption by activating or deactivating lights, air conditioners, heaters etc. [84].

In [65] a method of object recognition in AR is proposed. In [69], a framework of reliable transportation of both individuals and money is studied so that there is no risk of robbery on a campus. Security is an issue in [61] that by combining smart devices users can be alerted to anything threatening that might happen to a student. The advantages of using IoT are many, such as securing resources but also maneuvering the campus community itself. All aforementioned use cases give student the freedom to combine in situ with remote classes. Fig. 14 depicts the blended learning model as an intersection of home (i.e., remote) lectures along with lectures on campus [114]. For the home lecturing case, the instructor prepares video lessons, simulations and other multimedia material and shares them with students. Students study the material in their place and time. In the intersection of this combination lies the Flipped Classroom (FC) model, a contemporary didactic model that describes the way students share their time between remote and in situ classes.

F. ROBOTICS AND AUTOMATION – TECHNOLOGY APPLICATIONS

Experimental validation is crucial for establishing the effectiveness and robustness of algorithms for mobile robots. In this section we analyze architectures that authors propose for several kinds of experiments, ranging from single – robot to multi – robot systems and centralized to decentralized control schemes. We will next highlight some indicative use cases in Robotics and Automation field.

In [100], remote experiments in education, based on LEGO® for smart cities in proposed. In [31] two experiments that deal with the reverse kinematics and the visual service where an image is given and a remote user aims with control commands to reach the final destination are described. In [66] a robotic arm is designed, which measures circuit voltage remotely. Literature gives many open-source simulators, with which students can design and test robotic constructions. In experiments as described in [57], students have the ability to program a PLC to automate a real factory with 3D imaging. Students are asked to set up a controller and determine the positions of the servomotors with the ability to process data using MATLAB and Simulink. In [117] students play the role of an engineer and design housing models after natural disaster or migration. They digitally design the model and then built it using parts from a 3D printer. Another use case deals with people with mobility problems and proposes a smart parking system. In another experiment with Arduino platform, students are asked to tackle an environmental problem, and a robotic animal is designed and constructed to test its endangered species. This activity constitutes of a robotic arm to remotely control a circuit and also remotely collects measurements from real installations [110].

The aforementioned educational use cases arise from the need to solve an authentic problem. The contemporary didactic approach proposed relates to Problem based learning (PBL). An example focused on a problem related to environment and climatic change is proposed in [117]. A combination of open software and hardware platforms (i.e., Arduino based), sensors, actuators and recycled materials is proposed. Work in [117] includes disciplinary concepts ranging from physics and biology to CS and electronic engineering. According to Fig. 15, the authentic problems are related to real world problems, the solution of which is approached by PBL and project based. The requirements and definition of such problems lie at the intersection of the two methods and defines a cross – disciplinary dimension. Bottom line, students working with authentic problems are asked to apply critical thinking, creativity in conjunction with data analysis, classification and model proposal.

G. ENGINEERING – TECHNOLOGY APPLICATIONS

The future of education system will be enabled by a collection of emerging digital technologies, which will create ubiquitous, immersive, adaptive and personalized learning experience. Remote access lab prototypes are vital for the education of future engineers. In this subsection, we discuss several paradigms related to engineering fields. A remote lab that enables students to use robots for circuits creation is proposed in [109]. Power Hardware in the Loop remote experiments with real–time simulators is found in [40]. IoT activities to enhance learning curve around analog and digital circuits is proposed in [111]. The activity also includes wireless data transmission from device to device. Experiments using a multi – function energy converter for electric cars, wind turbines and solar systems are proposed in [54].

Experiments designed to boost students' understanding around 5G technology with Multiple – Input Single – Output (MISO) signal technology are proposed in [92]. In [80], students work with activities related to weighted Euclidean distance in order to share data among 5G mobile vehicles. The goal is to create a time mark and stamp on the site for monitoring. Data is stored and transmitted through fog to local nodes and uses cameras, sensors and a Raspberry Pi board [55]. In [112], an introductory course in operating systems and the acquisition of IoT expertise using boards such as Beagle Bone or Raspberry Pi are initially suggested. A course of computer architecture is then suggested, which bridges software and hardware in order for students to understand the computer stack. Finally, in [114], a security and engineering learning course for integrated systems in Field Programmable Gate Arrays (FPGAs) / Very High Speed Integrated Circuit (VHSIC) Hardware Description Language (VHDL) is given, so that students become familiar with designing wireless sensors. The work aims to create a robust system that does not fail, in case of a subsystem failure.

In [119], an interesting experiment on digital twin approach is proposed. The experiment targets to familiarize students with Industry 4.0 technologies and Cyber – Physical Systems (CPSs). Authors in [36] describe a series of activities divided into three categories. These are: Vibration table, Hydroelectric devices and Inclined plane. In the first one, the aim is that students understand the relationship between vibration frequency and degree of displacement in a building. In the second one, the activities concern relations between flow, pressure and power. In the third one, the activities are related to concepts of displacement, energy, force, speed and acceleration. The aim of experiment in [43] is for students to become familiar with the heating systems control. A digital controller is configured in real time with the use of a feedback system. The experiment includes an electric oven with a dimmer to adjust the power.

In [57], students design a LED control system online and pass values to a real remote system. In [59], authors refer to the SyntheticNET simulator, a platform used in both industry and education, because it provides design and automation solutions, enhanced with AI. In [116], a remote lab using Arduino board is described. One task refers to sensor's connectivity and the other to 3D RGB LED cube. Work in [108] describes the use of RFID and NFC technologies and provides examples as to how to use them, inside a campus. For example, we refer the following: cashless transactions, traffic monitoring, enter and learning a room monitoring. The Lab4CE tool is a course-writing tool that allows teachers to design and set learning objectives [75]. In [90] authors describe how with by using a smart application, students book their seats inside a library.

Fig. 16 presents the engineering design thinking as a five-stage loop. Work in [114] applies this method to activities focused on integrated systems. For example, one can match each stage with specific experiment stages, in order to produce a more hands-on teaching plan. These stages are the following:

1. Empathize: The world's complex system requires a holistic solution approach from students, which are assigned several roles during model design and solution production.

2. Ideate: Generation of technical ideas related to introducing operating systems for single – board computers, prototyping and hands-on FPGA programming activities for embedded systems programming skills.

3. Prototype: Experimentation with many potential solution models.

4. Test: Refinement and tuning model parameters. An example would be a model solution may operate on the edge of network, where high traffic volumes are present.

5. Define: Exploration the concepts in IoT, protocols, machine learning, data analytics and security.

H. 3D MODELING – TECHNOLOGY APPLICATIONS

Virtual labs are the interactive simulators, which are developed with the help of frontend and backend technologies. These technologies are HTML, CSS, JavaScript, Java, etc. Virtual labs could also be adopted as complementary tools to support better learning for theoretical concepts and give a more practical dimension to science, engineering and technology. In this section, we give some use cases based on 3D modelling.

In the experiment found in [38], 2D images are converted into 3D models in order to move on the X and Y axes without affecting virtual reality. In [51], through the Android augmented reality platform, a teacher explains basic concepts to students. In [88], activities related to 4D modeling concepts introduced. The materials are designed by using engineering software SolidWorks, Diptrace and Corel Draw.

V. CONCLUSION

5G and IoT enable educators to leverage mixed reality applications across the educational spectrum, providing students and trainees with more opportunities to understand what they're learning in a more engaging and interactive context. This paper analyzes the characteristics of contemporary pedagogical and STEM based didactic approaches that support educational technologies of 5G and IoT and engage students in project-based learning. Our work also presents a multi–dimensional categorization, regarding open software and hardware components usage, under certain criteria and according to educational approaches and certain technology clusters. In addition, it provides a state of the art, listing appropriate educational scenarios use cases, per scientific field and didactic approach, and highlights the trend in terms of digital technologies applied, to support smart learning – by – doing environments.

In essence, our current work systematically constructs a literature map able to consult which STEM related pedagogical method best suits each use case, according to open hardware and software tools involved. Following, the paper depicts which didactic approach fits mostly, according to the technological field one is focusing on. Moreover, it recommends correlations among hardware and software tools, didactic approaches and experimental processes.

VI. FUTURE WORK

The basic idea and main objective of our future work is the design and implementation of a simulator for 5G communication networks with IoT extensions. The simulator will be designed in a way to deconstruct difficult technical elements and parameters so that it can be used mainly for educational purposes in higher education. In addition, given the need that arose due to the pandemic, for the flexibility of running the labs mainly online, an innovation introduced by this proposal is how to combine remote labs and virtual labs with the simulator, so that the simulator takes into account real measurements from IoT devices. In this way, the experiments that can be performed and the use cases that are evaluated will be based on real data where necessary.

The entire learning process will follow STEM epistemology and engineering pedagogy, given that the 5G usage and learning scenarios will be structured in such a way that the students follow a scientific and research path. The most important innovation of the proposal concerns the hybrid model of using the laboratories, real and remote with virtual ones, considering that in order to make the 5G scenarios more realistic, the user will be able to choose to involve real materials and measurements during his experiment. We hope that this will be an effective tool to facilitate the sharing of equipment between Academic Institutions in the country and that students can connect to our proposed platform from anywhere and use real equipment when it may become available.

REFERENCES

[1] E. de Vries and H. Wörtche, "Remote labs didactics," in *Proc. IEEE Frontiers Educ. Conf. (FIE)*, Oct. 2020, pp. 1–3, doi: 10.1109/FIE44824.2020.9274072.

[2] D. C. Nguyen, M. Ding, P. N. Pathirana, A. Seneviratne, J. Li, D. Niyato, O. Dobre, and H. V. Poor, "6G Internet of Things: A comprehensive survey," *IEEE Internet Things J.*, vol. 9, no. 1, pp. 359–383, Jan. 2022, doi: 10.1109/JIOT.2021.3103320.

[3] I. Ali, I. Ahmedy, A. Gani, M. U. Munir, and M. H. Anisi, "Data collection in studies on Internet of Things (IoT), wireless sensor networks (WSNs), and sensor cloud (SC): Similarities and differences," *IEEE Access*, vol. 10, pp. 33909–33931, 2022, doi: 10.1109/ACCESS.2022.3161929.

[4] J. A. Fadhil and Q. I. Sarhan, "A survey on Internet of Things (IoT) testing," in *Proc. Int. Conf. Comput. Sci. Softw. Eng. (CSASE)*, Mar. 2022, pp. 77–83, doi: 10.1109/CSASE51777.2022.9759705.

[5] D. Lake, N. Wang, R. Tafazolli, and L. Samuel, "Softwarization of 5G networks–implications to open platforms and standardizations," *IEEE Access*, vol. 9, pp. 88902–88930, 2021, doi: 10.1109/ACCESS.2021.3071649.

[6] X. Wang, Y. Han, V. C. M. Leung, D. Niyato, X. Yan, and X. Chen, "Convergence of edge computing and deep learning: A comprehensive survey," *IEEE Commun. Surveys Tuts.*, vol. 22, no. 2, pp. 869–904, 2nd Quart., 2020, doi: 10.1109/COMST.2020.2970550.

[7] M. Gupta, R. K. Jha, and S. Jain, "Tactile based intelligence touch technology in IoT configured WCN in B5G/6G-a survey," *IEEE Access*, vol. 11, pp. 30639–30689, 2023, doi: 10.1109/ACCESS.2022.3148473.

[8] A. Verma and A. Singh, "New era of technology empowered education: Education 4.0 a systematic review," in *Proc. 9th Int. Conf. Rel., INFOCOM Technol. Optim. (Trends Future Directions) (ICRITO)*, Noida, India, Sep. 2021, pp. 1–7, doi: 10.1109/ICRITO51393.2021.9596245.

[9] S. Psycharis, K. Kalovrektis, and A. Xenakis, "A conceptual framework for computational pedagogy in STEAM education: Determinants and perspectives," *Hellenic J. STEM Educ.*, vol. 1, no. 1, pp. 17–32, Jun. 2020, doi: 10.51724/hjstemed.v1i1.4.

[10] M. Woschank and C. Pacher, "A holistic didactical approach for industrial logistics engineering education in the LOGILAB at the montanuniversitaet leoben," *Proc. Manuf.*, vol. 51, pp. 1814–1818, Nov. 2020, doi: 10.1016/j.promfg.2020.10.252.

[11] X. Xue, X. Yu, D. Zhou, X. Wang, Z. Zhou, and F. Wang, "Computational experiments: Past, present and future," 2022, *arXiv:2202.13690*.

[12] N. Aynas and M. Aslan, "The effects of authentic learning practices on problem-solving skills and attitude towards science courses," *J. Learn. Develop.*, vol. 8, no. 1, pp. 146–161, Mar. 2021, doi: 10.56059/jl4d.v8i1.482.

[13] K. A. Jones and R. S. Sharma, "An experiment in blended learning: Learning without lectures," in *Proc. IEEE Conf. e-Learning, e-Management e-Services (IC3e)*, Nov. 2017, pp. 1–6, doi: 10.1109/IC3e.2017.8409229.

[14] A. M. Wyglinski, D. P. Orofino, M. N. Ettus, and T. W. Rondeau, "Revolutionizing software defined radio: Case studies in hardware, software, and education," *IEEE Commun. Mag.*, vol. 54, no. 1, pp. 68–75, Jan. 2016, doi: 10.1109/MCOM.2016.7378428.

[15] S. G. Bilén, A. M. Wyglinski, C. R. Anderson, T. Cooklev, C. Dietrich, B. Farhang-Boroujeny, J. V. Urbina, S. H. Edwards, and J. H. Reed, "Software-defined radio: A new paradigm for integrated curriculum delivery," *IEEE Commun. Mag.*, vol. 52, no. 5, pp. 184–193, May 2014, doi: 10.1109/MCOM.2014.6815911.

[16] A. Plageras, S. Kourtis, A. C. Xenakis, K. Kalovrektis, S. Psycharis, and D. Vavougios, "Understanding ancient Greek civilizations: A STEAM teaching perspective," *Hellenic J. STEM Educ.*, vol. 1, no. 2, pp. 45–57, Dec. 2020.

[17] T. R. Kelley and J. G. Knowles, "A conceptual framework for integrated STEM education," *Int. J. STEM Educ.*, vol. 3, no. 1, Dec. 2016, doi: 10.1186/s40594-016-0046-z.

[18] L. Bryan and S. S. Guzey, "K-12 STEM education: An overview of perspectives and considerations," *Hellenic J. STEM Educ.*, vol. 1, no. 1, pp. 5–15, Jun. 2020, doi: 10.51724/hjstemed.v1i1.5.

[19] Y. Cheng, X. Wang, and S. He, "Research on the construction technology of college students' thought and behavior guidance system based on 5G environment," in *Proc. Int. Conf. Comput. Eng. Appl. (ICCEA)*, Mar. 2020, pp. 306–311, doi: 10.1109/ICCEA50009.2020.00073.

[20] F. Yang and W. Luo, "Sharing cloud platform applied to teaching system reform based on '5G+smart education' innovation," in *Proc. Int. Conf. Inf. Sci. Educ. (ICISE-IE)*, Dec. 2020, pp. 617–620, doi: 10.1109/icise51755.2020.00138.

[21] J. Pleasants, K. M. Tank, and J. K. Olson, "Conceptual connections between science and engineering in elementary teachers' unit plans," *Int. J. STEM Educ.*, vol. 8, no. 1, pp. 1–17, Apr. 2021, doi: 10.1186/s40594-021-00274-3.

[22] H. D. Mohammadian, "IoT-education technologies as solutions towards SMEs' educational challenges and I4.0 readiness," in *Proc. IEEE Global Eng. Educ. Conf. (EDUCON)*, Apr. 2020, pp. 1674–1683, doi: 10.1109/EDUCON45650.2020.9125248.

[23] M. Klopp and J. Abke, "Learning 4.0': A conceptual discussion," in *Proc. IEEE Int. Conf. Teaching, Assessment, Learn. Eng. (TALE)*, Dec. 2018, pp. 871–876, doi: 10.1109/TALE.2018.8615244.

[24] A. Musa and A. G. F. Alabi, "Disruptive engineering and education in emerging economies: Challenges and prospects," in *Proc. IFEES World Eng. Educ. Forum Global Eng. Deans Council (WEEF-GEDC)*, Nov. 2020, pp. 1–4, doi: 10.1109/WEEF-GEDC49885.2020.9293680.

[25] S. Yang and H. Bai, "Research on school education reform under the background of '5G + education,'" in *Proc. Int. Conf. Inf. Sci. Educ. (ICISE-IE)*, Dec. 2020, pp. 386–389, doi: 10.1109/icise51755.2020.00090.

[26] Y. Hong, J. Yang, Y. Chen, and H. Dong, "Research on the development of online education in the age of AI and 5G," in *Proc. 2nd Int. Conf. Educ., Knowl. Inf. Manage. (ICEKIM)*, Jan. 2021, pp. 233–237, doi: 10.1109/ICEKIM52309.2021.00058.

[27] Y. Siriwardhana, C. De Alwis, G. Gür, M. Ylianttila, and M. Liyanage, "The fight against the COVID-19 pandemic with 5G technologies," *IEEE Eng. Manag. Rev.*, vol. 48, no. 3, pp. 72–84, 3rd Quart., 2020, doi: 10.1109/EMR.2020.3017451.

[28] T. Karakasidis, "Virtual and remote labs in higher education distance learning of physical and engineering sciences," in *Proc. IEEE Global Eng. Educ. Conf. (EDUCON)*, Mar. 2013, pp. 798–807, doi: 10.1109/EduCon.2013.6530198.

[29] W. Osten, "Remote laboratories for optical metrology-from the lab to the cloud," in *Proc. Latin Amer. Opt. Photon. Conf.*, Nov. 2014, p. LTh2D.1, doi: 10.1364/laop.2014.lth2D.1.

[30] F. Schauer, F. Lustig, J. Dvořák, and M. Ožvoldová, "An easy-to-build remote laboratory with data transfer using the Internet school experimental system," *Eur. J. Phys.*, vol. 29, no. 4, pp. 753–765, Jul. 2008, doi: 10.1088/0143-0807/29/4/010.

[31] M. Casini, F. Chinello, D. Prattichizzo, and A. Vicino, "RACT: A remote lab for robotics experiments," *IFAC Proc. Volumes*, vol. 41, no. 2, pp. 8153–8158, Jul. 2008, doi: 10.3182/20080706-5-kr-1001.01377.

[32] W. Farag, "An innovative remote-lab framework for educational experimentation," *Int. J. Online Eng. (iJOE)*, vol. 13, no. 2, p. 68, Feb. 2017, doi: 10.3991/ijoe.v13i02.6609.

[33] M. Kalúz, L. Čirka, R. Valoa, and M. Fikar, "ArPi lab: A low-cost remote laboratory for control education," *IFAC Proc.*, vol. 47, no. 3, pp. 62–9057, Jan. 2014, doi: 10.3182/20140824-6-ZA-1003.00963.

[34] A. Hyder, "Design and implementation of remotely controlled laboratory experiments," Ph.D. dissertation, Inst. Technol., Georgia, 2010.

[35] A. K. Sutrala, M. S. Obaidat, S. Saha, A. K. Das, M. Alazab, and Y. Park, "Authenticated key agreement scheme with user anonymity and untraceability for 5G-enabled softwarized industrial cyber-physical systems," *IEEE Trans. Intell. Transp. Syst.*, vol. 23, no. 3, pp. 2316–2330, Mar. 2022, doi: 10.1109/TITS.2021.3056704.

[36] D. Lowe, P. Newcombe, and B. Stumpers, "Evaluation of the use of remote laboratories for secondary school science education," *Res. Sci. Educ.*, vol. 43, no. 3, pp. 1197–1219, Jun. 2013, doi: 10.1007/s11165-012-9304-3.

[37] M. Sauter, D. H. Uttal, D. N. Rapp, M. Downing, and K. Jona, "Getting real: The authenticity of remote labs and simulations for science learning," *Distance Educ.*, vol. 34, no. 1, pp. 37–47, May 2013, doi: 10.1080/01587919.2013.770431.

[38] P. Chakravarti, M. Pradhan, N. Choudhary, N. Mishra, S. Arya, and J. Sharma, "A review on virtual lab: A simulator for physical lab," *Int. J. Innov. Sci., Eng. Technol.*, vol. 8, no. 5, pp. 1–7, Aug. 2021.

[39] M. M. Ratamun and K. Osman, "The effectiveness of virtual lab compared to physical lab in the mastery of science process skills for chemistry experiment," *Problems Educ. 21st Century*, vol. 76, no. 4, pp. 544–560, Aug. 2018, doi: 10.33225/pec/18.76.544.

[40] E. Bompard, S. Bruno, A. Cordoba-Pacheco, C. Diaz-Londono, G. Giannoccaro, M. La Scala, A. Mazza, and E. Pons, "Connecting in real-time power system labs: An Italian test-case," in *Proc. IEEE Int. Conf. Environ. Electr. Eng. IEEE Ind. Commercial Power Syst. Eur. (EEEIC / I&CPS Europe)*, Jun. 2020, pp. 1–6, doi: 10.1109/EEEIC/ICPSEurope49358.2020.9160505.

[41] Z. Fang, "WITHDRAWN: Construction planning of university discipline based on 5G networks and Internet of Things system," *Microprocessors Microsystems*, Nov. 2020, Art. no. 103430, doi: 10.1016/j.micpro.2020.103430.

[42] H. Benmohamed, A. Leleve, and P. Prevot, "Remote laboratories: New technology and standard based architecture," in *Proc. Int. Conf. Inf. Commun. Technol., From Theory Appl.*, Apr. 2004, pp. 101–102, doi: 10.1109/ictta.2004.1307634.

[43] H. Benmohamed, A. Leleve, and P. Prevot, "Generic framework for remote laboratory integration," in *Proc. 6th Int. Conf. Inf. Technol. Based Higher Educ. Training*, Jul. 2005, pp. T2B/11–T2B/16, doi: 10.1109/ithet.2005.1560229.

[44] J. Grodotzki, T. R. Ortelt, and A. E. Tekkaya, "Remote and virtual labs for engineering education 4.0," *Proc. Manuf.*, vol. 26, pp. 1349–1360, Jan. 2018, doi: 10.1016/j.promfg.2018.07.126.

[45] M. Mezzavilla, M. Zhang, M. Polese, R. Ford, S. Dutta, S. Rangan, and M. Zorzi, "End-to-end simulation of 5G mmWave networks," *IEEE Commun. Surveys Tuts.*, vol. 20, no. 3, pp. 2237–2263, 3rd Quart., 2018, doi: 10.1109/COMST.2018.2828880.

[46] S. Zhang, "Evaluation of learners' visual attention in online English guiding system based on large-scale 5G and information mining," in *Proc. 2nd Int. Conf. Inventive Res. Comput. Appl. (ICIRCA)*, Jul. 2020, pp. 299–302, doi: 10.1109/ICIRCA48905.2020.9183302.

[47] E. Sancristobal, M. Castro, S. Martin, M. Tawkif, A. Pesquera, R. Gil, G. Díaz, and J. Peire, "Remote labs as learning services in the educational arena," in *Proc. IEEE Global Eng. Educ. Conf. (EDUCON)*, Apr. 2011, pp. 1189–1194, doi: 10.1109/EDUCON.2011.5773298.

[48] C. Viegas, A. Pavani, N. Lima, A. Marques, I. Pozzo, E. Dobboletta, V. Atencia, D. Barreto, F. Calliari, A. Fidalgo, D. Lima, G. Temporão, and G. Alves, "Impact of a remote lab on teaching practices and student learning," *Comput. Educ.*, vol. 126, pp. 201–216, Nov. 2018, doi: 10.1016/j.compedu.2018.07.012.

[49] M. Dawson, F. G. Martinez, and P. Taveras, "Framework for the development of virtual labs for industrial Internet of Things and hyperconnected systems," in *Proc. IEEE Learn. With MOOCS (LWMOOCS)*, Oct. 2019, pp. 196–198, doi: 10.1109/LWMOOCS47620.2019.8939660.

[50] I.-F. Yang, Y.-C. Lin, S.-R. Yang, and P. Lin, "The implementation of a SIP-based service platform for 5G IoT applications," in *Proc. IEEE 93rd Veh. Technol. Conf. (VTC-Spring)*, Apr. 2021, pp. 1–6, doi: 10.1109/VTC2021-Spring51267.2021.9448772.

[51] Y. Bahuguna, A. Verma, and K. Raj, "Smart learning based on augmented reality with Android platform and its applicability," in *Proc. 3rd Int. Conf. Internet Things: Smart Innov. Usages (IoT-SIU)*, Feb. 2018, pp. 1–5, doi: 10.1109/IoT-SIU.2018.8519853.

[52] A. B. Mathews and G. Glan Devadhas, "Machine learning approach for 5G hybrid technologies," in *Proc. Int. Conf. Inventive Comput. Technol. (ICICT)*, Feb. 2020, pp. 486–491, doi: 10.1109/ICICT48043.2020.9112519.

[53] T. Lei, Z. Cai, and L. Hua, "5G-oriented IoT coverage enhancement and physical education resource management," *Microprocessors Microsystems*, vol. 80, Feb. 2021, Art. no. 103346, doi: 10.1016/j.micpro.2020.103346.

[54] S. Bayhan, "LabVIEW-based remote laboratory experiments for a multi-mode single-leg converter," *J. Power Electron.*, vol. 14, no. 5, pp. 1069–1078, Sep. 2014, doi: 10.6113/jpe.2014.14.5.1069.

[55] A. Verma, A. Singh, D. Anand, H. M. Aljahdali, K. Alsubhi, and B. Khan, "IoT inspired intelligent monitoring and reporting framework for education 4.0," *IEEE Access*, vol. 9, pp. 131286–131305, 2021, doi: 10.1109/ACCESS.2021.3114286.

[56] T. Alam and M. Benaida, "Blockchain and Internet of Things in higher education," *Universal J. Educ. Res.*, vol. 8, no. 5, pp. 2164–2174, May 2020, doi: 10.13189/ujer.2020.080556.

[57] J. A. Marquez, A. Borrero, M. A. Márquez, and M. R. Sánchez, "A complete solution for developing remote labs," in *Proc. 10th IFAC Symp. Adv. Control Educ.*, Aug. 2013, pp. 96–101, doi: 10.13140/RG.2.1.2513.3841.

[58] Y. Guo, "Low-latency and high-concurrency 5G wireless sensor network assists innovation in ideological and political education in colleges and universities," *J. Sensors*, vol. 2021, pp. 1–11, Nov. 2021, doi: 10.1155/2021/9867800.

[59] S. M. A. Zaidi, M. Manalastas, H. Farooq, and A. Imran, "SyntheticNET: A 3GPP compliant simulator for AI enabled 5G and beyond," *IEEE Access*, vol. 8, pp. 82938–82950, 2020, doi: 10.1109/ACCESS.2020.2991959.

[60] K. N. Qureshi, A. Naveed, Y. Kashif, and G. Jeon, "Internet of Things for education: A smart and secure system for schools monitoring and alerting," *Comput. Electr. Eng.*, vol. 93, Jul. 2021, Art. no. 107275, doi: 10.1016/j.compeleceng.2021.107275.

[61] A. Zhamanov, Z. Sakhiyeva, R. Suliyev, and Z. Kaldykulova, "IoT smart campus review and implementation of IoT applications into education process of university," in *Proc. 13th Int. Conf. Electron., Comput. Comput. (ICECCO)*, Nov. 2017, pp. 1–4, doi: 10.1109/ICECCO.2017.8333334.

[62] D. K. Dake and B. Adjei, "5G enabled technologies for smart education," *Int. J. Adv. Comput. Sci. Appl.*, vol. 10, no. 12, pp. 201–206, Jan. 2019, doi: 10.14569/ijacsa.2019.0101228.

[63] C. Liu, L. Wang, and H. Liu, "5G network education system based on multi-trip scheduling optimization model and artificial intelligence," *J. Ambient Intell. Humanized Comput.*, pp. 1–14, Apr. 2021, doi: 10.1007/s12652-021-03205-w.

[64] J. Zhang, H. Zhong, J. Cui, M. Tian, Y. Xu, and L. Liu, "Edge computing-based privacy-preserving authentication framework and protocol for 5G-enabled vehicular networks," *IEEE Trans. Veh. Technol.*, vol. 69, no. 7, pp. 7940–7954, Jul. 2020, doi: 10.1109/TVT.2020.2994144.

[65] P. Ren, X. Qiao, Y. Huang, L. Liu, C. Pu, and S. Dustdar, "Fine-grained elastic partitioning for distributed DNN towards mobile web AR services in the 5G era," *IEEE Trans. Services Comput.*, vol. 15, no. 6, pp. 3260–3274, Nov. 2022, doi: 10.1109/TSC.2021.3098816.

[66] X. Xu, D. Li, M. Sun, S. Yang, S. Yu, G. Manogaran, G. Mastorakis, and C. X. Mavromoustakis, "Research on key technologies of smart campus teaching platform based on 5G network," *IEEE Access*, vol. 7, pp. 20664–20675, 2019, doi: 10.1109/ACCESS.2019.2894129.

[67] Y. Kim, J. Moon, and E. Hwang, "Constructing differentiated educational materials using semantic annotation for sustainable education in IoT environments," *Sustainability*, vol. 10, no. 4, p. 1296, Apr. 2018, doi: 10.3390/su10041296.

[68] T. Jong, "Learning complex domains and complex tasks, the promise of simulation based training," in *Proc. Comput. Aided Learn. Eng. Educ.*, Grenoble, France, Nov. 2019, pp. 1–8.

[69] F. A. D. S. Freitas, F. F. X. Vasconcelos, S. A. Peixoto, M. M. Hassan, M. A. A. Dewan, V. H. C. D. Albuquerque, and P. P. R. Filho, "IoT system for school dropout prediction using machine learning techniques based on socioeconomic data," *Electronics*, vol. 9, no. 10, p. 1613, Oct. 2020, doi: 10.3390/electronics9101613.

[70] R. Morales-Menendez, R. A. Ramírez-Mendoza, and A. J. V. Guevara, "Virtual/Remote labs for automation teaching: A cost effective approach," *IFAC-PapersOnLine*, vol. 52, no. 9, pp. 266–271, 2019, doi: 10.1016/j.ifacol.2019.08.219.

[71] E. Fabregas, G. Farias, S. Dormido-Canto, S. Dormido, and F. Esquembre, "Developing a remote laboratory for engineering education," *Comput. Educ.*, vol. 57, no. 2, pp. 1686–1697, Sep. 2011, doi: 10.1016/j.compedu.2011.02.015.

[72] K. Bangert, J. Bates, S. Beck, Z. Bishop, M. Di Benedetti, J. Fullwood, A. Funnell, A. Garrard, S. Hayes, T. Howard, C. Johnson, M. Jones, P. Lazari, J. Mukherjee, C. Omar, B. Taylor, R. Thorley, G. Williams, and R. Woolley, "Remote practicals in the time of coronavirus, a multidisciplinary approach," *Int. J. Mech. Eng. Educ.*, vol. 50, no. 2, pp. 219–239, Apr. 2022, doi: 10.1177/0306419020958100.

[73] D. Loghin, S. Cai, G. Chen, T. T. A. Dinh, F. Fan, Q. Lin, J. Ng, B. C. Ooi, X. Sun, Q.-T. Ta, W. Wang, X. Xiao, Y. Yang, M. Zhang, and Z. Zhang, "The disruptions of 5G on data-driven technologies and applications," *IEEE Trans. Knowl. Data Eng.*, vol. 32, no. 6, pp. 1179–1198, Jun. 2020, doi: 10.1109/TKDE.2020.2967670.

[74] L. Gomes and S. Bogosyan, "Current trends in remote laboratories," *IEEE Trans. Ind. Electron.*, vol. 56, no. 12, pp. 4744–4756, Dec. 2009, doi: 10.1109/tie.2009.2033293.

[75] J. Broisin, R. Venant, and P. Vidal, "Lab4CE: A remote laboratory for computer education," *Int. J. Artif. Intell. Educ.*, vol. 27, no. 1, pp. 154–180, Mar. 2017, doi: 10.1007/s40593-015-0079-3.

[76] E. Bogdanov, C. Salzmann, and D. Gillet, "Widget-based approach for remote control labs," *IFAC Proc. Volumes*, vol. 45, no. 11, pp. 189–193, Jun. 2012, doi: 10.3182/20120619-3-ru-2024.00091.

[77] P. Isto, T. Heikkilä, A. Mämmelä, M. Uitto, T. Seppälä, and J. M. Ahola, "5G based machine remote operation development utilizing digital twin," *Open Eng.*, vol. 10, no. 1, pp. 265–272, May 2020, doi: 10.1515/eng-2020-0039.

[78] J. Francisti, Z. Balogh, J. Reichel, M. Magdin, Š. Koprda, and G. Molnár, "Application experiences using IoT devices in education," *Appl. Sci.*, vol. 10, no. 20, p. 7286, Oct. 2020, doi: 10.3390/app10207286.

[79] S. M. Rakshit, S. Banerjee, M. Hempel, and H. Sharif, "Fusion of VR and teleoperation for innovative near-presence laboratory experience in engineering education," in *Proc. IEEE Int. Conf. Electro Inf. Technol. (EIT)*, May 2017, pp. 376–381, doi: 10.1109/EIT.2017.8053390.

[80] J. Cui, J. Chen, H. Zhong, J. Zhang, and L. Liu, "Reliable and efficient content sharing for 5G-enabled vehicular networks," *IEEE Trans. Intell. Transp. Syst.*, vol. 23, no. 2, pp. 1247–1259, Feb. 2022, doi: 10.1109/TITS.2020.3023797.

[81] M. I. Ciolacu, L. Binder, P. Svasta, I. Tache, and D. Stoichescu, "Education 4.0–jump to innovation with IoT in higher education," in *Proc. IEEE 25th Int. Symp. for Design Technol. Electron. Packag. (SIITME)*, Oct. 2019, pp. 135–141, doi: 10.1109/SIITME47687.2019.8990825.

[82] E. Yamao and N. L. Lescano, "Smart campus as a learning platform for industry 4.0 and IoT ready students in higher education," in *Proc. IEEE Int. Symp. Accreditation Eng. Comput. Educ. (ICACIT)*, Nov. 2020, pp. 1–4, doi: 10.1109/ICACIT50253.2020.9277679.

[83] P. Verma and S. K. Sood, "A comprehensive framework for student stress monitoring in fog-cloud IoT environment: M-health perspective," *Med. Biol. Eng. Comput.*, vol. 57, no. 1, pp. 231–244, Jan. 2019, doi: 10.1007/s11517-018-1877-1.

[84] R. Revathi and M. Suganya, "IoT based cloud integrated smart classroom for smart and a sustainable campus," *Proc. Comput. Sci.*, vol. 172, pp. 77–81, Jan. 2020, doi: 10.1016/j.procs.2020.05.012.

[85] T. Sutjarittham, H. H. Gharakheili, S. S. Kanhere, and V. Sivaraman, "Experiences with IoT and AI in a smart campus for optimizing classroom usage," *IEEE Internet Things J.*, vol. 6, no. 5, pp. 7595–7607, Oct. 2019, doi: 10.1109/JIOT.2019.2902410.

[86] J. Lee and D. Kim, "A study on innovation in university education: Focusing on 5G mobile communication," in *Proc. IEEE 17th Annu. Consum. Commun. Netw. Conf. (CCNC)*, Jan. 2020, pp. 1–4, doi: 10.1109/CCNC46108.2020.9045138.

[87] H. C. Leligou, E. Zacharioudakis, L. Bouta, and E. Niokos, "5G technologies boosting efficient mobile learning," in *Proc. MATEC Web Conf.*, vol. 125, Oct. 2017, p. 03004, doi: 10.1051/matecconf/201712503004.

[88] P. Purnamawati, R. T. Mangesa, R. Ruslan, and I. Idhar, "Development of learning tools using remote IoT labs with blended learning method in the department of engineering education," *J. Phys., Conf. Ser.*, vol. 1899, no. 1, May 2021, Art. no. 012164, doi: 10.1088/1742-6596/1899/1/012164.

[89] R. Jurva, M. Matinmikko-Blue, V. Niemelä, and S. Nenonen, "Architecture and operational model for smart campus digital infrastructure," *Wireless Pers. Commun.*, vol. 113, no. 3, pp. 1437–1454, Mar. 2020, doi: 10.1007/s11277-020-07221-5.

[90] A. Majeed and M. Ali, "How Internet-of-Things (IoT) making the university campuses smart? QA higher education (QAHE) perspective," in *Proc. IEEE 8th Annu. Comput. Commun. Workshop Conf. (CCWC)*, Jan. 2018, pp. 646–648, doi: 10.1109/CCWC.2018.8301774.

[91] T. Wirth, M. Mehlhose, J. Pilz, R. Lindstedt, D. Wieruch, B. Holfeld, and T. Haustein, "An advanced hardware platform to verify 5G wireless communication concepts," in *Proc. IEEE 81st Veh. Technol. Conf. (VTC Spring)*, May 2015, pp. 1–5, doi: 10.1109/VTCSpring.2015.7145679.

[92] V. Nassi and A. Goulart, "Laboratory experiments on 5G cellular technologies—A case study on the synergy of research and experiential learning," in *Proc. ASEE Gulf-Southwest Section Annual Meeting, ATT Executive Educ. Conf. Center*, Austin, TX, USA, Apr. 2019, pp. 1–5, doi: 10.26153/tsw/6921.

[93] X. Wang, Y. Zhong, X. Ge, X. Hei, Y. Gao, and Z. Xu, "Capstone projects design based on 5G experimental platform deployed on campus," in *Proc. IEEE Int. Conf. Teaching, Assessment, Learn. Eng. (TALE)*, Dec. 2020, pp. 835–840, doi: 10.1109/TALE48869.2020.9368451.

[94] Y.-H. You, J.-H. Park, and I.-Y. Ahn, "Complexity effective sequential detection of secondary synchronization signal for 5G new radio communication systems," *IEEE Syst. J.*, vol. 15, no. 3, pp. 3382–3390, Sep. 2021, doi: 10.1109/JSYST.2020.3001925.

[95] Z. Xu, X. Hei, D. Qu, and W. Li, "Pushing the 5G edge into the principles of communications course based on a blended lab platform," in *Proc. IEEE Global Eng. Educ. Conf. (EDUCON)*, Apr. 2021, pp. 339–343, doi: 10.1109/EDUCON46332.2021.9453970.

[96] Y. Liu, M. Peng, G. Shou, Y. Chen, and S. Chen, "Toward edge intelligence: Multiaccess edge computing for 5G and Internet of Things," *IEEE Internet Things J.*, vol. 7, no. 8, pp. 6722–6747, Aug. 2020, doi: 10.1109/JIOT.2020.3004500.

[97] A. H. Sodhro, S. Pirbhulal, G. H. Sodhro, M. Muzammal, L. Zongwei, A. Gurtov, A. R. L. de Macêdo, L. Wang, N. M. Garcia, and V. H. C. de Albuquerque, "Towards 5G-enabled self adaptive green and reliable communication in intelligent transportation system," *IEEE Trans. Intell. Transp. Syst.*, vol. 22, no. 8, pp. 5223–5231, Aug. 2021, doi: 10.1109/TITS.2020.3019227.

[98] P. K. Gkonis, P. T. Trakadas, and D. I. Kaklamani, "A comprehensive study on simulation techniques for 5G networks: State of the art results, analysis, and future challenges," *Electronics*, vol. 9, no. 3, p. 468, Mar. 2020, doi: 10.3390/electronics9030468.

[99] M. Gundall, M. Strufe, H. D. Schotten, P. Rost, C. Markwart, R. Blunk, A. Neumann, J. Grießbach, M. Aleksy, and D. Wübben, "Introduction of a 5G-enabled architecture for the realization of industry 4.0 use cases," *IEEE Access*, vol. 9, pp. 25508–25521, 2021, doi: 10.1109/ACCESS.2021.3057675.

[100] M. Casini, A. Garulli, A. Giannitrapani, and A. Vicino, "A MATLAB-based remote lab for multi-robot experiments," *IFAC Proc. Volumes*, vol. 42, no. 24, pp. 162–167, Jan. 2010, doi: 10.3182/20091021-3-jp-2009.00031.

[101] B. Kizilkaya, Z. Meng, G. Zhao, L. Li, and M. A. Imran, "Towards 5G-enabled education: Remote laboratory and training prototype," in *Proc. 4th U.K.-RAS Conf. PhD students Early-Career Researchers Robotics Home*, Jul. 2021, pp. 53–54, doi: 10.31256/Px3Rq7M.

[102] H. Rahimi, Y. Picaud, K. D. Singh, G. Madhusudan, S. Costanzo, and O. Boissier, "Design and simulation of a hybrid architecture for edge computing in 5G and beyond," *IEEE Trans. Comput.*, vol. 70, no. 8, pp. 1213–1224, Aug. 2021, doi: 10.1109/TC.2021.3066579.

[103] G. Cainelli and L. Rauchhaupt, "Introducing resilience in industrial 5G systems using a digital twin approach," in *Proc. 17th IEEE Int. Conf. Factory Commun. Syst. (WFCS)*, Jun. 2021, pp. 33–36, doi: 10.1109/WFCS46889.2021.9483618.

[104] B. Barros, T. Read, and M. F. Verdejo, "Virtual collaborative experimentation: An approach combining remote and local labs," *IEEE Trans. Educ.*, vol. 51, no. 2, pp. 242–250, May 2008, doi: 10.1109/te.2007.908071.

[105] K. Saleem, G. M. Alabduljabbar, N. Alrowais, J. Al-Muhtadi, M. Imran, and J. J. P. C. Rodrigues, "Bio-inspired network security for 5G-enabled IoT applications," *IEEE Access*, vol. 8, pp. 229152–229160, 2020, doi: 10.1109/ACCESS.2020.3046325.

[106] M. I. Ciolacu, L. Binder, and H. Popp, "Enabling IoT in education 4.0 with BioSensors from wearables and artificial intelligence," in *Proc. IEEE 25th Int. Symp. for Design Technol. Electron. Packag. (SIITME)*, Oct. 2019, pp. 17–24, doi: 10.1109/SIITME47687.2019.8990763.

[107] A. Lelevé, H. Benmohamed, and P. Prévot, "Sharing a system between simultaneous learners in remote laboratories," in *Proc. IFAC Workshop Internet Based Control Educ. (IBCE)*, Grenoble, France, Sep. 2004, p. 6.

[108] S. K. Shrestha and F. Furqan, "IoT for smart learning/education," in *Proc. 5th Int. Conf. Innov. Technol. Intell. Syst. Ind. Appl. (CITISIA)*, Nov. 2020, pp. 1–7, doi: 10.1109/CITISIA50690.2020.9371774.

[109] Y. Qiao, Q. Zheng, Y. Lin, Y. Fang, Y. Xu, and T. Zhao, "Haptic communication: Toward 5G tactile internet," in *Proc. Cross Strait Radio Sci. Wireless Technol. Conf. (CSRSWTC)*, Dec. 2020, pp. 1–3, doi: 10.1109/CSRSWTC50769.2020.9372659.

[110] B. Kizilkaya, G. Zhao, Y. A. Sambo, L. Li, and M. A. Imran, "5G-enabled education 4.0: Enabling technologies, challenges, and solutions," *IEEE Access*, vol. 9, pp. 166962–166969, 2021, doi: 10.1109/ACCESS.2021.3136361.

[111] Y. Chicas, A. Isidro, and O. Rodas, "Development of low-cost IoT devices to encourage STEM skills in guatemalan environments," in *Proc. IEEE Integr. STEM Educ. Conf. (ISEC)*, Aug. 2020, pp. 1–7, doi: 10.1109/ISEC49744.2020.9397811.

[112] L. G. Seng, K. L. K. Wei, and S. J. Narciso, "Effective industry ready IoT applied courseware–teaching IoT design and validation," in *Proc. IEEE Global Eng. Educ. Conf. (EDUCON)*, Apr. 2020, pp. 1579–1583, doi: 10.1109/EDUCON45650.2020.9125366.

[113] J. P. C. de Lima, L. M. Carlos, J. P. S. Simão, J. Pereira, P. M. Mafra, and J. B. da Silva, "Design and implementation of a remote lab for teaching programming and robotics," *IFAC-PapersOnLine*, vol. 49, no. 30, pp. 86–91, Nov. 2016, doi: 10.1016/j.ifacol.2016.11.133.

[114] N. Magotra, A. Qouneh, and J. Burke, "Internet of Things (IoT) and electrical and computer engineering curriculums," in *Proc. IEEE 62nd Int. Midwest Symp. Circuits Syst. (MWSCAS)*, Aug. 2019, pp. 845–847, doi: 10.1109/MWSCAS.2019.8885107.

[115] M. Elbestawi, D. Centea, I. Singh, and T. Wanyama, "Sep. learning factory for industry 4.0 education and applied research," *Proc. Manuf.*, vol. 23, pp. 249–254, Jan. 2018, doi: 10.1016/j.promfg.2018.04.025.

[116] S. Martin, A. Fernandez-Pacheco, J. A. Ruipérez-Valiente, G. Carro, and M. Castro, "Remote experimentation through arduino-based remote laboratories," *IEEE Revista Iberoamericana de Tecnologias del Aprendizaje*, vol. 16, no. 2, pp. 180–186, May 2021, doi: 10.1109/RITA.2021.3089916.

[117] C. Kynigos, M. Grizioti, and C. Gkreka, "Studying real-world societal problems in a STEM context through robotics," 2018, *arXiv:1806.03245*.

[118] P. Trentsios, M. Wolf, and S. Frerich, "Remote lab meets virtual reality–enabling immersive access to high tech laboratories from afar," *Proc. Manuf.*, vol. 43, pp. 25–31, Jan. 2020, doi: 10.1016/j.promfg.2020.02.104.

[119] U. Mokhtar and J. Ahmad, "5G communications: Potential impact on education technology in higher Ed," in *Proc. 5G Commun., Potential Impact Educ. Technol. in Higher Ed.*, Jul. 2020, pp. 1–8.

[120] M. Zhang and H. Zhang, "Construction of music teaching effect evaluation model based on 5G technology," in *Proc. Int. Conf. Data Process. Techn. Appl. Cyber-Phys. Syst.*, Singapore. Frankfurt, Germany: Springer, Jun. 2021, pp. 493–500, doi: 10.1007/978-981-16-1726-3_60.

[121] L. Oliva-Maza, E. Torres-Moreno, M. Villarroya-Gaudó, and N. Ayuso-Escuer, "Using IoT for sustainable development goals (SDG) in education," *Multidisciplinary Digital Publishing Inst. Proc.*, vol. 3, no. 1, p. 1, Dec. 2019, doi: 10.3390/proceedings2019031001.

[122] J. Chacón, H. Vargas, G. Farias, J. Sánchez, and S. Dormido, "EJS, JIL server, and LabVIEW: An architecture for rapid development of remote labs," *IEEE Trans. Learn. Technol.*, vol. 8, no. 4, pp. 393–401, Oct. 2015, doi: 10.1109/TLT.2015.2389245.

[123] L. S. Post, P. Guo, N. Saab, and W. Admiraal, "Effects of remote labs on cognitive, behavioral, and affective learning outcomes in higher education," *Comput. Educ.*, vol. 140, Oct. 2019, Art. no. 103596, doi: 10.1016/j.compedu.2019.103596.

[124] R. Heradio, L. de la Torre, and S. Dormido, "Virtual and remote labs in control education: A survey," *Annu. Rev. Control*, vol. 42, pp. 1–10, Aug. 2016, doi: 10.1016/j.arcontrol.2016.08.001.

[125] G. Haus, L. Ludovico, E. Pagani, and N. Scarabottolo, "5G technology for augmented and virual reality in education," in *Proc. Int. Conf. Educ. New Develop.*, Jun. 2019, pp. 512–516, doi: 10.36315/2019v1end116.

[126] A. Kunz and A. Salkintzis, "Non-3GPP access security in 5G," *J. ICT Standardization*, vol. 8, no. 1, pp. 41–56, Jan. 2020, doi: 10.13052/jicts2245-800x.814.

[127] F. Wu and D. Kong, "The application of computational experiments in water conservancy investment," in *Proc. Int. Conf. Mech. Sci., Electric Eng. Comput. (MEC)*, Aug. 2011, pp. 2543–2546, doi: 10.1109/MEC.2011.6026011.

[128] K. Kalovrektis, "An open hardware mechanism for remote implementation of laboratory activities in science, STEAM and educational robotics educational environments: Development, usability and technological acceptance by educators," Doctoral Dissertations, School Humanities Social Sci. Dept. Primary Educ., Univ. Thessaly, Volos, Greece, 2022.

[129] J. P. Rubim, V. P. Mota, L. G. Garcia, G. L. R. Brito, and G. F. Santos, "The use of remote experimentation as a teaching tool: A literature review," *Int. J. Inf. Educ. Technol.*, vol. 9, no. 11, pp. 826–830, Nov. 2019, doi: 10.18178/ijiet.2019.9.11.1312.

[130] S. Lad, B. Mahajan, R. Mandkulkar, V. Pugaonkar, and K. Sailakshmi, "Data acquisition system using LABVIEW," *Int. Res. J. Eng. Technol.*, vol. 4, no. 4, pp. 1852–1857, Apr. 2017.

[131] W.-H. Kuan, C.-H. Tseng, S. Chen, and C.-C. Wong, "Development of a computer-assisted instrumentation curriculum for physics students: Using LabVIEW and Arduino platform," *J. Sci. Educ. Technol.*, vol. 25, no. 3, pp. 427–438, Jun. 2016, doi: 10.1007/s10956-016-9603-y.

[132] A. Xenakis, K. Kalovrektis, and S. Brentas, "Design and implementation of a distant learning robotics tool to study spatial ability of students," in *Proc. 12th Annu. Int. Conf. Educ., Res. Innov. (iCERI)*, Spain, Nov. 2019, pp. 11–13.

[133] K. Kalovrektis, *LabVIEW for Engineers. Data Acquisition System. Development and Programming*. Leivadia, Greece: Tziola, Mar. 2017.

[134] R. S. Pol, S. Giri, A. Ravishankar, and V. Ghode, "LabVIEW based four DoF robotic ARM," in *Proc. Int. Conf. Adv. Comput., Commun. Informat. (ICACCI)*, Sep. 2016, pp. 1791–1798, doi: 10.1109/ICACCI.2016.7732308.

[135] S. Psycharis, K. Kalovrektis, E. Sakellaridi, K. Korres, and D. Mastorodimos, "Unfolding the curriculum: Physical computing, computational thinking and computational experiment in STEM's transdisciplinary approach," in *Proc. EJENG*, Mar. 2018, pp. 19–24, doi: 10.24018/ejeng.2018.0.CIE.639.

[136] S. Psycharis, K. Kalovrektis, E. Sakellaridi, G. Chatzarakis, and M. Oikonomopoulou, "Physical computing, computational thinking, and computational experiment in engineering pedagogy: An implication for the engineering education epistemology," in *Proc. Educon IEEE Global Eng. Educ. Conf.*, 2018, pp. 1–11.

[137] S. Psycharis, D. Mastorodimos K. Kalovrektis P. P. L. Stergioulas, and M. Abbasi, "Algorithm visualization and its impact on self-efficacy, metacognition and computational thinking concepts using the computational pedagogy model, STEM content epistemology," *IJPCE Int. J. Phys. Chem. Educ.*, vol. 10, no. 4, pp. 71–84, Dec. 2018.

[138] S. Psycharis, K. Kalovrektis, and A. Xenakis, "A conceptual framework for computational pedagory in STEM education: Determinants and perspectives," *Hellenic J. STEM (HJSTEM)*, vol. 1, no. 1, p. 1460, Jun. 2020, doi: 0.51724/hjstemed.v1i1.4.

[139] S. Psycharis and E. Kotzampasaki, "The impact of a STEM inquiry game learning scenario on computational thinking and computer self-confidence," *EURASIA J. Math., Sci. Technol. Educ.*, vol. 15, no. 4, p. 1689, Jan. 2019, doi: 10.29333/ejmste/103071.

[140] S. Psycharis, K. Kalovrektis, A. Xenakis, I. Paliokas, M. Patrinopoulos, P. Georgiakakis, P. Iatrou, P. Theodorou, T. Papageorgiou, and V. Ntourou, "The impact of physical computing and computational pedagogy on Girl's self–efficacy and computational thinking practice," in *Proc. IEEE Global Eng. Educ. Conf. (EDUCON)*, Apr. 2021, pp. 308–315, doi: 10.1109/EDUCON46332.2021.9454003.

[141] S. Psycharis and K. Kalovrektis, "Assesement and integrated steam in engineering education," in *Proc. IEEE Global Eng. Educ. Conf. (EDUCON)*, Mar. 2022, pp. 695–703, doi: 10.1109/EDUCON52537.2022.9766654.

[142] M. Papoutsidakis, A. Chatzopoulos, K. Kalovrektis, and C. Drosos, "A brief guide for the continuously evolving μController raspberry PI Mod.B," *Int. J. Comput. Appl.*, vol. 176, no. 8, pp. 30–33, Oct. 2017, doi: 10.5120/ijca2017915651.

[143] M. Papoutsidakis, A. Chatzopoulos, C. Drosos, and K. Kalovrektis, "An Arduino family controller and its interactions via an intelligent interface," *Int. J. Comput. Appl.*, vol. 179, no. 30, pp. 0975–8887, Mar. 2018, doi: 10.5120/ijca2018916684.

[144] K. Kalovrektis, M. Papoutsidakis, C. Drosos, and G. Stamoulis, "Information technology and μController applications to support experiential learning of students," *Int. J. Comput. Appl.*, vol. 175, no. 8, pp. 33–37, Oct. 2017, doi: 10.5120/ijca2017915649.

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