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Exploration of Practical Teaching with Digital Technology for Industrial Engineering Education in Local Universities of China

Yarong Chen, Shenquan Huang, Peihong Fu, Hongming Zhou, Wei Xue

School of Mechanical and Electronic Engineering, Wenzhou University, Zhejiang, China
Email: yarongchen@126.com

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Abstract

The wide implementation of "Made in China 2025" has had a significant influence on higher education in industrial engineering in China, and the required knowledge and skills of industrial engineers in enterprises have changed considerably. However, the current practical teaching approaches and content employed in industrial engineering education are insufficient to meet the realistic requirements. To address this issue, this paper reviews research on digital technologies in education and identifies the required digitalization engineering competencies and skills of industrial engineers through a joint investigation of job descriptions and graduates' feedback. A new practical teaching scheme with digital technologies for training qualified industrial engineers is presented. Finally, the key measures to successfully implement the new practical teaching scheme are introduced. The new practical teaching scheme is gradually being implemented and promoted at Wenzhou University and has achieved good results based on an investigation and analysis of the teaching effects. This study is expected to contribute to improve the practical teaching environment and outcomes through student's active and total participation in a realistic engineering problem-solving process with a digital simulation platform.

Keywords

Industrial Engineering Education, Practical Teaching, Digitalization Engineering Skills, Local Universities, Digital Technologies

1. Introduction

Released in 2015, "Made in China 2025" is a strategic plan to upgrade the manufacturing capabilities of Chinese industries. It represents an attempt to move the country's manufacturing up the value chain by rapidly developing ten high-tech industries. Chief among these industries are next-generation information technology and telecommunications, advanced robotics and artificial intelligence. These industries are central to the so-called fourth industrial revolution, which refers to the integration of big data, cloud computing, and other emerging technologies into global manufacturing supply chains. In this regard, "Made in China 2025" is an "initiative to comprehensively upgrade Chinese industry" that is directly inspired by the German "Industry 4.0". Industry 4.0 is a collective term for technologies and concepts of value chain organization that combines cyber-physical systems, the Internet of Things (IoT), and the Internet of Services (Sackey & Bester, 2016). Both "Industry 4.0" and "Made in China 2025" clearly show that the digital manufacturing era is coming. The major disruptive digital technology (DT) trends, such as big data, advanced analytics, human-machine interfaces and digital-to-physical transfer, remain potentially applicable to all sectors of manufacturing enterprises covering the entire process of product realization. These trends have a significant influence on working environments, and the acquisition of digital skills has become a prerequisite for individual, industry, and regional success.

Industrial engineering (IE) is an inter-disciplinary engineering profession that was gradually formed and developed based on the disciplines of manufacturing engineering, management science, and system engineering (Lima, Mesquita, Amorim, Jonker, & Flores, 2012). IE is concerned with the optimization of complex processes, systems, and organizations by developing, improving and implementing integrated systems of people, materials, information, equipment and energy (Salvendy, 2007; Kacem, 2017; Marin-Garcia & Lloret, 2011). With the wide and deep implementation and application of "Made in China 2025" in manufacturing, purchase, production, manufacturing, sales and maintenance processes have been changed by including concepts such as digital manufacturing and a high degree of automation and integration in all enterprise processes. These changes have far-reaching implications for business value creation, business models, downstream services, and work organization. Therefore, higher education in IE is facing enormous challenges. First, the applied fields of IE (i.e., processes, systems and organizations) become increasingly complicated. With the adoption of digital technologies (DTs), work processes and business models have become interconnected, which allows for collaboration and communication across departments, partners, vendors, products, and people. This transformation leads to organizational integration and process reengineering activities, which makes the applied fields of IE more complex. Second, the methods and tools of IE have become increasingly digitized. With the utilization of DTs, companies across industries have digitized their operations and processes. Consumer expectations and the advent of connected devices and platforms are driving the persistent digitalization of manufacturing. Digital tools play important roles in determining solutions to industrial and systems engineering problems. Third, the goals of IE application focus on the entire system planning, integration, control, improvement, and optimization. DTs and knowledge growth in entrepreneurship, the establishment of new economic policies, and administrative and financial technology demand greater efficiency and effectiveness throughout entire companies. It is necessary to train industrial engineers (IEs) with digital skills to respond to these new trends and to provide solutions to emerging problems. IEs are professional people with specialized knowledge and skills in business administration, management, mathematics, physical sciences, social sciences and methods of engineering analysis and design. This knowledge allows them to specify, predict, and evaluate the results obtained from systems or processes to guarantee the best operation in companies (Mummolo, 2007). IEs trained in schools will be working with these challenges, and more complicated and digitized systems will affect not only the work they perform but also how they perform this work. Consequently, higher education in IE must adapt to these challenges. For the coming digital manufacturing era, the practical teaching of IE must emphasize digital competencies and skills training beyond specialized knowledge and traditional skills.

IE has been evolving over the years to meet the needs and challenges of a rapidly changing and highly competitive society. A leading role is expected from the IE higher education system to bridge the gap between university research and development and regional industry development. Digital transformation is now changing the industry and society. Fostering students' acquisition of high-level digitized engineering and problem-solving skills has become a crucial issue in IE education. Using digital tools and methods of IE to solve complex engineering problems, such as logistics operation optimization based on the IoT and service-oriented operation optimization, has become a competency qualification of IEs who graduate from local universities (Huang, Qi, Liu, & Li, 2015). For example, industrial simulation and digital analytics have become key skill demands for IEs in the Wenzhou city labor workforce. Given the increasing number of regional manufacturing sectors, including low-voltage electrical appliance manufacturing, valve manufacturing, and automobile manufacturing, many digital tools and information systems (such as MES, ERP and FlexSim) for IE disciplines and tools to analyze and improve efficiency and effectiveness have emerged in recent years. IEs will play vital roles in the local industrial development of the smart manufacturing era. Although the realistic demand is for IEs with knowledge and skills related to both DT and traditional IE, unfortunately, the current practical teaching employed in IE education is insufficient to satisfy this demand. Therefore, a new practical teaching scheme and implementation measures for the digitalization engineering skills training of IEs in local universities in China are required to improve this situation.

2. Literature Review

It is common knowledge that, in general, the engineering discipline follows technological trends. The rapid development of technologies has produced innovations in teaching and learning modes and methods. The adaption and utilization of DTs in the educational system have provided an unprecedented opportunity to create advanced education around the globe.

For almost all higher education institutions, the most important issue is how to redesign their student services and courses with DTs to ensure the educational effects and academic development of students. As early as 2010, Collins summarized a number of prospects and challenges arising from the appropriation of DT into learning and educational practice. He suggested that new technology brought radical opportunities as well as significant challenges (Collins & Halverson, 2010). Higgins et al. researched the impact of DT on learning and presented a synthesis of the evidence from a meta-analysis of the impact in schools on student's attainment or, more widely, the impact on academic achievement. They concluded that the correlational and experimental evidence did not offer a convincing case for the general impact of DT on learning outcomes, so careful thought was needed to use technology to its best effect in the face of technological solutions to educational challenges (Higgins, Xiao, & Katsipataki, 2012). In this regard, some researchers have conducted research on how to use DTs to improve teaching methods and outcomes. Kashada and Li identified the factors that influence digital learning technology adaption and utilization in developing countries and provided empirical evidence to explain many complex factors in the context of top management support to facilitate the effective utilization of digital learning technology (Kashada & Li, 2018). Lytras et al. noted that the key challenges for modern engineering education were the rapid integration of knowledge to curricula and the design of participatory and student-centered learning models. They provided an integrated model that requires five success factors as prerequisites for the design of any STEM curriculum and specifically for engineering curricula (Lytras, Alhalabi, Ruiz, Papadopoulou, & Marouli, 2016). Li conducted a comprehensive investigation of digital technology-related engineering education in China by introducing new courses, teaching methods, tools and learning modes (Li, 2018). From these studies, we can draw the conclusion that educational reform that involves DTs and effective approaches can improve teaching environments and outcomes.

With the rapid development of DTs, educational sectors around the world are beginning to incorporate digital tools into the curriculum and to improve teaching approaches and effects. Typical research focuses on core courses in engineering science. Ma et al. presented the design of a software engineering course (sixth semester in network engineering) at the University of Jinan that uses virtualization technology to teach project-driven learning-by-doing software development processes (Ma, Teng, Du, & Zhang, 2014). Bi and Shi analyzed the connotations of blended learning and the architecture and main functions of the Moodle system and established a blended learning model based on the Moodle platform. The results of an investigation of the design and implementation of C Programming Language show that Moodle platforms can improve teaching effects and serve as a reference for the innovation of teaching models and methods (Bi & Shi, 2018). Miftachul et al. revealed that big data emerging technology with analytic processes provided a particular advantage in transforming the pattern of information in the innovative environment of online resources to enhance learning resources (Miftachul, Andino, Pardimin, Maragustam, & Roslee, 2018). Xia et al. researched a method to design and apply 3D visualization resources in teaching scenes and showed that 3D visualization resources can effectively improve students' interest in learning and help students understand knowledge (Xia, Li, & Zhou, 2018). The utilization of DTs in teaching curricula is also beneficial for the teaching environment and effects.

As a typical engineering discipline, higher education in IE follows technological trends, and DTs motivate many related educational reforms and innovation research. Sackey and Bester examined the likely impacts of Industry 4.0 on the IE education and curriculum in South Africa. They found that the educational emphasis has shifted from traditional IE methods to data-driven functions and cyber-physical systems. Skills such as "big data" analytics and novel human-machine interfaces must be emphasized in the IE curriculum (Sackey & Bester, 2016). Research on the innovation of the IE curriculum with DTs focuses on the key knowledge areas or software systems of IE, such as SMED and ERP, and the main approach is to develop interactive learning platforms. Lau et al. developed an interactive e-learning open-shell that incorporates a multimedia interface and web-based knowledge repository for IE. By using IMELS, the idea of exposing students to a learning environment that is realistic and seemingly full of complex problems is achieved. This environment supports students in learning through a web-based interface to accomplish their learning objectives (Lau & Mak, 2004). Moon et al. described a joint experience of an industry-scale ERP solution between Syracuse University in the US and Carlos III University in Spain and concluded that this solution could be used to develop professional skills for engineering students and improve academic curricula (Moon, Chaparro, & Heras, 2007). Weli tested a satisfaction model for students after they completed ERP training using the Technology Acceptance Model (TAM) and the Continuous Model Framework. The results showed that students felt satisfied with ERP training and that this affected their intentions to use ERP in the future (Weli, 2019). Mohamad and Ito introduced a simulation-based training system for lean manufacturing tools focusing on SMED that consists of an e-learning module and an S-module (Mohamad & Ito, 2013).

Although these studies have provided inspiration to develop educational reform and innovation in IE education, research related to the practical teaching of IE is relatively rare. With the implementation of "Made in China 2025", simulation and process virtualization technologies can completely mirror the physical factory in a virtual model. This enables IEs to consider a problem based on an overall picture of the system and apply their diverse skills to focus on the source of the problem, further increasing the plant's efficiency and quality. Therefore, it is feasible to conduct experimental and experiential learning with digital and virtual laboratories for IE education. In addition, IEs who graduate from local universities will play a vital role in the digitalization transformation of local industrial enterprises. This should also be considered in practical instructional design and development.

In this context, this study aims to identify and clarify the roles of IEs in the "Made in China 2025" environment, define the requirements of competencies and skills of IEs, and establish a practical teaching program and implementation measures. This study contributes to practical teaching with DTs for local universities in China. The purpose is to improve the practical teaching environment and outcomes for student's active and complete participation in a realistic engineering problem-solving process with a digital simulation platform.

3. The Digitalization Engineering Skills of IEs

IEs in the engineering discipline are educated and trained to solve problems of manufacturing systems and must develop a variety of skills and competencies. With the implementation of "Made in China 2025", private-owned enterprises in Wenzhou city will gradually realize digitalization transformation and ultimately attain smart manufacturing. IEs will play a vital role during this transformation and development.

During the process of digitalization transformation, a strong link between the physical and digital worlds will greatly improve the quality of the information or data required for the planning, optimization, and operation of manufacturing systems (Landherr, Schneider, & Bauernhansl, 2016). Using digital tools and software information systems for production decision-making and process optimization has become common in enterprises (Yu, 2015). The degree and pace of digitalization have become the most important competitiveness indexes of enterprises. From the perspective of IE, there are two challenges for an enterprise to realize the digitalization transformation. The first challenge is how to use professional software for production or process management, and the second is how to utilize the product data generated during the production process (Jiang, Fang, & Fan, 2013). Therefore, it is important for local universities to educate IEs who not only grasp traditional knowledge and skills but also master the skills required for software system implementation and process data utilization, which is a type of digitalization engineering skill for IEs. Although digitalization engineering skills are important for the education and training of IEs, there is no clear definition. In response to this demand, we identify and clarify the required digitalization engineering competencies and skills of IEs according to the educational objectives of Wenzhou University and the development trends of local industries with a joint investigation of job descriptions and graduate feedback.

The job descriptions come from popular workforce websites (such as https://www.51job.com/) and employers' surveys. We investigated 21 local classical companies, such as DELIXI, CHINT, and CWB. Related jobs in the surveys include production planning & scheduling control, quality management & control, inventory management & control, IEs, and information management & system design. The results of the graduate feedback are from 43 IE graduates of

Wenzhou University who had worked in the company for more than 3 years and whose work field was within the job scope described above. The results were analyzed, and the digitalization engineering skills were defined.

In general, the digitalization engineering skill of IEs involves the competency to standardize and digitalize a system or process and related data by utilizing professional software and digital tools and to provide support for decision-making and operation management through quantitative processing, data mining, and simulation analysis. It is obvious that digitalization engineering skills involve not only the basic skills of applying or developing professional software, such as ERP and MES, but also the extended skills of modeling, analyzing, improving and optimizing the integrated system (Mummolo, 2007; Moon, Chaparro, & Heras, 2007). The basic requirements for digitalization engineering skills are the capacity to use the professional software system, the ability to assist in the development of specialized information management systems for some functions of IE, and the ability to analyze and make decisions based on the data collected from the production on site. According to the knowledge area of IE discipline and the components of the system (Lima, Mesquita, Amorim, Jonker, & Flores, 2012; Marin-Garcia & Lloret, 2011), digitalization engineering skills include three areas: digitized design, digitized control, and digitized evaluation.

Digitized design involves the competencies of designing or redesigning the layout and work methods of a system, which include four skills: digitized planning & design of the facility layout, digitized design & analysis of the production process, digitized design & analysis of the operation method, and digitized planning & design of the information system. Digitized design is the most essential function of IE. For example, the design of the operation method and time measurement is the precondition of production planning and control. The outcome of digitized design is the standardization of the system, which is the foundation of enterprise digitalization. Digitized control involves the skills of collecting and utilizing the process data for the feedback control of a system, which includes three skills: digitized planning & control of product quality, digitized planning & control of production resources, and digitized planning & control of inventory. Closed-loop control is the critical step for the continuous improvement of a system or process and competition. Digitized control skills are generally accompanied by analytical skills. Digitized evaluations involve the skills of evaluating and improving the operational performance of a system, which include two skills: digitized analysis & evaluation of the operation processs and digitized analysis & evaluation of system performance. Big data analysis becomes increasingly difficult and time-consuming as the digitized manufacturer struggles to manage, update, and analyze product and consumer information. Data analytics essentially allow IEs to make educated and data-driven decisions in their roles. In essence, the digitized evaluation skills of IEs are the capacities to identify the root causes and trends of a problem by examining a large volume of data and fundamentally solving the problem.

4. The General Practical Teaching Scheme for IEs in Local Universities

Although digitalization engineering skills have become a qualification element for IEs in the smart manufacturing era, a review of current higher education research and reform in China indicates that the skills training of IEs is still focused on laboratory design and construction and the experimental design of specialized courses (such as Ergonomics, Logistics Engineering, and Production Planning and Control) (Chen, Jiang, & Hsu, 2005; Qin & Deng, 2014; Cai & Tao, 2015). There is little research on designing simulation experiments based on professional software systems (such as FlexSim, ERP and MES) (Ji, Yuan, & Ye, 2012). The current experimental environment is inadequate to educate and train the required digitalization engineering skills of IEs because of the following three shortcomings.

First, the existing practice is mainly real experiments, and there are relatively few virtual experiments. The emphasis in the trends of smart manufacturing activities is shifting from a traditional organization toward a more decentralized, integrational business orientation. These changes will likely lead to the overall simulation and digital processing of complex systems. However, the current situation is that approximately 60% - 70% of experiments in local universities are hands-on or real experiments, and digital and simulation experiments account for only 30% - 40%. Second, the available simulation experiments are only used to analyze and demonstrate the principles of certain types of problems, which represent a portion of the complete system in an isolated manner. The complex system of "Made in China 2025" comprises more elements (such as facility layout and production planning) than before, and there are connectivity and interrelated relationships between elements. For example, plant design is often directly related to production control and product quality, and well-organized machine or department arrangements create an efficient and effective plant. However, the real experiments or current simulation experiments, which are isolated and limited to a portion of the whole system, are unable to train IEs in systems thinking and comprehensive skills. Third, there is a possible mismatch between the current practical materials and the realistic engineering needs of regional industries. A lack of practice in real working environments makes it almost impossible to train actual engineers, and this is especially true for local universities. As stated in reference (Li, 2018), a problem faced by Chinese engineering education is that students lack engineering practice. The reason is that opportunities for internships with enterprises are scarce, and few engineering problems are used in the education process.

In this context, the IE department of Wenzhou University has conducted extensive investigation and research and decided to improve this situation with DTs. A general practical teaching scheme was established, and the architecture is shown in **Figure 1**.

The practical teaching scheme is a hierarchical structure covering five levels: "Industrial resources", "Material library", "Practical teaching platform",

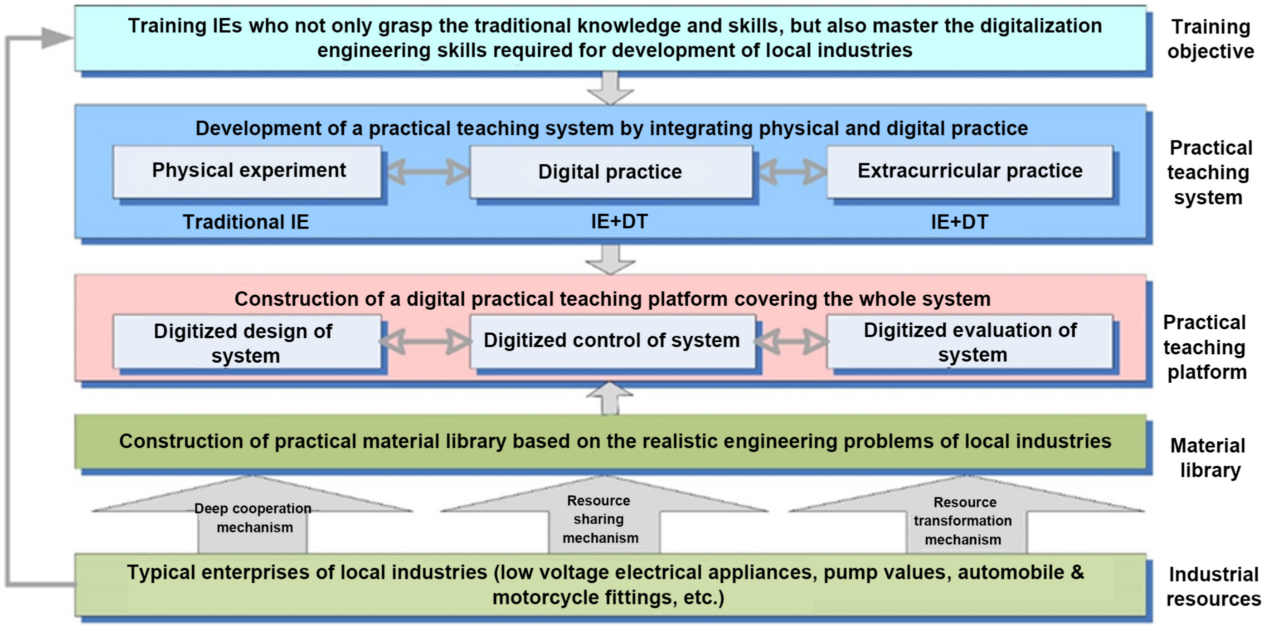

Figure 1. General architecture of a practical teaching scheme for the digitalization engineering skills training of IEs.

"Practical teaching system" and "Training or educational objective". The foundation is "Industrial resources", which play an important role in IE education and cultivation. "Industrial resources" are not only the sources of realistic engineering problems but also the sources of IEs' skills requirements. The required skills of regional enterprises for IEs are the training objective, and the engineering problems of these enterprises are the sources of digital practice project design. This enables the IEs of local universities to quickly integrate into local enterprises and apply the abilities and skills they have learned to solve practical engineering problems more easily and conveniently.

The "Material library" is a set of realistic engineering problems collected from regional industries that provide online resources for the knowledge and skills practice of IEs. Realistic industry resources play an important role in the practical education of IEs. The Accreditation Board for Engineering and Technology and Engineer 2020, an engineering education initiative, has recommended that engineering students be provided with opportunities to participate in real-world projects to supply them with the skills they will need in the workplace (Page & Stanley, 2014). Therefore, we collect the practice engineering problems related to IE from local companies to construct the materials library. The "training objective" is to foster IEs who not only grasp traditional knowledge and skills but also master the digitalization engineering skills required for the development of regional industries in the context of smart manufacturing. The "training objective" is the guideline for laboratory courses and project design.

The "Practical teaching system" is constructed by the integration of "IE" with "DT", which provides systematic information on what should be done to achieve training goals. By combining the "Material library" and "Practical teaching system", an overall digital "Practical teaching platform" is developed, which provides the details of digital practice of the design, control, and evaluation of the complete system. The specifications of key components are described in the following parts.

5. Measures for Implementing the Practical Teaching Scheme

5.1. Development of a Practical Teaching System by Integrating Digital with Physical Practice

Due to the increased complexity of modern manufacturing, it is almost impossible for students to learn the complete images of the integrated system by real experiments or to design, develop, implement and improve the system. Failing to provide this opportunity will disadvantage the development of the competencies and skills of IEs in the changing and demanding world. Simulation has been used in education for years and plays a vital role in engineering education, especially in laboratory exercises (Zavalani, 2015). Learning by simulation can be very effective because students have the opportunity to test the effects of various decision parameters on natural and man-made processes in a straightforward manner (Akkoyun, 2017). DTs make it feasible and convenient to construct a virtual laboratory environment or "virtual factory" of a real manufacturing system and allow students to perform cooperative learning and innovative skill development (Deshpande & Huang, 2011; Chavez, Dotong, & Laguador, 2014). In this context, the practical teaching system for skills training of IEs is presented by integrating digital and physical practice. The structure is shown in **Figure 2**.

The practical teaching system focuses on the training of nine engineering skills, especially digitalization engineering skills. It has three characteristics that differ from the traditional practical teaching system. First, the practical teaching system is designed to cover the entire system, which includes the design, control, and evaluation of the system to overcome the limitations of real experiments or traditional practice, which cannot provide students with the image of the entire company or enterprise. With the information and DTs, it is completely feasible to build a global digital modeling and simulation platform for IEs to analyze the overall system, which includes the design, control, and evaluation of the production system. The virtually integrated system aims to provide IEs with the opportunity to understand the operation mechanism of the different portions of the system and learn the interactions between different elements.

Second, practical teaching methods vary, including traditional real experiments and virtual practice and extracurricular practice. Specifically, a real (or physical) experiment is mainly an experiment of a key knowledge point of a curriculum, which is generally completed in a practical hands-on environment in the laboratory. These types of experiments mainly train professional knowledge and skills at the level of the manufacturing unit. Virtual practice is the digitized modeling, stimulating, analyzing and optimizing practice of a curriculum or course groups, which is completed in the digital practice platform. These types of practice focus on training the digitization engineering skills of IEs, especially

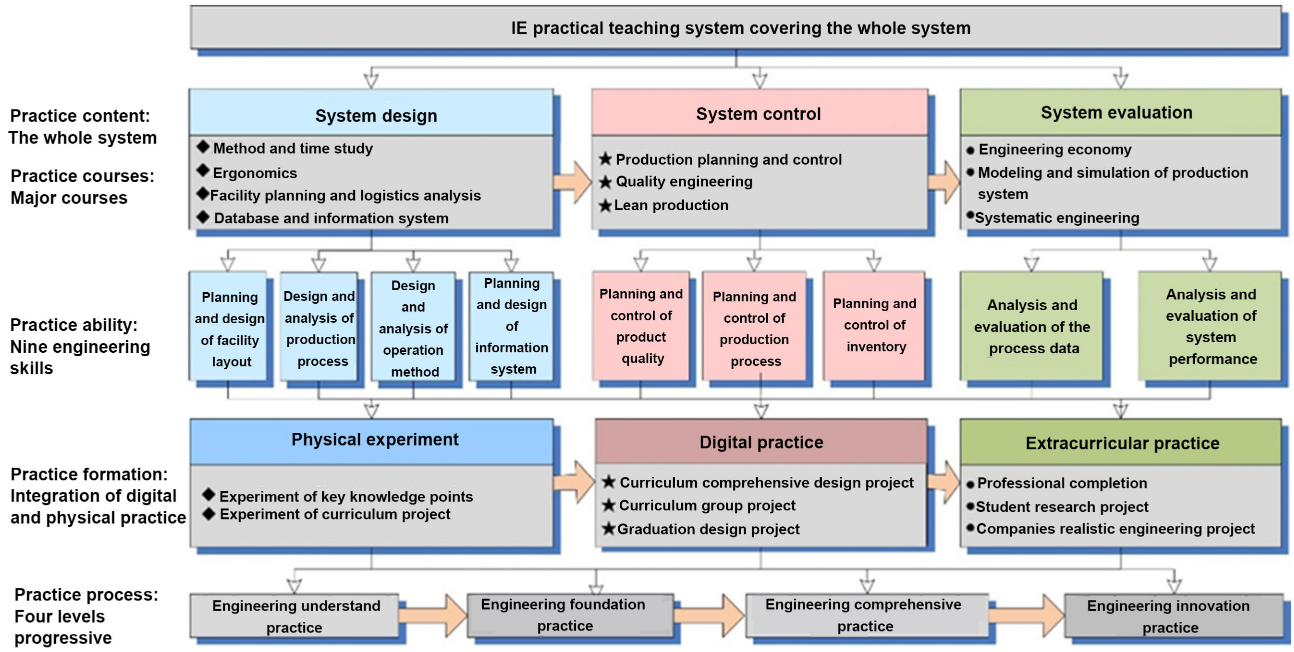

Figure 2. Structure of IE practical teaching system integrating physical with digital practice.

the comprehensive skills of global analysis and optimization of the whole system. Extra-curricular practice is practice using the digital practice platform outside the classroom, such as real-world projects and competition, which focuses on cultivating innovation and solving-problem skills. Because practical materials and instructions are provided in the network, students can perform practical training without the limitations of space and time. Virtual experiments and practice are important supplements rather than replacements for real experiments and provide a new way to train the digital engineering competencies and skills of IEs.

Third, the practice process has a step-by-step formation. The first step is to understand practice and then continue forward to foundation practice, comprehensive practice, and innovation practice. By gradually expanding the knowledge scope and depth, the practice field is extended from a single portion to the entire system.

The practical teaching system is designed to help IEs learn specialized knowledge and skills systematically through physical and digital practice. When IEs complete all of the experiments and practice, they have the ability to design, develop, implement, and improve the integrated system using sophisticated quantitative analysis. The reformation of practical teaching system not only improves students' learning effects but also provides high requirements for teachers' self-improvement. The new practical teaching system encourages teachers to meet the needs of knowledge and skills requirements and to help students develop skills by continuous learning and training.

5.2. Construction of a Material Library Based on the Realistic Engineering Problems of Regional Industries

A problem-based approach to learning is necessary to create a learning environment that assists students in developing their creativeness, critical and analytical thinking (Lau & Mak, 2004). In particular, as IEs address real problems, the adoption of problem-based learning with the use of real-time case problems in training them reduces the mismatch between what is taught and what is expected in the industry. One of the responsibilities of universities is to develop a quality graduate who will be armed with the knowledge needed after graduation and to expose students to real-world situations. For example, Page and Stanley presented a service-learning approach for ergonomics in which students apply the skills they learn in a classroom to a real-world problem identified by a community organization (Page & Stanley, 2014). To improve the training quality of IEs with realistic engineering problems that reflect the current needs of the industry, the material library is constructed. The materials and resources of the material library are collected from a typical enterprise in local industries, which allows IEs to learn in a virtual factory environment of a real manufacturing system through the digital practice platform.

Establishing a profound cooperative relationship with local enterprises is the most important step for collecting practical and engineering problems effectively and conveniently. Generally, relationships are established by providing professional methods and tools training and digital skills training to the related employers of local enterprises. Meanwhile, teachers and students should continuously provide consultation and technical guidance for engineering problems and participate in lean improvement projects to strengthen the relationship. Good cooperation is beneficial for the full integration of engineering practice into the teaching process and is important for the extensive collection of the realistic engineering problems of regional industries.

The realistic engineering problems of typical industries, such as pump valves, low-voltage electrical appliances, automobiles and motorcycle fittings, are collected by a video camera and recorded on the spot. The production process is captured with the video and is recorded in digital format. The details of the product realization, such as the product structure, technological process, quality standard, operation method, facility layout of the factory, introduction of different departments, and comments and instructions on the production, are investigated and recorded. The collected practical problems are sorted into different libraries according to the types of problems. According to the major knowledge areas of IE, the libraries generally include ergonomics, production planning, and control, quality management, simulation, system analysis, and project management (Lau & Mak, 2004). The same material library consists of practical problems of different industries, which enables students to choose problems freely from different industrial backgrounds based on their own interests and practical objectives. In addition, the problems in the library are classified according to their complexity, i.e., from the manufacturing unit to the whole system. This material library guarantees that practical problems are seamlessly connected with the engineering requirements of the enterprise and ensures that the training of IEs responds to the demand for regional industrial development.

To avoid distortion caused by sampling survey data, on the one hand, the on-site data are surveyed many times. On the other hand, we provide the students with the opportunity to visit the enterprise production workshop through close co-operation between universities and enterprises. The structure of realistic problems library for IEs' skills training is shown in **Figure 3**.

The material library offers students a combination of engineering practice skills and associated knowledge in a desirable interactive, multimedia and problem-based approach. Its key strengths lie in the ability to enhance student motivation and provide an integrated view of IE practices within a realistic and versatile problem-centered learning environment. In addition, the material library provides students the opportunity to navigate around the various industries' backgrounds to begin addressing the case problems as they will actually be working in the future. This is a good way to meet the requirements of career-driven IE programs by adopting projects and materials tailored to IE laboratories.

5.3. Construction of a Digital Practice Platform Covering the Entire System

Chinese colleges and universities are encouraged to adopt new technologies to build virtual simulation laboratories such as 3D modeling, sensors, artificial intelligence, and cloud computing. According to the Ministry of Education of the People's Republic of China, the Experimental Teaching Center of Automation Virtual Simulation developed by Tsinghua University and the Civil Engineering Virtual Simulation Experiment Center developed by Tongji University are all national-level virtual simulation laboratories (Li, 2018). Simulation built on real-time data to mirror the physical world in a virtual model of a plant is critical for the optimization of industrial systems and is indispensable in Industry 4.0 (Sackey & Bester, 2016). "Made in China 2025" also emphasizes the global optimization of the entire system. Using the software and information system to simulate the entire system is important for global optimization (Violante & Vezzetti, 2014). Therefore, the digital practice platform is built to provide a "virtual factory" to illustrate the critical issues of manufacturing systems based on the material library and professional software. The integrated simulation platform is a type of "panoramic" platform that effectively integrates IE and DTand covers the entire process of product realization. It is used to complete the global analysis and optimization of the whole system and to train the systematic thinking and skills of IEs. The basic framework of digital practice platform is shown in **Figure 4**.

The digital practice platform is oriented to improve the digitalization engineering skills of IEs by the project-driven learning-by-doing method (Ma, Teng, Du, & Zhang, 2014), which is developed through the integration of different professional software and some DTs, such as multi-media, virtual simulation, information technologies, data communication, and database and Internet communication technologies.

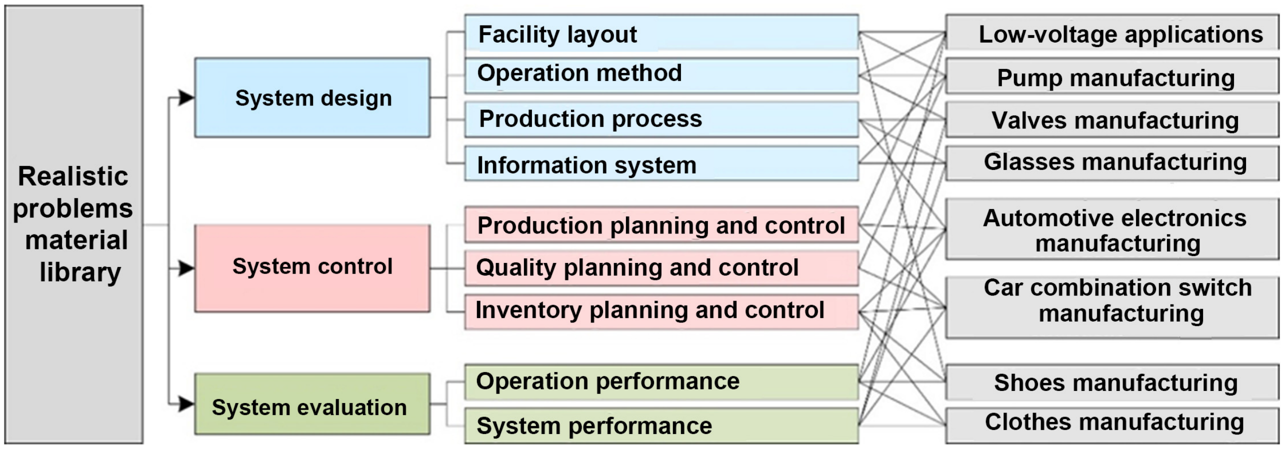

Figure 3. Structure of realistic problems library for IEs' skills training.

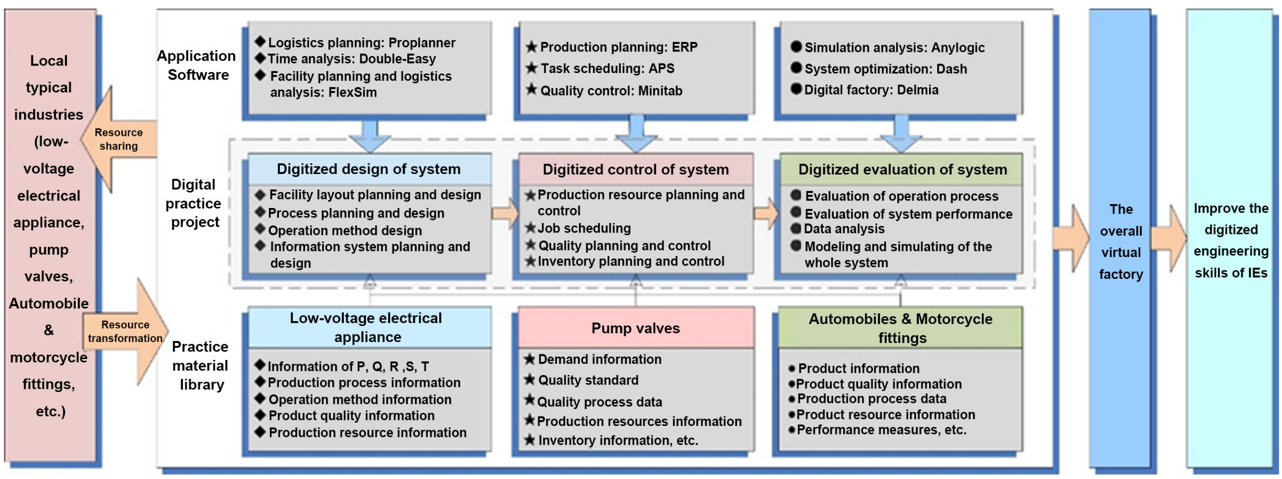

Figure 4. Framework of digital practice platform for IEs.

There are various professional application software packages related to IE on the market. For example, the classical commercial software includes ERP, MES, SCM, Proplanner, Simio, FlexSim, Dash, ILOG, Arena, Asprova, Delmia, AnyLogic, Tecnomatix, and Minitab. Different professional software has different functions. For example, software for production planning and control includes ERP (SAP of Germany, Yonyou of China) and APS (Asprova of Japan, i2 of America). IEs should learn and grasp the application skills of professional software as much as possible. However, most IE departments operate under increasingly limited budgets. The appropriate application software packages are gradually purchased according to the education and training objectives, analysis of the professional software market and the skills requirements of local industries.

After professional software is purchased, the integrated practice platform is established by installation, cooperation, and integration and sharing information. The digital practice platform adopts an open architecture and an object-oriented design paradigm. The difficulties of software integration lie in the differences among software, such as different data structures and input and output data formations. The common method for the integration of different software is information and communication technologies (Wang, 2008). The coordinated information platform is achieved through teachers' further research and cooperation with third-party professional programming companies and software development companies.

Laboratory courses and experiments are developed and designed for the key knowledge and skills of the IE-based digital practice platform, and all of the experiments and practice are related to realistic engineering problems from the material library. Some classical experiments and practice projects are shown in Table 1.

The virtual practice platform provides a basis for the analysis and solution to production-related problems of the overall system. By modeling and simulating the real production system from the material library, a realistic "panoramic" discrete manufacturing environment is established. The virtual system maps the real integrated system to illustrate the interrelation between each department, such as production, logistics, and quality. IEs practice the skills with a series of interactive simulations that demonstrate how IE tools and knowledge are applied and their impact on the process performance. This practice greatly improves the systems thinking and comprehensive problem-solving skills and cooperation abilities that are vital for teamwork. Importantly, this practice enables IEs to grasp the required competencies and skills of the enterprise. The simulation practice based on the digital platform makes the practice process more vivid and subjective, triggers students' learning enthusiasm and achieves better results. It not only provides the opportunity to solve complex system problems, in the integrated computer environment of multiple links and different levels of

Table 1. Experiment and practice projects based on virtual simulation platforms.

System portion	Experiment curriculums	Experiment contents	Experiment objectives
Design	Facility planning and logistics analysis Ergonomics Work study Database and information system	Layout planning and design Operation method design Materials movements and processes design Methods study Time measurement Database design and management Information system design	Human-machine interface design with digital tools Operation method design with digital tools Production process design with digital tools Facility layout design and implementation with digital tools Information system design
Control	Production planning and control Quality control Lean production	Production planning Job scheduling Inventory control Quality planning Design of experiment SPC Root-cause analysis	Closed-loop control of product quality Monitoring and controlling production processes with digital tools Application of quality tools with digital methods Real-time inventory analysis and optimization control
Evaluation	Modelling and simulation System engineering Operation research Engineering economy	Virtual factory modeling Data communication and networks automation Data analytics	On-site data collection and analytics Advanced simulation and virtual plant modeling Data communication and networks design

collaborative simulation, design, analysis, and optimization but also allows IEs to prepare for future work.

Because the construction of digital practical platform involves the integration of different software programs using information and communication technologies, the practice platform of Wenzhou University is still undergoing gradual development and construction. More practical and experimental projects will be developed and will provide students with a more flexible discrete manufacturing environment oriented toward the full process management of product realization. In the future, we also aim to construct Massive Open Online Courses for experiment course with DTs.

6. Conclusion

This paper addresses some emerging challenges of IEs' education and training with the coming of the smart manufacturing era and presents a new practical teaching scheme for the digitalization engineering skills training of IEs in local universities of China. The core element of the practical teaching scheme is the construction of the virtual factory platform, which is important for IEs to systematically, simulate, analyze and optimize the entire system. To respond to the needs of engineering practice, realistic problems were collected from the classical enterprises of regional industries. Therefore, the virtual factory provides students with the opportunity to simulate a likely real discrete manufacturing environment and to practice the systems thinking and problem-solving and analytical skills to meet the requirements of digitalization engineering. The virtual factory is not only for IEs' skills training but also for teachers' scientific research and consulting.

To investigate the effectiveness of the practice program, we conducted a two-year follow-up study. Ninety IE undergraduates from Wenzhou University participated in the study, and competency test results from employers were used to measure changes in their digitalization engineering skills. The results showed that after completing this reformed practice program, the students had greatly improved their digitalization engineering skills. Some limitations should be further studied in the following reform. For example, the virtual practice should cooperate with the real world, and a virtual-reality project can be designed in future research.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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