Conceptual development of learning factory for industrial engineering education in Indonesia context as an enabler of students’ competencies in industry 4.0 era

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Abstract. Industry 4.0 becomes more and more important in recent years because manufacturing industries are facing huge challenges in improving productivity for global competition. Industry 4.0 provides new opportunities to improve the resource and process efficiencies by combining information and communication technologies such as autonomous robots, internet of things, cloud computing, big data, augmented reality, additive manufacturing, etc. This integrated cyber-physical production system raises complexity within production system that implies new competencies required for industrial engineers which has been proven for years that the role of industrial engineer greatly influences a manufacturing industry’s success by designing, implementing, improving and optimizing a complex processes of an integrated systems that consist of people, money, knowledge, information, equipment, energy and materials. The competencies required in Industry 4.0 could be categorized under technical competencies and social competencies. A learning factory with real world system is often used to train students a new set of competencies by hands-on and direct experiences. Therefore, a learning factory can make a substantial contribution to competencies enhancement for industrial engineering students. This paper presents a conceptual of Industry 4.0 Lab as a learning factory for industrial engineering education as an enabler of students’ competencies in industry 4.0 era. A fully automated small production of filling bottle system integrating and demonstrating various Industry 4.0 concepts technologies is chosen. The learning modules and didactic approach are developed by integrating industrial engineering body of knowledge, Industry 4.0 value drives and Industry 4.0 levers in the creation of technical and social competencies required.

Keywords: Industry 4.0, industrial engineering, competencies, learning factory

1. Introduction
The industrial world is currently improving and is also transforming towards a more advanced industry. One of these transformations has a big influence on manufacturing companies which can be seen from the increasingly complex and varied market demand for products that encourage companies to start utilizing the internet and the digital world in the production process [1]. Utilization of the internet and the digital world as advanced technology is the main key in efforts to increase productivity [2]. This trend has been put forward by Germany called Industry 4.0, which aims to improve communication between people, machines and other resources so that the production process is centrally controlled and autonomous [3].

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According to the results of the discussion held by the United Nations Industrial Development Organization [4], the challenges that will be faced by developing countries is in preparing resources with special skills, increasing the scale of companies and factories, as well as funding to run industry roadmaps 4.0. Indonesia as a developing country certainly faces these challenges. Therefore, Indonesia has compiled a national agenda consisting of 10 national priorities called "Making Indonesia 4.0". One of the contents of the national agenda is to improve the quality and competencies of human resources which will be carried out by redesigning and aligning the national education curriculum with future industry needs [5], including industrial engineering education.

Certainly not necessarily with the curriculum changes that occur make Indonesia ready to adopt Industry 4.0. This requires something that can bridge the Industry 4.0 with existing students as future workers. One solution that can be done by the university is by providing a learning facility that called a learning factory. In a learning factory, the students can learn and practice in production system directly because a learning factory provides a scope of a production system that is almost close to the original by using a variety of industrial equipment [6]. Therefore, learning factory can be used as a facility to train and prepare students for industry 4.0 transformation [7].

2. Literature Study

2.1 Industrial Engineering Education

In general, industrial engineering is a science related to the planning, design, development, improvement, implementation, installation and evaluation of the performance of complex processes or systems that are integrated between people, equipment, technology, and information [8]. The focus of industrial engineering is on industrial systems, especially in manufacturing, which has been proven for years that the role of industrial engineering greatly influences its success [9].

![Figure 1. Industrial Engineering Body of Knowledge, adopted from [10]](image_url)

In doing its work, industrial engineering uses simulation assistance along with mathematical tools, such as statistics and computational methods for system analysis, modelling, evaluation and optimization [8]. According to Institute of Industrial and System Engineers (IISE) [10], just like with other engineering families, industrial engineering must also include basic sciences such as Calculus, Statistics, Probability, and Physics. After mastering these sciences, industrial engineering will deepen their knowledge by studying 12 industrial engineering area of knowledge or called the Industrial Engineering Body of Knowledge as shown in Figure 1.
2.2 Industry 4.0

The development and creation of new methods as well as implementing them in the industry indicate that the industry continues to evolve. As known that industry has undergone a revolution three times and entering the fourth industrial revolution [11]. The fourth industrial revolution or known as Industry 4.0 was first introduced by Germany in 2011. The concept was created to support the development of the industrial sector and became one of the strategies to maintain its position as one of the most influential countries in the manufacturing industry and machining in the world [12].

According to Sung [13], Industry 4.0 is a continuation of the digitalization of manufacturing that has been done in industry 3.0, where the emergence of this phase is driven by the existence of several problems, such as an extraordinary increase in data, computing power and connectivity, the presence of new forms of interaction between humans and machines such as touch interfaces and augmented-reality systems, as well as improvements in sending information or digital instructions to the physical world. While Strange and Zucchella [14] considered Industry 4.0 as a foundation for global companies that use the latest technology enablers as shown in Figure 2 so that the entire work environment becomes interconnected and integrated. Thus, companies can obtain information in real time between elements as an effort to optimize costs, availability and use of resources.

![Figure 2. Industry 4.0 technologies enablers](image)

A more technical description of Industry 4.0 was conveyed by Roblek et. al. [16] which stated that Industry 4.0 as a state based on concepts and technologies consisting of Cyber-Physical Systems (CPS), the Internet of Things (IoT), and the Internet of Services (IoS) to communicate continuously through internet so as to enable interaction and exchange of information. The exchange of information that occurs also varies, both between humans and humans (C2C), humans and machines (C2M), and between machines and machines (M2M). The technologies that have been mentioned along with other technologies such as radio identification (RFID), cloud computing and data mining, also participate in the development of smarter manufacturing processes or referred to as smart manufacturing [17].

Unlike the previous industrial era, the Industry 4.0 approach through the integration of machine and operator systems is carried out horizontally and vertically used in the production planning stage and business processes so that machines and operators can exchange real time information directly [18]. The technology base in this era is intelligent automation of CPS with a decentralized arrangement that allows manufacturing companies to have a mass production process that is flexible as known as mass customization [12].

The main objectives using the above technologies in Industry 4.0 is to strive for maximum value creation across the manufacturing/production processes through continuous and autonomous exchange
of information and data. Figure 3, by Baur & Wee [19], depicts eight value drivers and 24 dependent industry levers in Industry 4.0. Key value drivers of an Industry 4.0 include: (1) resources/process, (2) asset utilization, (3) labor, (4) inventories, (5) quality, (6) supply/demand match, (7) time to market and (8) service/aftersales.

**Figure 3.** Industry 4.0 value drivers and levers [19]

### 2.3 New Competencies in Industry 4.0 Era

Competency is a term that is often used to express a person's work potential at work. Competency is defined as a group of knowledge, skills and attitudes that can compare someone who has high performance with people who only have average performance. Another definition of competency is the ability of employees to include knowledge, attitudes, and skills in completing work effectively and efficiently so that it can have a contribution to the company [20]. Competency can also be interpreted as observable performance and the quality of one's work [21]. The overall definition of competency is explained by Königová [22] where competence is defined as a series of knowledge, abilities, skills, attitudes, and values that affect the development of an individual and how the individual participates in the success of everyone in the company.

In Industry 4.0, technological advancements such as machine automation, real-time measurement of data, and remote production arrangements must be adapted by companies to meet changing customer needs over time. Companies in the Industrial 4.0 era also must be able to adapt quickly and flexibly in responding to constraints such as sudden production disruptions or last-minute production change requests in meeting customer needs. To meet these challenges requires the support of human resources who have sufficient technical qualifications and competencies [23]. This is supported by Prifti [24] which says that quality human resources have a very important role in dealing with Industry 4.0. Competent human resources are very important for companies because competent human resources can optimize the sophistication of technology use in achieving expected productivity [25].

Jobs in Industry 4.0 will be interconnected, so competences such as interdisciplinary working, collaboration, communication, and teamwork will have a special role called as social competencies [24]. Social competencies include individual social values. Examples are the ability to teach the knowledge he has to others, leadership skills, and the ability to work in teams. These social competencies can describe the interaction that will be built by individuals with other people in the future. The concept of social competencies can also include social skills, social communication, and interpersonal communication. Social competencies are important competencies and can determine whether someone can work effectively or not [26].
In principle, there are two types of competencies, namely general and specific competences. General competencies are general characteristics and skills possessed by individuals, while specific competences explain how these characteristics and skills make an individual an expert in the field he is working on [22]. General competencies refer to social competencies, while specific competencies refer to technical competencies. Table 1 shows technical competencies and social competencies required in Industry 4.0 adapted from Karre at. al. [2].

Table 1. Competencies required in Industry 4.0 era [2]

| Technical Competencies | Must | Should | Could |
|------------------------|------|--------|-------|
| IT knowledge and abilities | Knowledge management | Computer programming and coding abilities |
| Data and information processing and analytics | Interdisciplinary/generic knowledge about technologies and organizations | Specialized knowledge about technologies |
| Statistical knowledge | Awareness for IT-security and data protection | Awareness for ergonomics |
| Organizational and processual understanding | Specialized knowledge of manufacturing activities and processes | Understanding of legal affairs |
| Ability to interact with modern interfaces | | |

| Social Competencies | Must | Should | Could |
|---------------------|------|--------|-------|
| Self and time management | Trust in new technologies | | |
| Adaptability/ability to change | Continuous improvement and lifelong learning | | |
| Teamwork abilities | | | |
| Social skills | | | |
| Communication skills | | | |

2.4 Learning Factory
Initially, the learning factory was developed by the National Science Foundation (NSF) in America in 1994. The initial learning factory model was used to expand the knowledge gained by students or employees, where they will be confronted directly with real problems in the industry so that all processes and technology which is in the learning factory is based on reality. The model encourages students to be able to solve the problems given, one of them is by designing processes, products and system according to their needs [27].

The aim of the learning factory is to integrate government and industry into engineering education. Sometimes there are obstacles in manufacturing/production applications between government, industry, and universities, so that is where the learning factory exists as a liaison between them. The learning factory uses practiced based engineering education and a real-life project that can connect universities and industry as shown in Figure 4.

The most important element in learning factory is a didactic method and approach because it has a big influence on the success of the learning process [29]. Learning factory provides many benefits as a learning system including, generation and application of knowledge in the learning factory, solving of real problem situations, self-organized learning in groups, partial models of real factory providing a rich learning content, alternation of hands on phases in the learning factory and systematization phases.

Many universities in the world already used learning factory as a step to support students to adapt to industrial development, for example like the Chrysler World Class Manufacturing Academy in Michigan uses full-scale physical learning factory for experimental learning related to competencies needed. IFA learning factory at the University of Hannover provides learning related to lean thinking, factory layout planning, ergonomics, and others that are more directed towards human factors. Integrated learning factory at the University of Windsor, Canada in the form of modular and changeable assembly systems consisting of robots and manual assembly systems, computer vision inspection and several materials handling modules [30].
3. Industry 4.0 Lab Conceptual Design

3.1 Industry 4.0 Lab Model Description

The Industry 4.0 Lab comprises a hybrid simulation environment, which combines the benefits of virtual and hardware simulation and components in order to design or analyse industrial manufacturing/production system. The main physical components are the workpieces and the machine tool demonstrators as well as transport lines which connect various machine tool demonstrators. The demonstrators with their ability to communicate in different ways and the flexible transport system provide an effortless integration of hardware components into the overall system. The software is designed for quick integration of sensors, actuators, and other devices using standard communication protocols. The hardware components provide the interfaces for an easy connection and integration of new hardware. The laboratory’s development focuses are against the present background in particular as shown in Figure 5:

- Integration of manufacturing/production system into industrial engineering education
- Demonstration of Industry 4.0 technologies and application in manufacturing/production system
- Students’ competencies enabler in Industry 4.0

The manufacturing/production model developed should enable learners to actively transfer gained knowledge to practical tasks that meet the following principles [32]:

- Holism and complexity. The model should reflect the real production system that has multidimensional aspects of processes and technologies and address more than one real industrial problem.
Self-activity or self-organized learning. The model should allow students to do the activities by
himself and experience hands-on learning.

Practical and learning orientation. The model should be able to run repeatedly with economic cost
in order to enable effective learning.

Social and cooperative action. The model should be able to be played in a group so the social
interaction and cooperative teamwork could be fostered among the students.

Target orientation and critical reflection. At the end of the activity, the model should be able to be
evaluated based on the learning activities carried out corresponds to the learning objectives.

The suggested Industry 4.0 Lab is a fully automated small production of filling bottle system
integrating and demonstrating various Industry 4.0 concepts technologies as illustrated in Figure 6.
Filling bottle system is chosen because it meets the principles above. The production system is
designed to fulfill the Industry 4.0 trend that runs multiple products without planned sequence, an
intelligent product with RFID technology, intelligent workstation, intelligent system and mass
production but execute individualized production or lot size one.

The process overview and the main components of the Industry 4.0 Lab are:

1. **Input**: the empty bottle equipped with RFID with product information and specification enter the
   system
2. **Filling**: the workstation read product information and specification written in RFID and start to fill
   the bottle with the correct liquid corresponds to RFID data
3. **Capping**: the workstation read product information and specification written in RFID and close the
   bottle with correct bottle cap color corresponds to RFID data
4. **Labelling**: the workstation read product information and specification written in RFID and print
   the label with the correct product variant name corresponds to RFID data then stick to the bottle
5. **Inspection**: the workstation is equipped with a camera for a visual check, the workstation read
   product information and specification written in RFID, a visual check is executed based on the
   parameter setting, for example, the color of the liquid, liquid height, label position and name
   written on the label. If fail, the product will be routed to reject station while the accept product will
   be routed to the packing station
6. **Packing**: the packing workstation is manual station and operator will pack the product into the box

![Figure 6. Overview of the Industry 4.0 Lab](image)

### 3.2 Exemplary Learning Modules for Industry 4.0 Lab

The learning modules will be offered to industrial engineering students from year 2 to year 4
according to learning modules based on syllabus distribution. It covers topics from work design &
measurement, facilities engineering & energy management, quality & reliability engineering,
ergonomics & human factors, supply chain management and product design & development. Table 2
illustrated examples of the learning modules in Industry 4.0.
The leaning modules of didactic concept for Industry 4.0 Lab are content-specific modules of industrial engineering body of knowledge. Within the learning modules, the respective Industry 4.0 values and levers represent a content-related and thematic concretization of the modules. From competences perspective, modules are designed focusing technical competences and social competences as the learning outcomes. The developed modules, once fully employed, will be given an insight into Industry 4.0 value drivers and levers and competences required.

### 3.3 Learning Scenario

In the Industry 4.0 Lab, the students have to solve real production problem during practicum activities. The learning processes in the learning factory are inspired by problem-based and experiential learning. The learning processes do not focus on the theoretical principles of Industry 4.0 but on its applications and impact on manufacturing/production system. By this method, the students have opportunities to explore, experiment and implement the possible solution for the problem given. The students work on specific problems and tasks, such as material flow, quality control, ergonomics, resource utilization, information flow, etc. which are similar to industrial applications and related improvement can be implemented directly.

The didactic and methodological approach in the Industry 4.0 Lab is based on two setup states: (1) the initial current state and (2) the optimized future state. Learning factory tours will be given at the first session of practicum activity. Tours through the learning factory allow a general overview of all the issues addressed and simultaneously introduce an understanding of the interrelations of the networked manufacturing/production processes. The students will try different stations with different roles in the learning factory to learn and experience the modern form of production processes and which possibilities the system offered.

When the practicum activity starts the system is set up under suboptimal conditions in terms of workspace, material and information flows which is similar to traditional/classic production system. The students learn how to operate the processes themselves and also the methods to discover improvement opportunities to change the traditional/classic production system to industry 4.0.

Table 2. Example of Learning Modules for Industry 4.0 Lab

| Knowledge area | Industry 4.0 value drivers | Industry 4.0 levers | Technical competencies | Social competencies |
|----------------|-----------------------------|---------------------|------------------------|---------------------|
| Work design & measurement | Labor | Human-robot collaboration | Organizational & processual processing (m) | Self & time management (m) |
| | | Remote monitoring and control | Ability to interact with the modern interface (m) | Adaptability/ ability to change (m) |
| | | Digital performance management | Knowledge management (s) | Teamwork abilities (m) |
| | | Automation of knowledge work | Specialized knowledge about technologies (c) | Social skills (m) |
| | | | Awareness for ergonomics (c) | Communication skills (m) |
| Facilities engineering & energy management | Asset/utilization | Routing & Machine flexibility | IT knowledge & abilities (m) | Self & time management (m) |
| | | Remote monitoring and control | Data & information processing & analytics (m) | Adaptability/ ability to change (m) |
| | | Augmented reality for MRO | Statistical knowledge (m) | Teamwork abilities (m) |
| | | Predictive maintenance | Ability to interact with modern interfaces (m) | Social skills (m) |
| | | Remote maintenance | Interdisciplinary/generic knowledge about technologies & organizations (s) | Communication skills (m) |
| | | Virtually guided self service | Specialized knowledge of manufacturing activities & processes (s) | Trust in new technologies (s) |
| | | Smart energy consumption | Specialized knowledge about technologies (c) | Continuous improvement & lifelong learning (s) |

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compliant. These opportunities are discussed, and possible solutions are worked out in a group that enables technical and social competences are intertwined. Selected solutions are implemented directly in the Industry 4.0 Lab and the improved setup is iterated towards the future state. The benefits of the implemented improvements are quantified through production processes in the new setup and the comparison of predefined key performance indicators such as throughput time, a number of defects, resources utilization, etc.

4. Conclusion and Outlook

Industry 4.0 transforms the manufacturing system and changes the rules of the game for production. Connecting the machines by information and communication technologies promises the increment of productivity as a focus of industrial engineering. In this paper the conceptual Industry 4.0 Lab as a learning factory is presented by integrating industrial engineering education into the learning modules and learning scenarios. The approaches used in the Industry 4.0 Lab are real production problem, problem-based and experiential learning, group activities, transformation of current state to future state based on Industry 4.0 key drivers and levers.

The Industry 4.0 Lab was developed starting with the need of new competencies to face the challenges in Industry 4.0. The competencies model was developed in line with the requirement of Industry 4.0 due to the increase of technologies complexity and interconnected, cross functional and collaborative work in Industry 4.0 environment. The model shows that a learning factory and the didactic approaches used will foster technical and social competencies for Industry 4.0 era.

The Industry 4.0 Lab as a learning factory could become a framework for industrial engineering education in Indonesia to keep a pace of the current industries in Indonesia and their adoption of Industry 4.0. Even though the model itself as well as the learning modules are designed specifically for industrial engineering students’ competencies but could be a starting point and guidelines for similar engineering educations by integrating its curriculum into the model. Further work, inter-disciplinary of engineering educations will bring more benefits to the Industry 4.0 Lab and Industry 4.0 implementation.

The introduced Industry 4.0 Lab has presented a possible implementation by universities in Indonesia with proper roadmap and strategies to cope with development cost. One of the strategies is by deploying low cost hardware and system with free available software for shop floor application. Developing the Industry 4.0 in phases, such as short-term priorities, mid-term horizon and the long-term perspective could be considered. The short-term priority is a development of smart production or assembly line with IoTs, follows by focusing on asset utilization and human-robot collaboration as mid-term horizon and finally the long-term perspectives includes integrating ERP to create smart enterprise.

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