Industrial Electronics Education: Past, Present and Future Perspectives

Abstract — Industrial electronics covers a wide range of technologies and applications, being a key enabling technology in numerous industrial, domestic and biomedical applications, among others. In this context, industrial electronics education has become a relevant and challenging topic for society and industry. This paper covers its evolution and state-of-the-art methodologies and provides an overall view of its status around the world. Finally, future trends and challenges in industrial electronics education are discussed.

Index Terms — Industrial electronics, education, e-learning, life-long learning, open innovation.

I. Introduction to Industrial Electronics Education

Industrial Electronics (IE) discipline includes a diverse range of technical areas devoted to the application of electronics and electrical sciences for the enhancement of industrial and manufacturing processes. This includes latest developments in intelligent and computer control systems, robotics, factory communications and automation, flexible manufacturing, data acquisition and signal processing, vision systems, and power electronics (Fig. 1). This makes IE inherently multidisciplinary, and with many interdisciplinary synergies, playing a key role as an enabling technology in multiple domestic, biomedical and industrial applications.

Nowadays, modern higher education has evolved worldwide to establish a humboldtian paradigm [1] where teaching and research coexist. This synergetic coexistence has been demonstrated to provide positive feedback in terms of resources, satisfaction and learning outcomes [2]. Moreover, this higher education

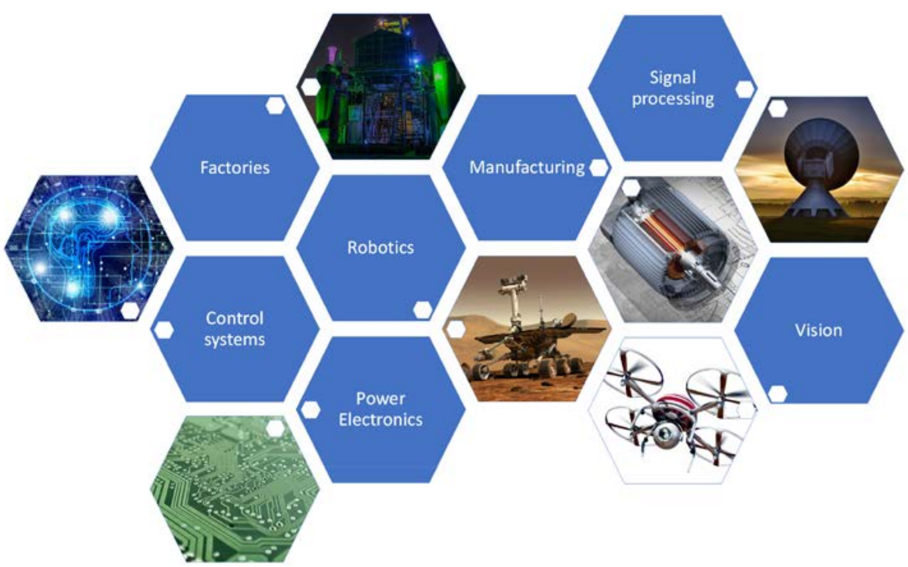

Fig. 1. Industrial electronics society (IES) main areas of interest.

paradigm has evolved to include technology transfer to society and industry as a relevant third leg in higher education, and particularly in engineering and IE (Fig. 2).

In this context, industrial electronics education has become a priority for industry and society to satisfy the need for these professionals [3] in industry, academic and social service spheres. This is especially important and challenging in a modern context of highly specialized and constant-evolving technologies and society, requiring constant evolution of educational processes and life-long learning activities to adapt them to the current socio-economic and technological background [4].

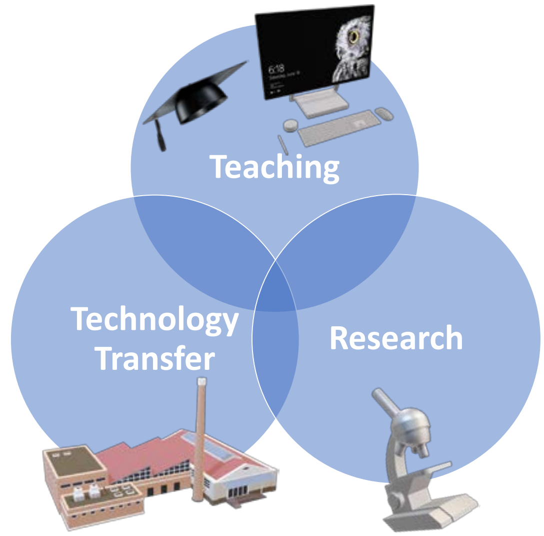

Fig. 2. Higher education components.

This paper aims at reviewing the evolution and current state-of-the-art methodologies in industrial electronics education. A short historical review, the main current methodologies and educational trends, and the links with industry are presented in Section II. Section III reviews and discusses non-presential learning, whereas continuing education is discussed in Section IV. Section V presents and discusses the IE educational context worldwide. Finally, this paper presents some closing notes on the future challenges and trends on IE education, including multi-, inter- and trans-disciplinarity as inherent characteristics of industrial electronics.

II. State-of-the-art in Industrial Electronics Education

This section presents a brief review of industrial electronics education and evolution and role of the Industrial Electronics Society (IES) in it (Fig. 3). Besides, the main educational methodologies and trends are discussed as follows.

A. Brief history of IE education and IES

The second industrial revolution brought significant engineering advances in many fields, being the origin of the electrical engineering and, consequently, leading to the appearance of the first electrical engineering curricula in the end of the XIX century. By that time, advances took place mainly in Europe and US, following the former a more theoretical higher education, whereas the latter focused on workshop training [5]. Despite the tragic happenings in the first half of the XX century, new electric and electronic techniques such as advanced communications, radars, microwaves or control systems, among others, appeared. These technologies boosted the interest on industrial electronics and led to the creation of electrical engineering curricula in most technical universities, following a theoretical-content orientation to develop modern technologies. At the same time, and promoted by the increased interest in this field, the first meeting of the IRE Industrial electronics group took place in 1951, setting the foundations of the current Industrial

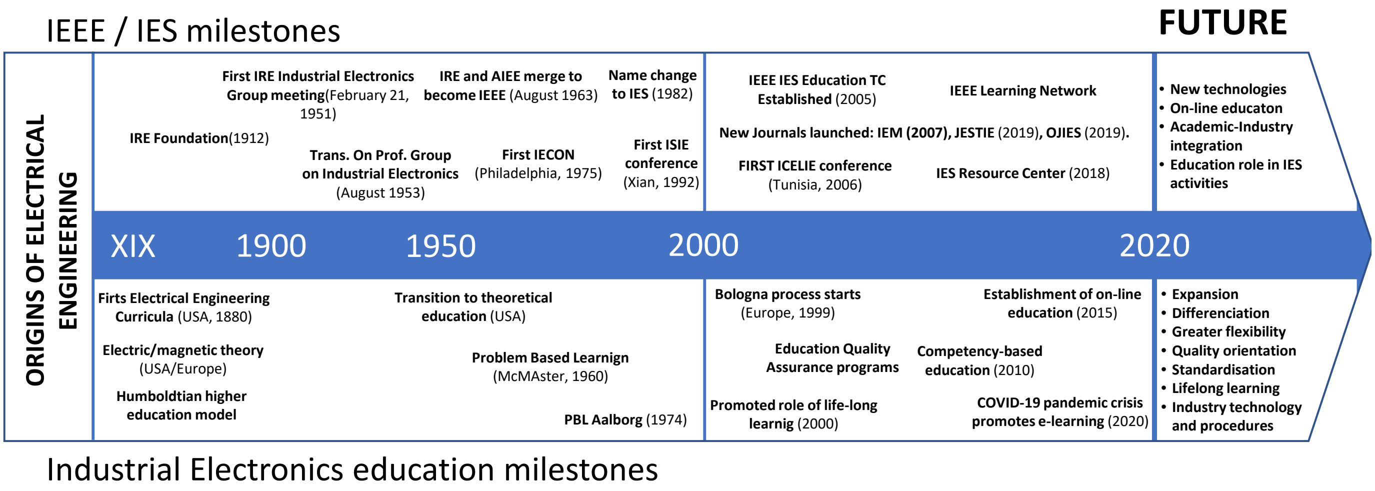

Fig. 3. Historical review of IES and education milestones.

Electronics Society, whose actual name was adopted in 1982. During the next decades, industrial electronics curricula were consolidating in most universities, and modern teaching techniques appeared as a response to industrial and social demands, being among them problem- and project-based learning, simulation-aided learning, and improved hands-on training. That implied, in fact, a reorientation to a more practical engineering content linked to industry needs. During the 70's and 80's, IES activities also increased, leading to the first IECON conference in 1975. The last decades has brought major changes to IE education due to major technological and societal challenges. On the one hand, new technologies have irrupted with key applications such as renewable energies, electrical transportation, advanced robotics and manufacturing, artificial intelligence and the internet of things, among others. On the other hand, education has been globally transformed from a teacher-centric model to a student-centric model, promoting new methodologies and competency-based learning models, and the role of remote and life-long learning has gained increased attention. IES activities also accompanied and helped this expansion, with the celebration of the first ISIE conference (1992) and the later creation of the Technical Committee (TC05) on Education in Engineering and Industrial Technologies (in 2005), launching of several focused Special Sessions within major IES conferences (starting in 2015-17 and being currently a regular contribution to IES conferences technical programs), and the ICELIE conference, first held in 2006. These technical activities were also consolidated through a set of special sections launched in IES journals, such as IEEE Transactions on Industrial Electronics and IEEE Transactions on Industrial Informatics [6-10]. During 2017, Technical Committee clusters within IES were created, promoting interdisciplinary activities, including educational ones, that are inherently in the essence of IES.

The remainder of this section will cover the state-of-the-art methodologies being applied as a result of the aforementioned evolution and the links between education and industry, whereas future trends and challenges will be discussed at the end of this paper.

B. Educational tools

Educational tools used in industrial electronics do not differ from other approaches used in engineering and comprises a set of activities, methodologies, and hardware/software tools aimed at improving the teaching-learning process.

Despite their decreasing importance in modern education systems, and being many times mistakenly undervalued, **lectures** are still the main tool used to transmit knowledge to a great audience. The concept of lecture has however evolved from a teacher-centric concept to a wider vision that includes further student participation, not only in the lecture itself but also on auto- and peer-assessment processes, and an increased importance of on-line lectures as a method for preparation or study after the presential session.

Industrial electronics-related subjects are usually application oriented and, consequently, problems and laboratory sessions are an essential part in most syllabus. **Problem sessions** gives the student the opportunity to put in practice theoretical contents, further developing his engineering skills. In recent years, a common trend has been followed, moving from complex analysis problems to multidisciplinary design problems. This has been demonstrated to achieve higher levels of abstraction, i.e. deeper knowledge, and lead to more successful learning-teaching processes. At the same time, **laboratory sessions** give the opportunity to the student to deal with real hardware and software tools and instrumentation, and develop important analytical, practical, and team-work skill for their future electrical engineer career. In this context, many versatile laboratory tools for hands-on training are available [11] and, even remote laboratories have been implemented to allow the student putting in practice the new knowledge without being constrained to presential laboratory sessions. Following the same principles of student-centric education and interactivity, **simulation tools** [12] have become an essential tool in IE education to carry out the simulation from the basic concepts to complex real-scale systems. For instance, simulation tools like Psim, Matlab/Simulink, Simplorer, and Plecs are commonly used in power electronics, motor drives, and power conversion systems. They allow fast simulation speed and friendly user interface and they provide a powerful simulation environment to meet simulation and development needs. It is worth noting that this learning allows them not only to facilitate a better understanding of the converter operating mode, but also to predict the experimental results obtained from their laboratory work. Satisfaction and appreciation are expressed when their simulation model results are compared and found close to those of the experimental ones. This allows them to assess the accuracy of their model for the given assumptions made prior to their topology model configuration. By doing so, this procedure is building their confidence and enabling to understand the system design insights with respect to its operating principle to its inherent design details. This is certainly helping to consolidate their knowledge and reinforce their simulation skills for any future converter design. In fact, this allows to acquire the know-how to perform any converter/system pre-design, before going into components selection and later to PCB prototyping.

Finally, most industrial electronics-related curricula end with a **research project** implementation to address the industry needs. These projects can be carried out in an academic context, during an industry internship, or using a mixed approach, fostering industry-academia synergies that will be later discussed. At their graduation, the students find that their learning experience have brought them satisfaction and motivation as they become equipped with required skills, and ready for successful entrepreneurship in their future carrier. In perspective, this teaching ought to be constantly improved and supported, by any means to suit the technological development and to bring it hopefully to the international standards where innovation and creativity become part of graduate student qualities and skills.

In addition to these classical educational tools being currently present in most IE curricula, modern teaching trends include new activities, or adaptation of the previously discussed ones, all of them oriented to promote better teaching-learning processes and skills development. Most of them are oriented to promote active learning [13], since it has been proved to obtain better educational results. These include the well-known project and problem based learning [14], but also new trends such as flipped classroom [15] and new self- and peer-assessment techniques to make the student participate in all the education phases. In addition to these educational tools, next section will deal in more detail with some specific aspects of increasing importance in our current socio-economic context: non-presential learning and life-long learning, and the link between education and industry.

C. Link between education and industry

Higher education has an inherent link to industry, especially when speaking about industrial electronics, since most of the educational efforts are oriented to creating better professionals for a highly dynamic industry. In a modern context, this industry and university are not isol ated anymore, and have also to interact with many other technological and social agents (Fig. 8).

In this context, collaboration with industry [2, 16-18] through education and research programs has been a reality, collaborating in several aspects such as funding laboratories and staff positions, courses from industry and students internships, among others. This collaboration has been bidirectional, providing the academia life-long learning activities [19] for a challenging and continuously evolving industrial framework. Considering this situation, a major challenge and opportunity for success is set on identifying and exploiting the university–industry relationship to obtain synergies that allow increases in the efficiency and competitiveness of both organizations.

Considering the point of view of Industry, research and development (R&D) have become the keystone to face the increasing competitiveness in a globalized market. The main challenge of many companies is the increase of the added value of their products through innovation and one of the strategies to achieve this aim has been the Open Innovation paradigm. This was firstly introduced by Henry Chesbrough [20, 21]. He states that companies can and should use both internal and external ideas to enhance their technology. Companies must change their inwards vision of innovation towards an outwards vision. Therefore external partners, including suppliers, research institutes and universities, play a relevant role in the R&D process [22, 23]. This new trend in the industrial sphere enabled enhanced interaction between industry and academia, providing new educational opportunities [2].

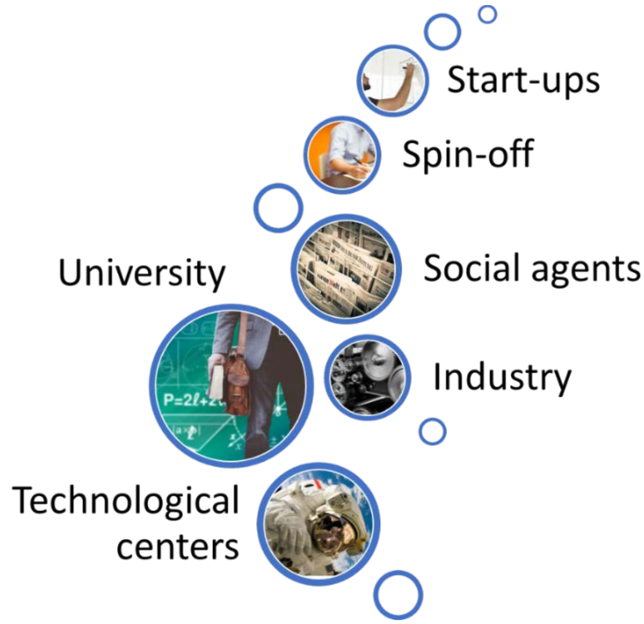

Fig. 4. Agents involved in the modern education context.

Nowadays, agile methodologies [24] are being deployed in many industries, placing more emphasis on people factors and focusing of talents and skills of individuals. This methodology makes people work together with enhanced communication and interaction, using their individual talents to reach common goals efficiently. These methodologies place less focus on fixed a-priori plans and is based on the empirical process control theory. While this methodology was firstly introduced to software development, it is now being extended to many other areas, including hardware, and potentially affecting to all industrial electronics areas. This methodology is already providing opportunities to implement such techniques in the higher education context [25]. It includes concepts, that are in many cases not new but adapted and evolved from other methodologies, such as short-term tasks and learning concepts, learning/working groups, gamified activities and reflection at personal, squad and class levels to define next steps and extract conclusions. This methodology is already having significant impact on industry, and is expected to inspire future trends on industrial electronics education [26].

III. NON-PRESENTIAL LEARNING

E-Learning is currently embraced by many Universities around the world due to several factors. One of these factors is its economic attractiveness to academic institutions. Other factors include the flexible educational needs of the student's clients and the accessibility through the wide coverage of internet domains.

Currently, there are some numbers that should be taken into account when analyzing e-learning. Most of the literature on active learning show significant benefits in terms of long-term retention and competence development, as well as improved student satisfaction [27]. In this context and according to Forbes, e-learning industry is expected to reach 325 B$ revenue by 2025, highlighting the importance of this industry. Therefore, e-Learning can be evolved to suit a target and a stand-alone economic objective.

However, e-Learning does not only require the availability of suitably trained academic staff, but also training the learner for e-Learning. This includes several factors that can directly, or indirectly, impact on the learning process. Also, good preparation and training of this could happen in isolation of the overall objectives of the learning process. Here lies the risk. e-Teaching should be offered without sacrificing the overall educational objectives of the courses.

E-Teaching is not a departure from the normal educational process. e-Teaching must be recognized as a means not an objective. However, it entails new methods, tools and philosophy for active learning and curriculum delivery. Lots of investment and resources have to be committed and spent on e-Teaching before the start of the learning (or e-Learning) process. Most often there is a mix-up between e-Teaching and e-Learning. While e-Learning's emphasis is related to the learner's (student) end, the development of e-Teaching module emphasis should be at the teacher's end.

Designing and delivering e-Teaching materials goes through different phases of development. Those phases are illustrated in Fig. 4 as follows: Inception, Instructional design, Construction (including graphic design, animation, staff training, SW and HW setup, animation and method of delivery, feedback mechanisms, and theory, examples, virtual Labs, etc.) and, finally, Delivery.

The e-Learning process takes place at the recipient (student) end. e-Learning process would require the following students e-Learning environment: Appropriate computer literacy, appreciation of self-directed learning, management of time and priorities, ability to reflect and deduce, ability to organize work, family and study, and punctuality.

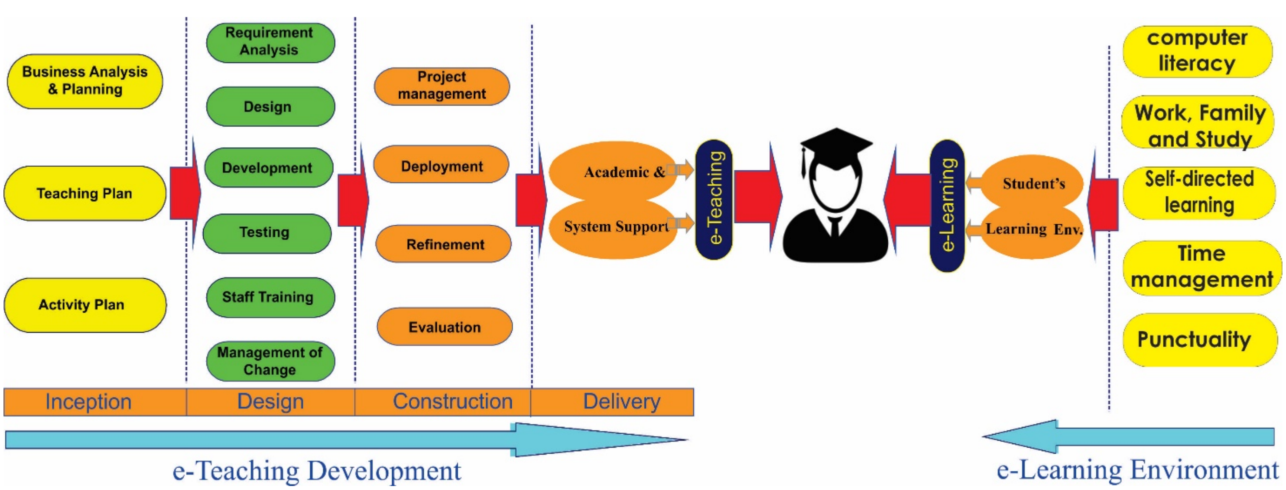

Fig. 5. E-teaching development and e-learning environment.

A. *e-Teaching development and components*

The e-Teaching program can be conceptualized in four phases: inception, design, construction and delivery (Fig. 4). The phases occur at a macro level over time, but those of design, construction and delivery are iterative, following an action research model. In this paper, a deeper vision to the design phase is provided in the following lines, whereas the interested reader can find additional information in [28, 29].

The design phase takes account of student characteristics and teacher characteristics. Questions of access to internet, information literacy levels, time, location as well as learning and teaching preferences, are addressed in choosing appropriate technologies. While new technologies provide opportunities for academics to transform their teaching and create an environment of e-teaching, pedagogies must suit the learner and teacher as well as the curriculum.

The development of the Internet has allowed distance education to become increasingly interactive and collaborative. The use of distance e-Teaching and e-Learning (DTL) is on the rise among digital natives alongside our evolution toward smart societies. However, the DTL systems today lack the necessary sophistication due to several challenges including data analysis and management, learner-system interactivity, system cognition, resource planning, agility, and scalability [30]. Communication tools such as email and discussion forums first allowed faster and easier discussion; chat and online video-conferencing extend the potential further. Collaborative tools such as wikis and blogs greatly facilitate group work and push the potential in new directions. These new technologies change the way educational designers and teachers work to create learning environments. Many authors suggest that these changes result in a paradigm shift which allows teachers to explore new approaches in distance education [31]. In the current distance program, the new technologies have enabled a shift from passive to active learning using a social-constructivist pedagogy [31]. In this environment feedback to students is frequent and immediate. In addition, use of learning materials can be dynamically modified to address issues as they arise. Teaching academics can monitor the progress of students and redress misunderstandings. Course design usually have an input for the end-user industry to make sure of the course material relevance to intended industry. However, more recently educationalist presented a conceptual argument for course design student-staff partnership relationships [32].

In addition to these collaborative tools the instructional design included re-interpreting content delivery and even enabling remote lab usage [33, 34]. The computer environment allowed for greater use of visual representation with animation and video to present information and to contextualize it. Use of video in presenting case studies is used to enhance the authenticity of learning [35].

Studies on the impact of new technologies on teachers [36] indicate that academics embrace the challenge of e-teaching/e-learning to varying degrees. They suggest that developing teacher presence online is essential for a successful e-learning environment and that staff development is the key to its establishment. Staff training and support are critical factors in the development and implementation of e-learning. That includes support in managing change as academics grapple with the new technologies and the pedagogic they facilitate.

B. The e-learning perspective

The new possibilities for engagement and collaboration change the way distance students learn. The social-constructivist pedagogy requires that they engage with academics, peers in their workplace and in the unit; with content in a variety of forms, and with authentic activities. The design incorporates flexibility with support for learning at multiple levels.

The flexibility of delivery and in the instructional design allows learners to organise and balance work, family and study. The weekly structure of activities and feedback encourages students in management of time and priorities. The balance between flexibility and structure contains the learning experiences.

Learners are supported through the e-teaching environment with resources from research and from the library, as well as specific resources designed and developed for the course. The e-learning environment is created when students enter the e-teaching space and engage with teachers, peers, media and content (Fig. 4).

C. Experimentation and remote laboratories

Remote laboratories can be one major contribution to support experimentation [37], one aspect of paramount importance within industrial electronics engineering education (and engineering education in general).

A variety of options to support experimentation is possible to consider, namely:

- different types of interaction of the user with the experiment (including the traditional lab where the user interacts directly with the experiment and/or its control interface, to the cases where the user interacts with the experiment using a computer-assisted interface),

- different types of experiments in terms of their nature (involving physical devices and equipment, or simulated models for the devices and equipment), and

- different types of situations when considering the location of the user and the experiment (where user and experiment can be considered at the

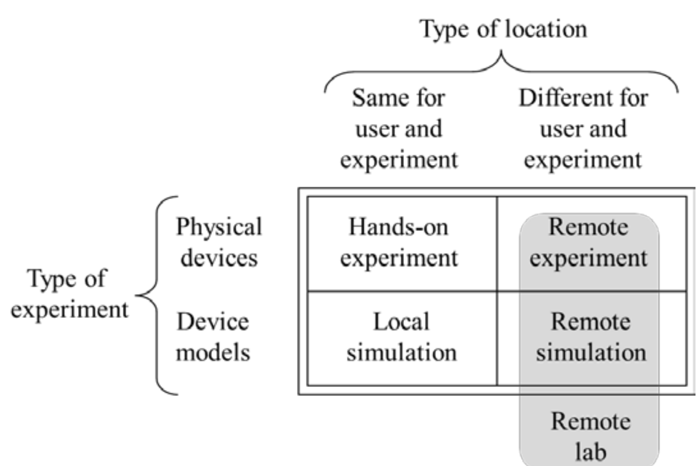

Fig. 6. Types of experimentation.

same location, or at different locations).

Fig. 5 characterizes the different types of experimentation [34], where the right hand column presents what is commonly referred as the remote lab, that can integrate physical devices operation and control, as well as remote simulations.

Remote labs can contribute to allow access to experimentation anytime, anywhere, as much as the student wants, and at the same time integrate in their operation safety mechanisms supporting unsupervised usage and operation of the experiments. Remote labs have been used in a multitude of areas [33, 38, 39], covering all areas of interest of industrial electronics.

Each experiment type has firm advocates and detractors, as referred in [40]. While some are arguing that simulation can mitigate needs for university space (and heavy investments in machinery) giving additional flexibility for students managing their study time, others are emphasizing the needs of exposure to real apparatus experimentation (at least in some levels of the teaching/learning process) and the role that remote labs can have on that, keeping students' flexibility to define their own schedule.

Nowadays, significant efforts have been paid to the implementation of such platforms. One of the most relevant examples is the IoT-LAB [37, 41], where an heterogeneous platform composed of over 1500 wireless sensor nodes spread in 6 different locations in France is provided, or the "G. Savastano" remote laboratory [42] which involves 20 Italian universities and provides didactic activities devoted to measurement experiments.

D. New trends: b-learning, m-learning and the required technological change.

Despite the fact that there are many forms of e-learning depending on their context, contents, implementation, and technologies involved, there are two trends that that should be specifically discussed: blended learning [43, 44] and mobile learning [45].

Blended learning, or b-learning, is based on the combination of collaborative learning, typically using PBL techniques, and independent learning. This technique provides two key advantages: provides a smooth transition from classical presential learning to new e-learning techniques and tries to provide the benefits from both worlds. This can be easily applied in the IE context to combine theoretical contents learning with problems and projects resolution including practical training. For this reasons, b-learning is arising as an interesting learning alternative in many areas.

E-learning is highly sensitive to technological changes, and mobile learning, or m-learning, is an example of that. M-learning is related specifically to e-learning courses developed mainly for their use in mobile platforms. These devices are nowadays widespread due to their decreasing costs and increasing technical capabilities, making these courses possible. The main advantages are the ability to continue the learning process outside the educational premises, its immediateness, improved interaction, and the ability to provide a more diverse educational context and group activities.

One of the main challenges of e-learning relies in the fact that all these techniques require a significant technological change, requiring additional resources, adaptation to the new teaching/learning infrastructure and support. Finally, it is important to remark that, in this context, e-learning and the use of new technologies offers improved possibilities for feedback that include, but are not limited, to activity completion status, tests, interaction with other students, or surveys. This is essential to ensure the quality of the educational process, helps reinforcing theoretical contents and provides paths for quality assurance. This reflection has been added to this version of the paper.

IV. Life-long learning and continuing education

Life-long learning is directly connected to the ability of a student to pursue an independent-study after starting his/her professional career, either as an employee, a researcher, an academician or an entrepreneur. Since many specific engineering topics are not fully address in the course curricula is therefore fundamental that the young (and not so young) engineer will be engaged in independent and self-study activities in order to have successful professional growth in his/her the career. This self-study involves, amongst other issues, the ability to track technological advances, to read and understand technical documents, to take up training on use of the so-called ‘modern tools’, to read research articles and to follow ‘on-line’ courses to overcome the possible gap between his/her professional needs and the curricula undertaken [46]. Self-study engagement is very interesting because it can involve a set of distinct partners under the same goal: to overcame engineering curricula gaps. On-line courses, within the life-long learning perspective, can (and should) involve researchers, academicians, industry experts, engineering service providers and products manufacturer. Only through a perfect symbiosis between them a good, attractive, functional, sustainable and effective product can be offered to engineering professionals.

Not considering teaching tools for under and graduate studies, there are several topics that are in the front line to be addressed by interactive ‘on-line’ long life education courses. For example, one can consider cyber-physical systems [47], grid protection [48], power quality [49-51], induction machine fault detection and diagnosis [52, 53], industrial electronics [54-56], or analog electronics [57]. The later work considers m-learning combined with competitive gamification, thus increasing the attractiveness of the learning process in a long life paradigm.

An example of a remote life-long learning education tool dedicated to power quality teaching was presented in [58]. The system can be remotely accessed, either from a regular computer either from a mobile device. The teaching materials and tutorials were developed by experts on the field and cover the several types of power quality disturbances, identifying each type and respective problem sources, measurement techniques and corrective measures. Particular attention is paid to the measurement techniques, since the trainees will

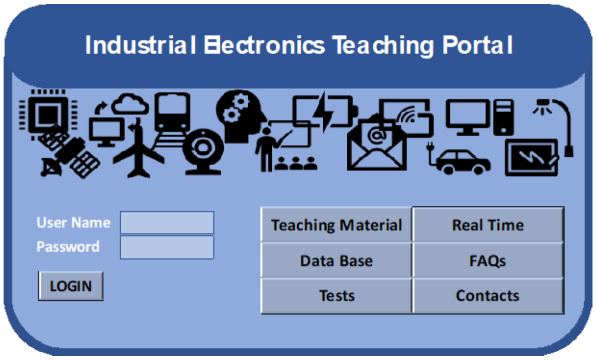

Fig. 7. Conceptual IE teaching portal: interface.

	Teacher	Registered User	Unregistered User
Teaching Material	FULL	FULL	PARTIAL
Database	FULL	FULL	PARTIAL
Test and Assignements	FULL	FULL	NO ACCESS
Real Time Monitoring	FULL	FULL	FULL

Fig. 8. Access levels for different sets of users.

be encouraged to apply them in order to discern about power quality issues. For this purpose, the database plays a very important role. The system presents itself as a valuable tool for power quality life-long learning, particularly taking advantage from the on-line database and from the real time acquisition system.

The previous system, and other industrial electronics life-long learning and continuing education tools, can (and should) be remotely accessed, either from a regular computer either from a mobile device. Fig. 6 presents the conceptual access available for the students. The teaching materials and tutorials are developed by experts on the respective field and cover the several topics on the industrial electronics domain. As presented in Fig. 7, different access levels should also be considered for different types of users.

V. International Vision of Industrial Electronics Education

A. Africa

Africa is struggling with significant socio-economic and political challenges that are impacting their citizen’s lives, and education is not an exception. There are also significant differences among the continent, and even withing the same country due to social fragmentation. There are some countries that can be identified as substantial leaders in terms of technology and education, such as South Africa, Egypt and Nigeria, followed by Algeria, Tunisia, and Morocco. The rest is struggling to overcome the challenges due to lack of infrastructure and shortage of budget. There are other countries, like Gambia, Cameroon, Senegal, and even Eritrea that are diversifying their education thanks to internet through mobile communication, and local and international partnerships, where innovation is becoming a part of their solution for economic advancement.

Nowadays, there are growing concerns in most countries regarding the lack of ability to develop the student’s skills to face the needs of the real-world marketplace. To this end, diverse approaches and strategies are currently sought and implemented in Africa. Exceptionally, South Africa is leading engineering education, ready to take up the challenges that meet the fourth industrial revolution which lies ahead. In this respect, a variety of courses in their curriculum are incorporated ranging from artificial intelligence to data science to equip engineering and computer scientists with the necessary skills to solve current complex problems. However, this experience is difficult to follow in the other countries due the number to trained manpower available with respect to the available funding, and therefore the option for a broader and non-specialist training becomes the standard. Furthermore, other countries see that there is a need to introduce electronics, robotics, and programming, so that learners can touch and experiment, i.e. hands-on training, as a part of the curriculum. By doing so, it is expected that learners, by the end of their studies, will be willing to go on creating their own companies after incubators, through innovative systems that meet the residential and the industrial needs. In addition, due to the enormous potential for the use of renewable energy in Africa, particularly solar energy, special courses are being taught, in addition to the opening of research centers committed to lead in the development of this energy in variety of projects from agriculture to supply remote areas where electricity network is almost inexistent.

In conclusion, there is a real awareness to develop and make engineering education more attractive in Africa in variety ways. As it is reflected in [59], the improvement of political and social context in some countries opens the door for a promising future of engineering education in those countries. However, significant efforts are still to be made to bring industrial electronics education to the highest level and, most importantly, extend it to the whole continent.

B. America

America has had a key role in the development of electrical engineering, led by the USA in the XIX century and, consequently, also had a significant impact in the early industrial electronics education. Electrical engineering education has followed a similar path to the development of engineering education in the USA [60]. It all started in 1882, when Thomas Edison opened the first power plant in Manhattan, and the Massachusetts Institute of Technology (MIT) established the first electrical-engineering curriculum in the USA. Since then, electrical engineering has significantly evolved and, particularly, industrial electronics has gained scientific and industrial relevance, being present in most of the public and private technical universities across USA.

Engineering education in the USA started with the purpose of “promoting the application of science to the common purposes of life” [60], and during the XIX century an adaptive process of curricula creation took place, pioneering in some aspects such as the inclusion of laboratory sessions. In the first decades, electrical engineering education in the USA was practice-oriented, paying special attention on practical aspects of engineering. However, after the developments happened during World War II, weaknesses in electrical and electronics areas were revealed, fostering changes in these areas. This started a scientific period of electrical engineering education, influenced by the European model. Nowadays, engineering education has reached a new era of development, where service to society and solving societal challenges has become essential.

In a similar manner, Education is South America has been influenced and followed the development path of USA, but also, for historical reasons, has had a significant European influence. In the next years, one of the main challenges is the integration of the higher education systems of Mercosur countries in an integrated higher education program [61]. This is in an early stage of development and aimed to follow a similar path to the European Higher Education Area that will be later discussed.

C. Asia

The academic societies are one of the essential driving forces of industrial electronics education in East Asia. Many of them provide the education programs on the specific topics of the industry, and these programs are open to the students and the young engineers. Below, the education background in Japan is discussed in detail as a representative example of East Asia, although the education environment is similar in other countries in East Asia.

In Japan, the Institute of Electrical Engineers of Japan (IEEJ) and the Institute of Electronics, Information, and Communication Engineering (IEICE) are two major local societies of the industrial electronics. IEEJ provides education courses in motor drive, mechatronics, and power electronics [62, 63]. These courses are held annually. Each course comprises 4 or 5 two-day workshops, which includes a lecture on the fundamental knowledge on this technical field and a factory tour to experience the actual activities in the manufacturing process. IEICE also provides a number of education programs. Among them, one of the most challenging programs is the biannual design contest on the wireless power transfer system. In this contest, the participants are requested to design the wireless power transfer systems under the same given specifications and competed for the performance. This contest is open both to university students and young engineers in the industry. Actually, 30 teams from universities and companies participated in the last year's contest (autumn).

The aforementioned education programs are given in the local language, i.e. Japanese, and therefore are targeted at the domestic engineers. Meanwhile, international collaboration in industrial electronics education was limited in the past decades. However, in recent years, some new collaboration programs have been launched in the field of power electronics for promoting the exchange of technical knowledge and deepening the personal interaction among engineers of different countries [64-67]. IEEJ organized or co-organized two countries' bilateral annual workshop (or symposium) between Japan and Korea (Japan-Korea Joint Technical Workshop on Semiconductor Power Converter) [65] from 2008 and between Taiwan and Japan (Taiwan-Japan Symposium on Power Conversion) [66] from 2011. Recently, these two programs have been integrated into the trilateral annual symposium named "Symposium on Semiconductor Power Conversion" (S2PC) [67] in 2014. This symposium not only offers the technical lectures but also the poster session, in which the master course and doctor course university students are encouraged to introduce and discuss their research.

D. Australia

Australia is a vast country with many industries located in geographically remote areas. With the fast rate of technology advancement engineers need to continuously upgrade their professional knowledge and skills. However, engineers in those remotely located industries have limited access to such professional development. Therefore, flexible learning is the key answer to the continuous education needs for many engineers who cannot attend a University's after-hours classes. Australian Universities responded to those needs in the sixties and seventies by establishing paper-based distance education courses.

Australia, in 1990's, established six national "Distance Education Centres" (DEC) throughout the country. One of those centres was located at Gippsland Campus (then under Monash University). The teaching of Industrial Electronics was then part of the Electrical Engineering, Electro-Mechanical, and Reliability Engineering degrees. Industrial electronics study made a perfect sense to distance education cohort. Under the paper-based distance education scheme the students were supplied with the study materials. They were also required to attend a compulsory residential school of one week per semester. The residential school was mainly for Lab-work and practical sessions. This was also a requirement for accrediting the degree program.

The distance education material sent to students were composed of unit and study guides, and resource materials including extracts from text books, relevant technical papers, and standards. However, with the introduction of the internet the following electronic materials were added to the list of dispatched materials, including WebCT-supported study guides and resource materials, practical case-studies through video streamed interviews and audio clips, among others.

Subsequently, the paper-based distance education in Australia was converted to be totally electronics through e-Teaching and e-Learning. e-Learning is currently embraced by many Universities around the world due to several factors. One of these factors is its economic attractiveness to academic institutions. Other factors include the flexible educational needs of the students clients and the accessibility through the wide coverage of internet domains. Therefore, e-Learning can be evolved to suit a target and a stand-alone economic objective. The main benefits of the integrated delivery approach can be summarized as: Access to learning anywhere anytime, flexibility of learning pace, media-rich hyper-linked and interactive content, extended contact with lecturers and class-mates through e-communications, computerized assessment, online tracking and monitoring of the learning process and self-directed learning.

E. Europe

Education in Europe in the last decades has been defined by the European Higher Education Area (EHEA) and the Bologna process. This is a unique collaboration among 48 countries with the aim of improving education methodology, promote structural reforms and shared tools and increase mobility and academic and professional mobility among the European area. In engineering and, in particular, industrial education, it was expected to address and minimize the impact of many detected flaws in European education [68] regarding methodology, homogenization and internationalization [69]. This process was started in 1999 and has been gradually implemented during the 2000's, being deployed in 2010 with a variable grade of satisfaction in terms of workload and academic results [70]. A remarkably successful program has been the Erasmus+ program [71], enabling mobility of students and staff among Universities of the participating countries.

Among the main changes dealing with industrial electronics education, the Bologna process has promoted a transition from a teacher-centric education system to a student-centric education with a special focus on skills and professional competences [72]. This has enabled the implementation of methodologies not used before in most European universities such as continuous evaluation, rather than final exam assessment, project- and problem-based learning [73], the use of remote laboratories and on-line platforms for non-presential [74] and life-long education, among others. In this context, Denmark and Aalborg as its flagship University has been a representative example pioneering on the implementation of the EHEA and introducing PBL concept in 1974 [75] even before the Bologna process was conceived.

Together with the advances in educational methodologies, education system accreditation, which was already one of the major shifts in engineering education in the XX century [76], has been taken to the next level, providing assessment for institutions, teaching staff, and curricula, among others. Many countries has established its own accreditation agencies and quality assurance systems aiming to ensure education quality standards and satisfaction for students, staff, and society. Moreover, within the EHEA context, European efforts have been made to establish accreditation systems at the EU level to provide homogenization and enhance synergies between the participating countries. The European Association for Quality Assurance in Higher Education (ENQA) was established in 2000 to disseminate information, experiences and good practices in the field of quality assurance in higher education agencies. In the context of engineering education, the European Network for Accreditation of Engineering Education (ENAEE) was created. This entity was founded in 2006 with the aims of developing joint European education quality assurance systems, and it grants the EUR-ACE® label to accredited engineering programs with the objective of facilitating academic and professional mobility and recognition.

VI. FUTURE PERSPECTIVES AND FINAL REMARKS

Industrial electronics is nowadays a discipline with a wide range of applications with a major socio-economic impact. As such, IE education plays a key role in our society, and occupies prominent positions in most education systems worldwide. Nowadays, our socio-economic and technological context brings frenetic changes to our daily lives, that used to take decades, in just few months. This is a major challenge for the industrial electronics community and brings a relevant list of education-related challenges to be addressed, some of them are discussed as follows.

Multidisciplinarity, interdisciplinarity and transdisciplinarity. Industrial electronics is an inherently multi-disciplinary discipline that covers areas including energy; control, mechatronics and robotics; and information and communications technologies. In the past, it has already been challenging to establish common points and synergies between all disciplines to improve education and enhance science advance. Nowadays, this challenge is renewed and even bigger. IE professionals are called to address complex problems in an interdisciplinary context to solve real-life problems [77] in many areas such as energy, biomedical, food industry, transportation or security, among others. This will require important educational efforts to develop special skills and competencies to make the new professionals competent in the current socio-economic context.

New and emerging technologies. Technological evolution is advancing at the highest rate in history, and this has a direct impact in IE education. This require IE curricula to be constantly updated and adapted to new technologies. Classical knowledge areas such as power electronics, drives, robotics or sensors are now be complemented and/or replaced by courses on smart buildings, transportation electrification, advanced robots, cyber-physical systems, internet of things, machine learning, or cybersecurity and data protection in an Industry 4.0 context [78].

Life-long education. As a consequence of the rapid evolution of our technical and socio-economic background, education is no longer a static element that is gained at the beginning of our professional life. Education has become nowadays a dynamic element that needs to be worked during our whole professional live. In the past, this used to be restricted only to specialization courses. However, nowadays the challenge is even bigger, being necessary learning completely new disciplines, or bridging the gap between classically separated disciplines combined in a new product. All these aspects requires will require the implementation of carefully designed life-long education programs, and the adaptation of Industry and Academy to this new context.

Global education. Globalization started at the beginning of the XX century, having a significant impact in all aspects of modern life, and education has not been an exception. Despite the many benefits of globalization, which has helped spreading knowledge and making technologies available worldwide, there are also certain challenges regarding education that have to be addressed. Among them, it is worth to mention the need for bridging the technological and cultural gaps between different institutions and geographical areas, providing worldwide trusted educational workspaces and educational quality assurance systems, and fostering internationalization and mobility, not only in students and industry, but also in academic staff.

Digitalization. Our society is evolving towards digitalization in every aspect of our daily lives, from communications in personal and professional lives, to the multimedia contents we see or financial management. In this context, IE education must evolve and make use of all the new digital platforms to provide better education and be able to reach new generation. This requires, not only using all the new digital tools available, e.g. social networks, but also making a special effort in reflecting on the best use of these new tools in education. Among the many challenges of digitalization, security security and personal information protection aspects that must be carefully addressed in the near future. In this area, the IEEE P2834 working group is working towards the establishment of a Standard for Secure and Trusted Learning Systems.

e-Learning. As a consequence of globalization and digitalization, e-learning has arisen as a powerful tool to provide flexible and convenient education. Since the creation of the first digital platforms and Massive Open Online Courses (MOOCs), e-learning has gained increased attention and it is expected to have great growth in coming years. Yet, as it has been previously discussed, there are significant challenges to be faced in order to ensure quality learning, being the establishment of the appropriate e-learning environment among the most important ones. This require addressing challenging organizational challenges that include not only technological issues related to teaching and assessment platforms, but also resistance to change, support from the key institutional players, and the development of new teaching and learning abilities. Besides, despite flexibility offers great advantage for e-learners, there are still significant challenges regarding high dropout rates [79] that have to be addressed with the appropriate motivation, and support for both technical and academic issues.

At the time of writing this document, the COVID-19 pandemic crisis is impacting worldwide and, among the many devastating consequences, has created a new scenario where e-learning has become fundamental at all learning levels: schools, universities, and life-long learning. This must serve to foster the development of new and effective methodologies and tools for e-learning in a promising future for these technologies.

Societal, cultural and demographic changes. Nowadays, our society evolves quickly, not only from a technological point of view, but also from a social, cultural and demographic point of view. This brings inherently new elements to education, modifying tools, techniques, methodologies and interests of both, teachers and learners. In this area, new initiatives are required to provide faster inclusion of developing countries in industrial electronics education which may include training of staff, the use of e-learning techniques, and promoting programs for students and professors interchange. In this sense, the Erasmus+ program developed in Europe may serve as an excellent example for interchange and the potential positive results for both students and staff.

Our fast evolving society becomes a major challenge for education, where flexibility and open-minded view of the teaching-learning processes becomes essential. Some paradigmatic changes are the social importance of health-related technologies and, specially, climate-change related challenges, policies and technologies to address this overwhelming challenge. These are key elements to which IE education must react and which are in connection with the next key future challenge. Consequently, the Industrial Electronics community should develop agile tools and mechanisms able to react and adapt quickly to new emerging trends coming from the different sources such as industry, scientific community, society, or the administration policies, among others. Establishing ad-hoc committees to react to such emerging trends, and not limited to the education area, is essential to ensure efficient service in the current fast evolving world.

Attracting new young professionals and achieving parity. Finally, and in line with the previous challenge, IE needs engaging young professionals that are nowadays attracted by other areas for economic or cultural reasons, or just technical trends. This is especially important when talking about gender parity which is clearly far from perfect in the IE sphere. In this sense, remarkable initiatives are being carried out in the IES including young professionals' awards and grants, and the Women in Engineering initiative, aimed at fostering women's involvement in scientific and technical activities. In this area, it is clear that additional initiatives must be started, and that we all must pay special attention to all educational levels to better explain the industrial electronics engineer role to improve its social awareness. It is then essential to extend these and new initiatives to pre-university levels, boosting initiatives such as IEEE TISP with focus on industrial electronics; at university level, to ensure equal access and motivation to achieve parity; at research level, by providing incentives to motivate and recruiting new female Ph.D. students and researchers; and, last but not least, at professional level, by ensuring equal professional development, which will serve also as motivation and example to all the previous early stages.

In this area, special efforts must be also paid in advertising the impact of industrial electronics in the society in all the involved areas. The industrial electronics community must pay special attention on marketing to the new students and young professionals the potential of his professional career and its rewards, not only from a career development point of view, but also the strong potential impact in society. In this complex and evolving professional and educational context, industrial electronics community must not lose the technological and educational leadership to other emerging areas, but rather ally with them and use the knowledge in these areas to boost industrial electronics with digitalization, big data, advanced machine learning and augmented reality, or nano-science, among others. Consequently, establishing links and continuous communication and cooperation among technical committees and technical societies will become essential in the near future.

In summary, industrial electronics education is called to play a major role in our society. Our social and technological context has advanced fast in the last years, bringing new challenges that must be addressed together by Industry and Academia, and where professional societies, such as the Industrial Electronics Society, must play a relevant role. This paper has reviewed the history and current status of industrial electronics education, and the main future challenges have been highlighted. The authors have tried to highlight the relevance of this topic for IES and our global society and expect it to be a fostering element for future educational activities and developments.

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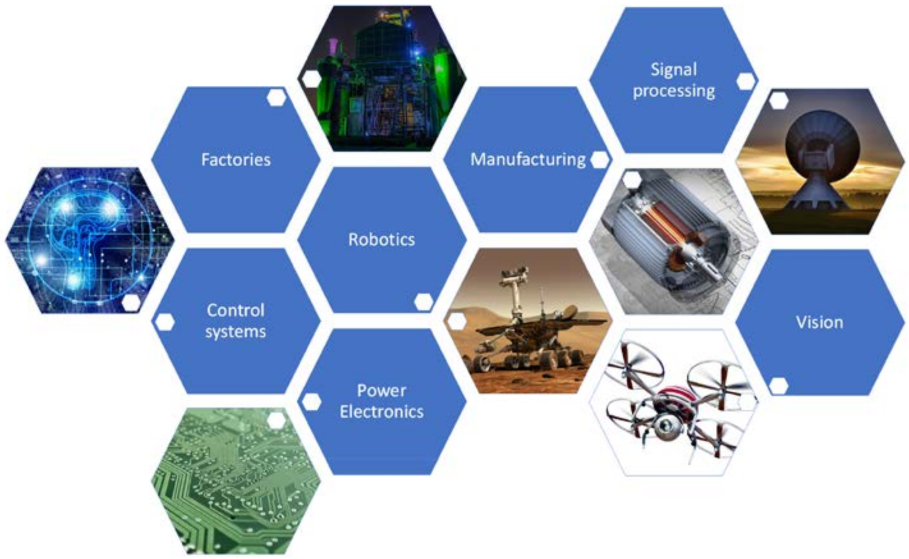

Fig. 1. Industrial electronics society (IES) main areas of interest.

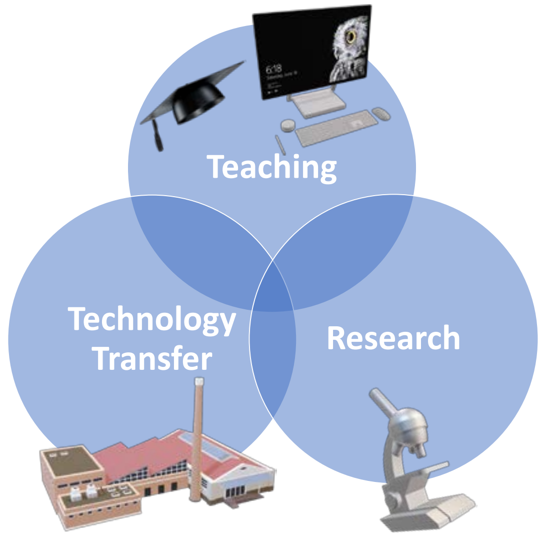

Fig. 2. Higher education components.

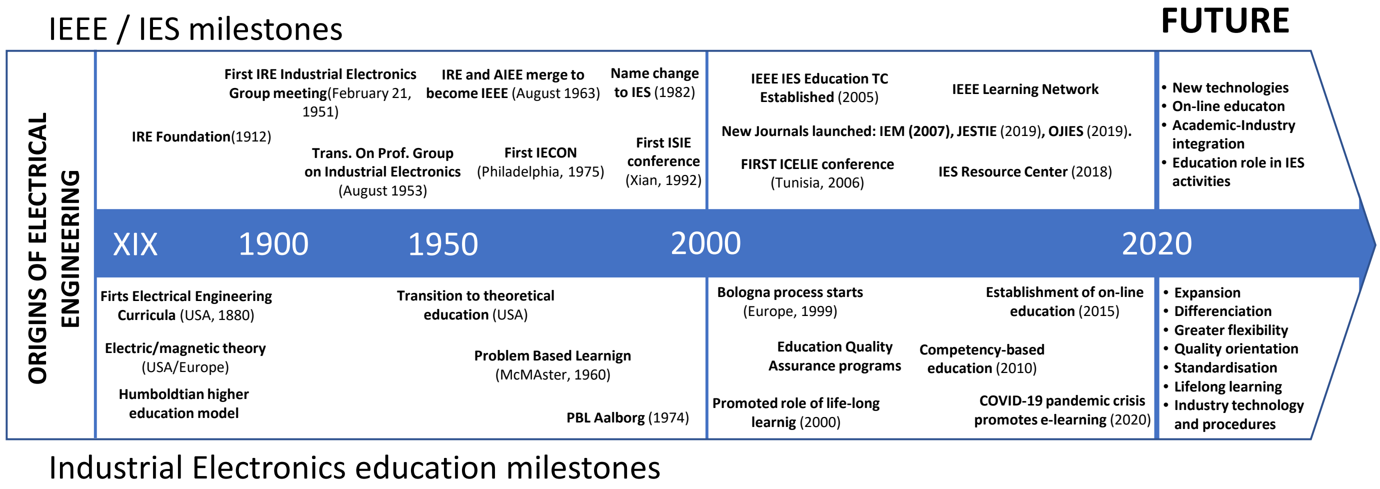

Fig. 3. Historical review of IES and education milestones.

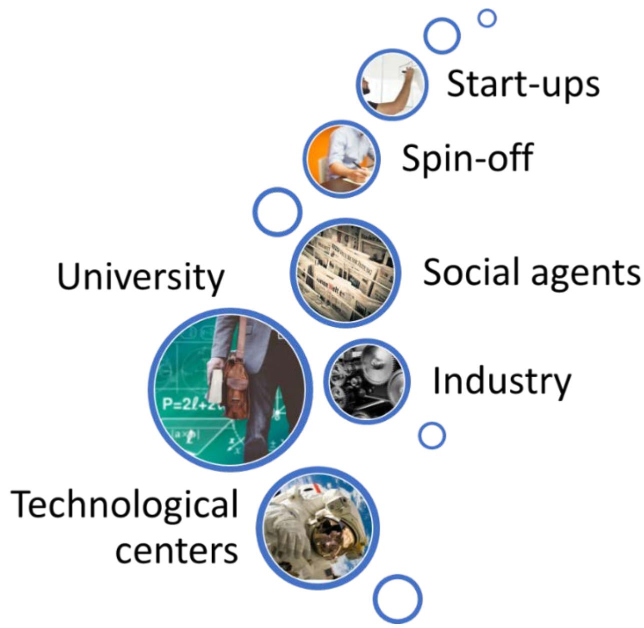

Fig. 4. Agents involved in the modern education context.

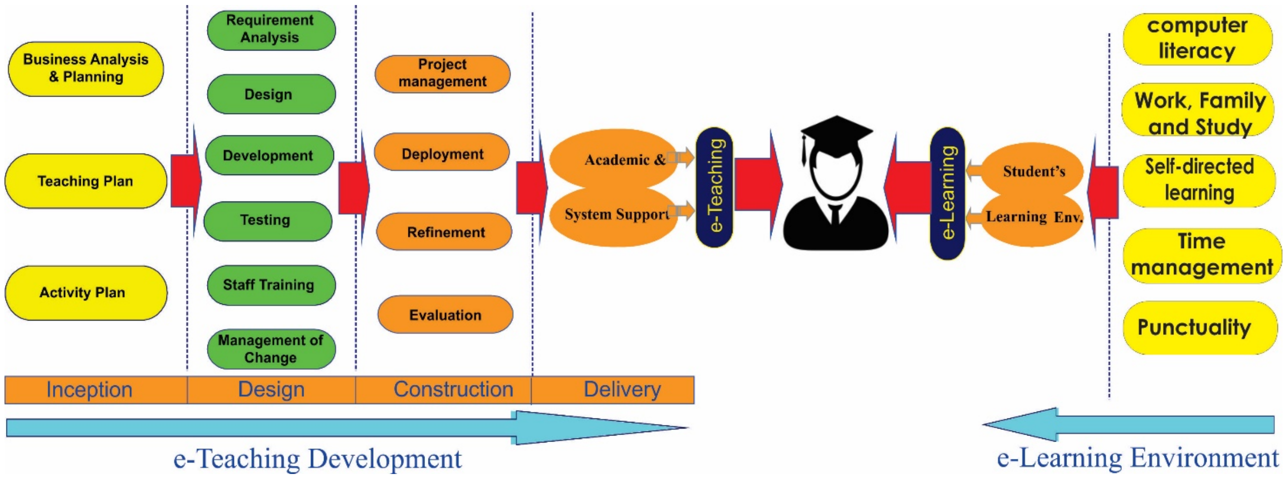

Fig. 5. E-teaching development and e-learning environment.

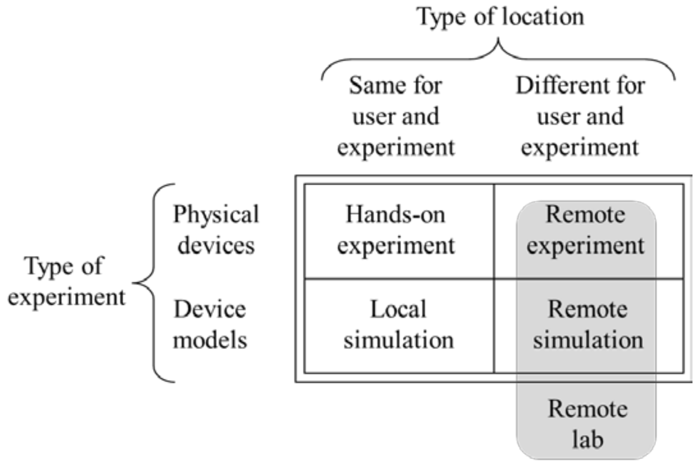

Fig. 6. Types of experimentation.

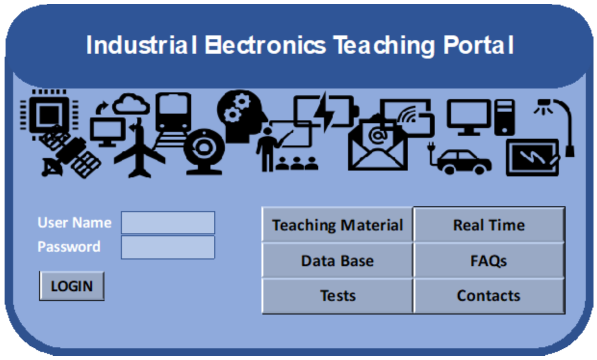

Fig. 7. Conceptual IE teaching portal: interface.

	Teacher	Registered User	Unregistered User
Teaching Material	FULL	FULL	PARTIAL
Database	FULL	FULL	PARTIAL
Test and Assignements	FULL	FULL	NO ACCESS
Real Time Monitoring	FULL	FULL	FULL

Fig. 8. Access levels for different sets of users.