Skill Development for Industrial Engineer in Industry 4.0

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***Abstract*— Industry 4.0 refers to the fourth industrial revolution and technological evolution from embedded systems to cyber-physical production systems. A significant challenge for the future lies in the transfer of Industry 4.0 concepts and technologies to the enterprises. Despite the change in a manufacturing system, new skill requirements to work with the changing environment would be required. This study examines the impacts of Industry 4.0 on an industrial engineer's skill. The proposed skill development framework does not enhance only hard skills, which known as specific technical skills, but also identify the requirements of soft and meta-skills too. Research methods include a literature review and a questionnaire survey of industrial engineer's required skills. Results indicate that traditional industrial engineering functions transform to data-driven and cyber-physical system. The soft skills which are significant for IEs are problem-solving, systematic thinking, ability to work with others, presentation, and willing to learn and explore new knowledge.**

Keywords—Industry 4.0, Skill development, Industrial Engineering, Engineering Education

I. INTRODUCTION

In recent years, the manufacturing industry has begun changing significantly due to the introduction of concepts and technologies based on the fourth industrial revolution, which is known as Industry 4.0. The focus of Industry 4.0 is to integrate production, information technology, and the internet. Thus, information and communication technologies are combined with classical industrial processes in Industry 4.0 [1]. To remain competitive, lead times, flexibility, and the ability to produce many versions of products in low batch sizes, must improve. More functionality and customization options are provided to the client and more flexibility, transparency and globalization for the supply chain.

Based on the principle of Industry 4.0, production creates the conditions to replace traditional manufacturing processes. These processes are replaced by flexible reconfigurable manufacturing system, offering interactive, collaborative decision-making systems. Thus, employee jobs are expected to change in terms of content and new types of job are also being created. These changes are affecting the types of jobs that graduates go into, as well as the skills required to do those jobs. As a consequence, the Higher Education Institutes (HEIs) have to prepare students for the changing graduate labor market.

This work is a part of the SHYFTE project from the European Commission. This project aims to develop the novel teaching and learning approaches to build the skill4.0 for the Higher Education students in four domains: industrial engineering and management, software engineering and big data analytics, wireless network analytic, and Artificial Intelligent. This work is in the beginning stage of the project, which is the skill requirements identification phase. This paper focuses on an industrial engineering domain and aims to identify the skill requirements for this domain in the context of Industry 4.0.

The rest of the paper is structured as follow. The next section (section 2) provides an overview of Industry4.0 categories and concepts. Subsequently, section 3 explains the skill development framework, which consists of three phases: skill requirements identification, teaching and learning approaches exploration, and teaching and learning approaches identification to develop the skills. However, this work emphasizes the first phase (skill requirement identification). Next, section 4 focuses on the skill requirements for industrial engineer and identify the needed skills. Finally, section 5 outlines the conclusion and the suggestions for future research works.

II. INDUSTRY 4.0 CONTEXT

The characterization and definition of Industry 4.0 still vary greatly. The Communication Promoters Group of the Industry-Science Research Alliance (FU) made a first definition of the term Industry 4.0 in 2011 [2]. The first definition is very vague. This definition makes it even harder, especially for companies, to cope with the complexity of this topic, as people often seem to interpret essential parts entirely differently. Currently, Hermann et al. (2015) proposed the concept of Industry 4.0 using a literature review. The literature review identified four key components of Industry 4.0, namely Cyber-Physical Systems (CPS), Internet of Things (IoTs), Internet of Services, and Smart Factory. Technologies like machine-to-machine communication and Smart Products are not considered to be independent Industry 4.0 components, as machine-to-machine communication is an enabler of the Internet of Things, and Smart Products are a subcomponent of CPS. The authors perceive big data and cloud computing as data services, which utilize generated data in Industry 4.0 implementations, but not as independent Industry 4.0 components [3].

Matt et al. (2018) [4] categorized the Industry 4.0 concept based on a Systematic Literature Review (SLR). Based on the selected inclusion and exclusion criteria and the search string “Industry 4.0” in the database Scopus a total amount of 733 paper could be reduced to a sample of 27 papers. The remaining 27 papers used to conduct a content analysis identifying 42 Industry 4.0 concepts (see table I). The different concepts were clustered into the following first level dimensions:

- Operation: consists of 9 concepts
- Organization: consists of 10 concepts
- Socio-culture: consists of 3 concepts
- Technology: consists of 20 concepts

TABLE I. IDENTIFIED INDUSTRY 4.0

	Categories	I4.0 Concept
Operation	Agile manufacturing system	Agile manufacturing system
		Self-adapting manufacturing systems
		Continuous and uninterrupted material flow models
		Plug and produce
	Monitoring and decision system	Decision support systems
		Integrated and Digital Real-Time Monitoring systems
		Remote Monitoring of products
	Big data for production	Big data Analytics
	Production planning and control	ERP/MES
Organization	Business model 4.0	Digital Product-service systems
		Servitization and Sharing Economy
		Digital Add-on or upgrade
		Digital Lock-in
		Freemium
		Digital point of sales
	Innovation strategy	Open Innovation
	Strategy 4.0	Industry 4.0 Roadmap
	Supply Chain Management 4.0	Sustainable Supply Chain Design
		Collaboration Network Models
Socio-cultue	Human resoruce 4.0	Training 4.0
	Work 4.0	Role of the Operator
	Culture 4.0	Cultural Transformation
Technology	Big data	Cloud Computing
	Communication & Connectivity	Digital and connected workstations
		E-Kanban
		IoT and CPS
	Cyber security	Cyber Security
	Deep learning, M/C learning, AI	Artificaial Intelligence
		Object self service
	Identification and tracking technology	Identification and Tracking Technology
	Additive manfufacturing	Additive Manufacturing (3D-prining)
	Maintenance	Predictive Maintenance
		Tele-Maintenance
	Robotics & Automation	Automated Storage systems
		Automated Transport systems
		Automated Manufacturing and Assembly
		Collabortive Robotics
		Smart Assistance systems
	Virtual Reality, Augmented Reality and simulation	VR and AR
		Simulation
	Product design and development	PDM and PLM
	Standard 4.0	CPS Standards

III. SKILL DEVELOPMENT FRAMEWORK

A. *Skill Categorization*

In order to identify the skill requirements associated with career management skills, the skill categories should be clearly defined. There are variations in categorization (see Table II), but the main emphasis refers to core skills, transferable skills, hard skills, soft skills, meta-skills [5] to [8]. The term core skills is generally used by academics to denote skills that are disciplinary specific, whereas the term transferable skills is used to denote skills that are essentially non-disciplinary. In addition, they found this classification to be inconsistent as skills labelled as core in one subject discipline are defined as transferable in another [6]. Transferable skills include communication skills (both input and output), interpersonal skills (working with and relating to others individually and in groups), problem-solving skills, numeracy, information technology and in some model self-management and foreign language ability [5].

Another group categorization divides skills into three groups [7]: hard skills, soft skills, and meta-skills. Hard skills are associated with specific technical abilities or solid factual knowledge required to do a job These skills can be termed as “what you know” [9]. The examples of hard skills for Industry 4.0 are designing, programming, CPS dispatching, etc. [7]. Soft skills can be defined as interpersonal, human, people or behavioral skills necessary for applying technical skills and knowledge in the workplace [10] or can be termed as “how you use it” [9]. The examples of soft skills are communication, collaboration, problem identification and solving, etc. Meta-skills are involved in that kind of adaptation. It enables one to select, adapt, adjust and apply one's other skills to different situations, across different social contexts and perhaps similarly across different cognitive domains [11].

The Partnership for 21st Century Skills (P21) proposed the 21st Century Skills model in 2002 to identify the importance skills for all students in US K-12 education. The 21st Century skills comprises of three main areas: life and career skills, learning and innovation skills, and Information, media, and technology skills (see Table II) [8].

TABLE II. SKILL CATEGORIZATION

Reference	Skill category	Definition or examples
Kemp and Seagraves (1995)	Core skills	N/A
	Transferable skills	- Communication skills - Interpersonal skills - Problem-solving skills - Numeracy - Information technology - Self-management - Foreign language abililty
Evans (2008)	Core skills	Skills that are disciplinary specific
	Transferable skills	Skills that are essentially non-disciplinary
	Carreer management skills	A related set of meta-skills which enable individuals to develop and use the full range of their other skills
	Meta-skills	- Learning how to learn - How to select and apply skills to different contexts - Self-awareness - Self-promotion - Opportunity awareness - Matching and decision-making

Reference	Skill category	Definition or examples
		- Networking - Boundary management - Personal action planning
Loshkareva et al. (2018)	Hard skills	- Design - Programming - CPS dispatching - CPS maintenance - Data management - Knowledge transfer and usage - Quality control
	Soft skills	- Communication - Collaboration - Problem identification and solving
	Meta skills	- Environmental intelligence - Sustainable skills - Continuous learning - Multidisiplinary transfer - Creativity - Adaptivity
21st century skills	Life and career skills	- Flexibility and adapability - Initiative and self-direction - Social and cross-cultural skills - Productivity and accountability - Leadership and reponsiblity
	Learning and innovation skills	- Creativity and innovation - Critical thinking and problem solving - Communication and collaboration
	Information, media, and technology skills	- Information literacy - Media literacy - ICT (information, communciations and technology) literacy

In order to define the skill requirements in a specific job domain in Industry 4.0 context, this work deploys the skill categorization from Loshkareva et al. [7] (see Fig. 1). Hard skills are technical abilities and specific knowledge of the job domain. Soft skills are interpersonal skills necessary for applying hard skills in the workplace. The necessary soft skills identification depends on the job domain and job characteristics. Thus, it is important to have a clear scope of job domain. Meta-skills involve in an adaptation of hard and soft skills to a broad set of problems. Meta-skills development takes more time than hard and soft skills development. It needs deep-learning and practice repeatedly until the subconscious knows how to do the thing. Thus, it is not an easy task to develop meta-skills for the students in higher education, but the university should provide facilities, teaching and learning approaches which support the meta-skills development.

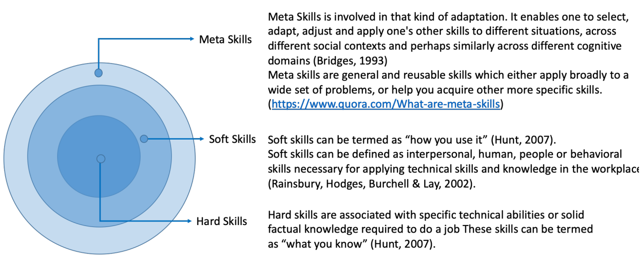

Fig. 1. Skill categorization

B. *Skill Development Framework*

The skill requirements identification in Industry 4.0 is a broad and complex issue in both academic and practical implementation. Especially, an identification which leads to design curricular and teaching & learning approach. This work proposes the skill development framework in order to design teaching and learning approach for developing the needed skills in Industry 4.0 (see Fig. 2). The proposed framework comprises of three main phases as follow:

- The first phase is the needed skills requirements identification. The job domain and related context should be clearly defined in order to identify the job characteristics and specific knowledge requirements. Then, the skill requirements in term of hard skills, soft skills, and meta-skills are identified based on the literature review, survey, or in-depth-interview methods.
- The second phase is the categorization of teaching and learning approaches. The related teaching and learning approaches should be explored and categorized. The suitable approaches will be allocated to each skill requirements in the next phase.
- The third phase is the designing suitable teaching and learning approaches for each skill development.

This work focuses on the first phase of the skill development framework. The industrial engineering domains is selected as an implementation of the proposed framework. The next section will explain the methods and results of this implementation.

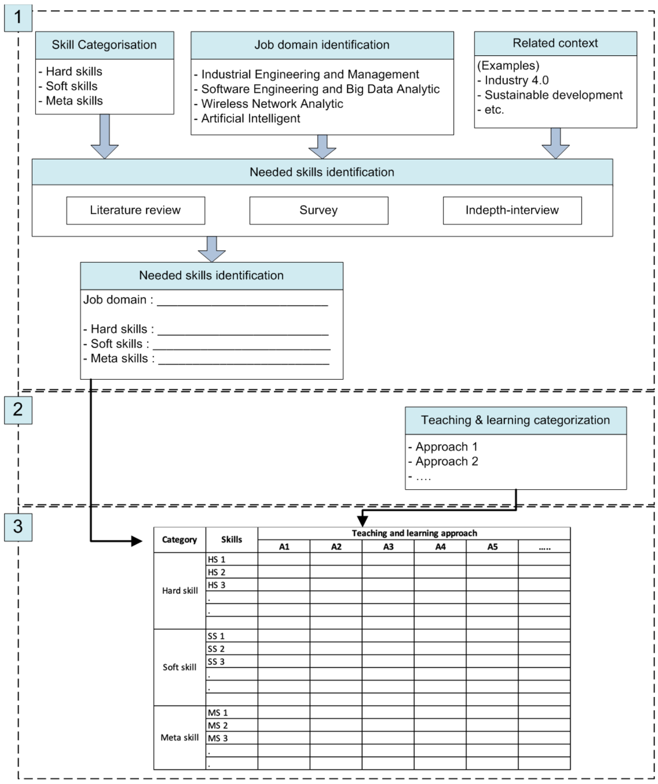

Fig. 2. Skill development framework

IV. SKILL REQUIREMENTS FOR INDUSTRIAL ENGINEER

A. *Industrial Engineer in Industry 4.0 era*

The definition of Industrial Engineering, which is defined from the American Institute of Industrial Engineers, is "Industrial engineering is concerned with the design, improvement, and installation of integrated systems of men, materials, equipment and energy. It draws upon specialized knowledge and skill in the mathematical, physical and social sciences together with the principles and methods of engineering analysis and design to specify, predict, and evaluate the results to be obtained from such systems" [12].

The job functions of industrial engineers (IEs) changed from primarily with work simplification and methods improvement, plant layout, and direct labor standards.in the 1960s to be in the areas of scientific inventory management, systematic design and analysis, and project engineering. 1970s. These changes, along with increased information processing capabilities, pointed toward a future where industrial engineering functions and roles would provide input and impact the decision and planning processes of management at higher levels [12].

During the 1980s to 1990s the role of the industrial engineer expanded significantly to include organizational leadership responsibilities in both the design and integration of manufacturing and service systems. The growth of complex arrays of computerized machines, the design and integration of information systems that could effectively control and handle data related to production system play an important role for IE in this decade [12].

The effect of Industry 4.0 on production systems is to the flexibility and ability to produce many versions of products in low batch sizes which leads to greater efficiencies and a revolution of relationships in the supply chain. CPS, IoTs, Internet of Services, and Smart Factory turn the production system into flexible, reconfigurable manufacturing systems, offering interactive, collaborative decision-making mechanisms. These changes effect IE's role in manufacturing system. IEs need competencies in deploying and optimizing augmented-reality systems and IT skills in advanced analytics for simulation. Soft skills will become more important. IEs will be required to provide and optimize step-by-step guidance and instructions for multi-machine operators. IEs will have to be open to change, possess flexibility to new roles and work environments [13].

B. *Research Methodology*

This study captured the opinions of industrial and academic sectors on the issues of the skill requirements of industrial engineer in the Industry4.0 era. A semi-structured questionnaire was created and deployed for data collection. The initial list of the questions was developed based on the literature review and revised by a group of academic expertise in industrial engineering. These questions have been modified several rounds based on early reviews by academic and industrial practitioners who are specialized in industrial engineering and Industry 4.0.

The questionnaire covered four main topics, including respondent background, IE's specific knowledge requirements, IE's soft skill requirements, and IE's meta-skill requirements.

After several rounds of discussion, questionnaire was finalized. A web-based survey system was designed and established for collecting data. This questionnaire was distributed to 80 industrial and academic respondents who work as engineer, manager, chief executive officer and business owner in IE domain. Survey responses collected during September 2018 and establishing one discussion workshop with 15 industrial practitioners on 8th September 2018. From 80 sent questionnaires, forty-two complete responses were received which translate to a response rate of 52%. Another 15 responses were gathered during the discussion workshop. c

C. *Data Analysis and Discussion*

1) *Respondent Background*

The web-based questionnaire achieved 57 responses, which 96% of respondents graduated in industrial engineering bachelor's degree. Considering a work experience of respondents, 38% are working in industrial sectors more than 10 years (see Fig. 3.).

Figure 4 shows the job position of respondents. 60% of respondents work as an engineer in various position such as process engineer, productivity engineer, material engineer, supplier quality engineer, quality assurance engineer, industrial engineer, data Science/ machine learning engineer, production planning engineer, etc. 26% of respondents work as a manger in various position such as general manager, project manager, plant manager, production manager, sale planning manager, etc. 5% of respondents are chief executive officer in various position such as deputy director, plant director, and chief executive director. Another 5% of respondents work as a university lecturer in industrial engineering and management fields. 4% of respondents are business owners in both manufacturing and service sectors.

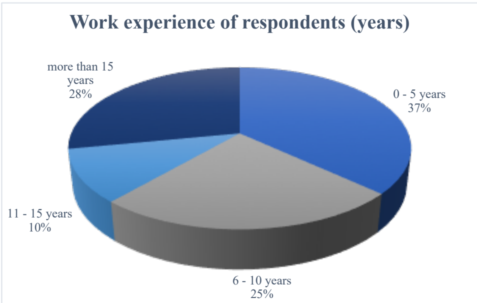

Fig. 3. Work experience of respondents (years)

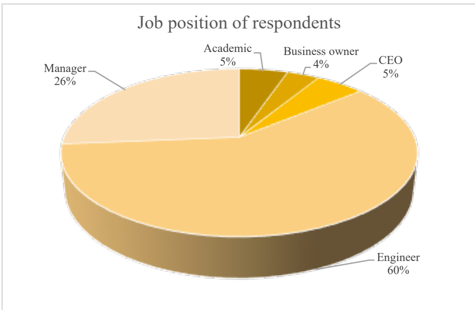

Fig. 4. Job position of respondents

D. Hard Skills for Industrial Engineer

The second section of the questionnaire surveys IE's specific knowledge which is very important in Industry 4.0 era. The results show in Fig. 5. Most of the respondents (89%) agree that production management is very important for IE. Following with logistics and supply chain engineering and management (82%), robotics and automation production (79%), production technology (77%), engineering material (67%), and work-study and ergonomics (51%) respectively.

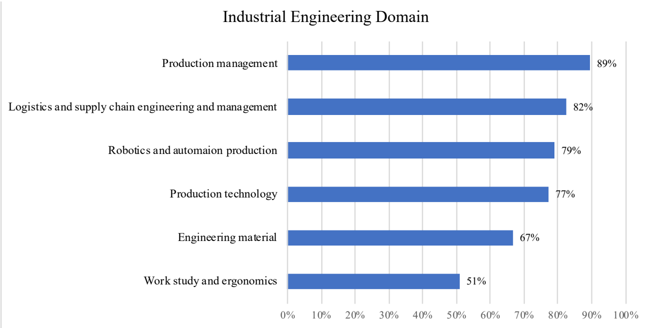

Fig. 5. IE knowledge requirements

According to the workshop, the set of technical skills in some knowledge area was pointed out as follow:

- **Technical skills for production management** such as analyze, modelling and simulate the production system based on big data from sensors, use of digital devices to monitor and control system, design production system and use of collaborative robots, use of additive manufacturing technologies, managing human resources, interconnected through digital devices, etc.
- **Technical skills for logistics and supply chain engineering and management** such as developing or use of IT system to support supply chain management (e.g. collaboration platform on cloud), analyze big data to design, implement, control and monitor logistics and supply chain activities, use of real time management, monitoring, and tracking technologies, etc.
- **Technical skills for robotics and automation production** such as implementation of human-robot collaboration, designing multi-machine worker assistance system.
- **Technical skills for production technology** such as evaluating alternatives and identifying, selecting, and implementing manufacturing technologies, use of CAD/CAM process design and concurrent engineering.
- **Technical skills for work study and ergonomics** such as design friendliness work station or manufacturing system for optimizing human-robot collaboration with ergonomically-convenient jobs.

E. Soft Skills for Industrial Engineer

The third section of the questionnaire surveys IE's soft skill requirements. This work divides soft skills for IE into three groups i.e. critical thinking skills, collaboration skills, and communication skills.

Critical thinking is the ability to analyze carefully and logically information and ideas from multiple perspectives. This ability is a vitally important skill in the engineering workplace. The results from the survey (see Fig.6) show that both problems solving and systematic thinking are the most important skills (89%) of critical thinking for IEs. Following by data analytics, evaluation, and synthesis (86%), and reasoning skill (70%) respectively.

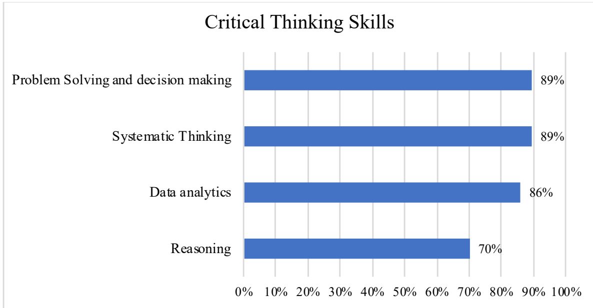

Fig. 6. IE critical thinking requirements

Industry 4.0 era necessities new cross-functional roles with different knowledge and skills that combine IT and production knowledge. The decision-making changes from centralization to decentralized decision-making. Thus, IEs have to work collaborating with multi-disciplinary sections. The collaboration skills, then, play an important role for engineer to work with others effectively. The results from the survey (see Fig.7) show that team-working skill is the most important skill for collaborative working. Follow by productivity working (84%), flexibility and adaptability (74%), and leadership skill (65%).

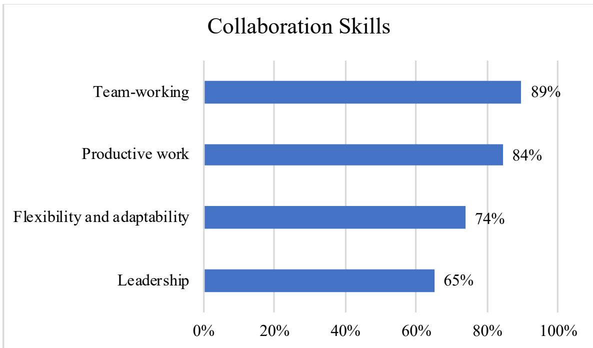

Fig. 7. IE collaboration skill requirements

Communication skills enable people to communicate effectively with one another. The development of communication skills is now considered to be a desirable feature for required skills in Industry4.0 era [7, 8]. The results from the survey (see Fig.8) show that presentation skill (88%), including oral presentation and written report, is the most important skill for IE's communication skill. Follow by effective communication and discussion (75%), effective listening skill (75%), and digital media communication (65%) respectively.

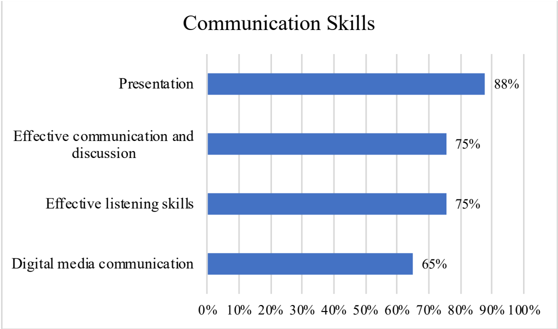

Fig. 8. IE communication skill requirements

F. *Meta skills for Industrial Engineer*

Industry 4.0 era requires to continuously innovate new services, better processes, and improved products for the manufacturing system. It is no surprise that creativity and innovation are very important for an engineer in this era. Refer to the discussion on section III, to developing meta-skill needs a long-term development. Thus, the university should provide teaching and learning facility to support students to do practical practices and establish a life-long learning environment for them.

The results from the survey (see Fig.9) show that the skill of willing to learn and explore new knowledge is IE's most important (89%) skill in term of creativity and innovation skill. Follow by multidisciplinary transfer (77%) and creative thinking and idea generation (75%) respectively.

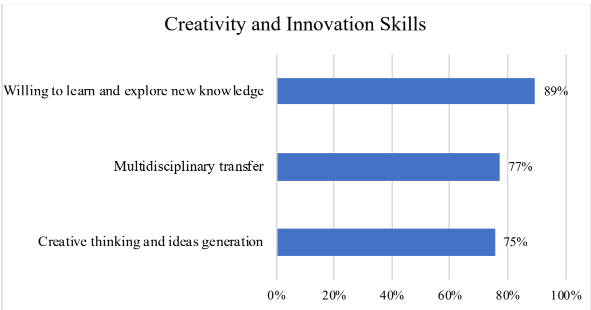

Fig. 9. IE creativity and innovation skill requirements

V. Conclusion

This work attempts to investigate the skill requirements in the Industry 4.0 context for developing IE's skills. It provides an understanding of IE in a flexible, automated, data-driven industrial system. The industrial revolution, involving new and integrated technologies that function on substantial data transfers. The role of IE changes from primarily with work simplification and methods improvement to more management and making a decision based on multi-disciplinary information. IE needs a strong competence to work in the dynamic and real-time manufacturing system. Thus, only hard skill is not enough to work in these environments. This work identifies the skill requirements in term of hard skill, soft skill, and meta-skills for IE.

Future research could focus on teaching and learning approaches, which is suitable for developing the set of required skills for IE students.

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