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Implementation of Smart Manufacturing System Learning Kit: Study of Engineering Teachers' Performance and Engagement

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Abstract: Nowadays, engineering education is a shift from practice-based with textbooks to practice-based with authentic materials. Especially the learning factory paradigm is a fundamental approach that refers to a realistic manufacturing environment for education, training, and industry research. However, engineering teachers experience a lack of knowledge and technology used in smart factory learning and a lack of learning material covering the industrial manufacturing content. Due to the rapid advancements in technology, there is a need to ensure that engineering teachers receive knowledge and skills that they may not have previously. This study offers three-day professional training with smart manufacturing system learning kits that can be used to encourage teachers' learning in STEM education. The participants are engineering teachers (n=38) in electronic, mechanical, and mechatronic engineering majors. The findings show practical implementation and recommendations to enhance engineering teachers' performance and engagement, which positively attitude the learning process.

Keywords: Industry 4.0, engineering education, learning factory, STEM education.

1. Introduction

Today's industry faces many challenges, such as growing technology, transformative digital transformation, and customer needs. To overcome those challenges, many enterprises must rely on industry 4.0 technology to enhance manufacturing standards, especially in developing countries that find a way to ramp up workforce production effectively (Zhang & Ming, 2021; Loumpourdi, 2021). A learning factory is a learning environment closely matching an industrial production setting to simulate production processes realistically while enabling practical training in various topics and professional levels through technologies and processes inside the learning factory based on current industry standards (Scheid, 2018). A learning factory is implementing several technologies in the industry 4.0 environment that drive existing technological developments and the ability to process large amounts of data (Centea, Singh & Elbestawi, 2019; Vijayan, Mork & Giske, 2019). The manufacturing system needs to consider Industry 4.0 to stay competitive in the market. Cause the workforce has to adapt to the workplace transformation brought by digitalization, automation, and the robotics transformation process (Rangraz & Pareto, 2021). Thus, Industry 4.0 was conducted in manufacturing enterprises where automated assembly lines, industrial robots, codes, and algorithms have replaced the manual setup.

The Thai government has implemented many policies to harness the potential of engineering education related to industry 4.0. Especially the professionalization of engineering teachers is a crucial objective in developing industrial workers. The effective mechanism induced this engineering teacherto upskill related to new technology that undertakes easy-to-achieve activities such as engineering teacher training to offset professional staff in the educational institutions necessary for sustainable growth as part of the Thailand 4.0 initiative to support economic sectors. Meanwhile, an engineering teacher instructs students in practical career skills in educational institutions. They must improve their competencies and professional training to cope with the growth of industry 4.0.

Based on the above, the authors have proposed developing a smart manufacturing system learning kit based on the learning factory paradigm for engineering teachers using learning material to connect to the learning factory paradigm. The research aims to evaluate engineering teachers' performance and engagement in smart manufacturing system training.

2. Related Work

In the last decade, the fourth industrial revolution 4.0, or industry 4.0, represents the radical transformation of an industry that has resulted from the integration of emerging technologies (Hernandez-de-Menendez, 2020). At the heart of Industry 4.0, smart factories integrate physical and cyber technologies that make the technologies more complex and precise to improve manufacturing processes' performance, quality, controllability, management, and transparency (Shi et al.,2020).

Various learning factories have been established in industry and vocational college environments to foster vocational students' competencies. Learning in realistic production environments that compete with the industry standard enables the development of problem-solving competencies among vocational students to support the industry need. Several studies address that learning factories have been an example of a good ecosystem where research and technology transfer between academia and industry happens (Ferrario el al., 2019). Learning factory concepts in the academic environment offers practice-based learning for engineering curriculum that equilibrium analytical and theoretical knowledge with manufacturing skills and hands-on experience in the design of manufacturing systems and product realization in the industrial system (Matt, Rauch & Dallasega, 2014).

In addition, the ability to connect the availability of vast amounts of data, the maturity of analytics and intelligent systems, and advanced manufacturing techniques are bringing about smart manufacturing systems (SMS) and a new data-driven era for manufacturing (Clough and Stammers, 2021).This concept applies digital technologies and consists of building a controlled workspace using a large-scale wireless technology deployment in manufacturing industries requiring a digital factory to create digital products (Tabaa, Chouri, Saadaoui & Alami, 2018).

Industry 4.0. characterized by increasing automation and the employment of manufacturing system that is integrated with operational technology and information technology to improve manufacturing operations through sensor systems and advanced data analytics in the manufacturing industry (Lenz, MacDonald, Harik & Wuest, 2020). Many studies propose the learning material for utilization in the learning process.

For example, Mourtzis, Angelopoulos & Dimitrakopoulos (2020) offered a highly automated and flexible manufacturing cell to enhance skills, competencies, and hands-on experience for a new generation of engineers. Berman, Hamidah, Mulyanti & Setiawan (2021) offered low-cost, portable air conditioning teaching and learning kits to improve students' understanding of vocational education. Mohammad et al. (2021) proposed a smart factory reference model as a guide to upgrading an existing production system towards the vision of Industry 4.0 using readily available components. It is a modular production system connected to a server accessible locally or through the internet with the application software to create the user interface. Some education institutions attempted to provide engineering teachers with opportunities for teacher professional development to maintain a standard of teaching and technical skill to cope with industrial requirements (Schmidt, 2019).

This study proposed the methodology for professional development training for engineering teachers in Thailand, including the learning activities of training modules and learning kits. Additionally, they evaluate their learning performance, whether they have achieved the educational objectives and how they think about this training.

3. Materials

3.1 Development of Smart Manufacturing System Learning Kit

In general, in teaching and learning factories for vocational education, using the existing commercial products available in the market is expensive. This study is based on a low-cost concept using a simple design and affordable materials and components intended to simulate the industry situation, allowing the students to apply their theoretical knowledge in practice. The development of a Smart Manufacturing System (SMS) learning kit consists of the three stations made of aluminum profile 20x20. Each station includes sensors (machine vision), conveyors, a selective compliance articulated robot arm or SCARA robot, articulated robot. Overall stations were controlled with a programmable logic controller (PLC) to connect hardware devices and online services through Sysmac Studio Software to support ladder, structured text, and function block programming. Furthermore, Node-RED was used to show the dashboard performed data monitoring graphically. The design basis of the smart manufacturing kit consists of three stations, as seen in Figure 1.

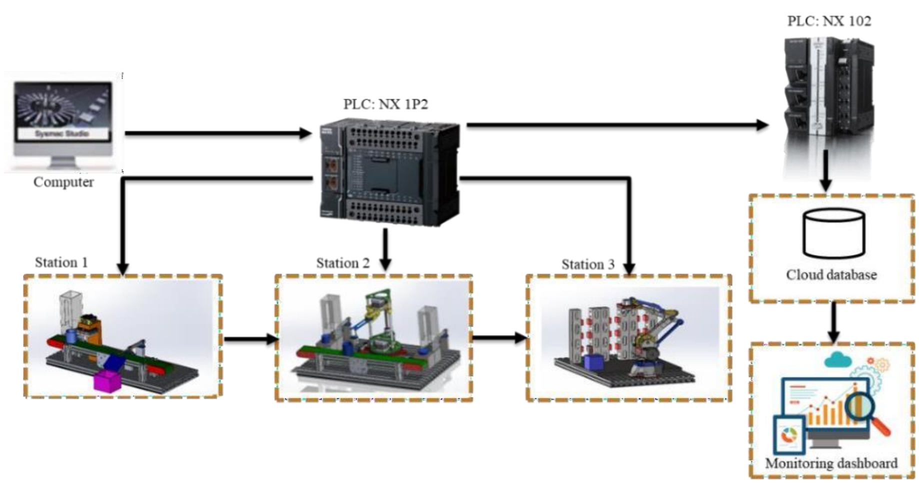


Figure 1. Design of Smart Manufacturing System schema.

Station 1: The loading station is a prototype for controlling the loading station of a factory automation system. It serves to load workpieces into the conveyors run and transport workpiece carriers. Then workpiece was then detected based on machine vision that can help achieve real-time data analysis in a manufacturing environment. It can be implemented in any industry to perform realtime monitoring of workpieces (Kumar et al., 2021). A conveyor forms for the workpiece carrier, fed to the next station as a PLC order.

Station 2: The assembly station is a prototype that employs the SCARA robot used for this station's pick & place and assembly operations workpiece. SCARA robot was used in assembly automation when coordinated with the control unit and other periphery gadgets.

Station 3: The warehouse packing station is a prototype for storing goods that uses Articulated Robotic Arms with multiple joints and articulated robotic arms to move and lift items in the warehouse. They’re typically used for receiving functions, such as moving things from pallets to racks, picking, packing, and shipping.

Therefore, the concepts of this training course for using the learning activities and evaluated performance following by educational objectives are listed by topic: Manufacturing process component, Computer, and programmable logic controller (PLC) connection, PLC Ladder Programming, Programming Control Pneumatic Cylinders, Photoelectric sensor, Control of DC Motor, Vision Inspection Systems, Robot Programming Control, Vacuum Grippers control, and Design of Dashboard.

3.2 Training Module

In this study, the 3P learning module proposed by Chookaew & Howimanporn (2022) was used in the training activity to create a training module that will keep engineering Teachers motivated and engaged as follows:

Module 1: Preparing the fundamental concepts is necessary to apply knowledge into practice, especially the core concepts are basic knowledge of the manufacturing process. This module points to Industry 4.0 technology related to new technology with three stations of SMS learning kit

Module 2: Practice with the hands-on activities are tasks given to the engineering teacher to operate the manufacturing process in the industry. This module is active learning pedagogy, and industrial applications were employed to support engineering teachers' work skills. It is vital to combine concepts and practice and include active tasks that intertwine the challenges of applying theory to problem-solving in industry. They have divided into groups to perform a hands-on activity. They use Sysmac Studio software to configure and program with PLC, then use Node-RED to connect interfaces and online monitoring.

Module 3: Presentation of the training outcome. In this module, engineering teachers performed and displayed task achievement. They share knowledge and work together to present the mission of the training activity. This module can incorporate technology into engineering teacher training and create more engaging, memorable, and enjoyable training.

4. Methodology

4.1 Participants

The participants in this study were 38 engineering teachers at technical and vocational education and training colleges in Thailand. Their age was 25 to 55 years. They taught majors related to industrial technology, including mechatronics, mechanical, and electrical engineering. In addition, they had bachelor’s degrees and master’s degrees, all of which were in engineering or engineering education and averaged 5-10 years of teaching experience. The experiment was conducted in a training room equipped with a laptop and SMS learning kit.

4.2 Measuring Tools

The measurement instruments included the performance checklist to evaluate the engineering teachers’ knowledge and skills used after training activities. The performance checklists, rating scales, and rubrics are tools that state-specific criteria and allow engineering teachers to gather information and judge what they know and can do to align with the learning outcomes. It was constructed by experts who are instructors and trainers related to the smart manufacturing system. The performance checklists are clarified when engineering teachers use the criteria to evaluate performance to help them analyse each level as five levels: excellent, good, fair, marginal, and inadequate. It has 100 scores from 10 activities that cover ten concepts.

In addition, a questionnaire to evaluate the engineering teachers’ perception of the training activities. The items in this engagement questionnaire were adapted to a revised version from Chookaew et al., (2020) and translated into the Thai language. It includes three dimensions of engineering teachers’ engagements after attending the learning activity, consisting of 11 items to assess behavioral engagement (3 items), cognitive engagement (4 items), and emotional engagement (4 items). At the same time, the latter examines students’ satisfaction on 5-point Likert scale (1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = agree, 5 = Strongly Agree).

4.3 Training Procedure

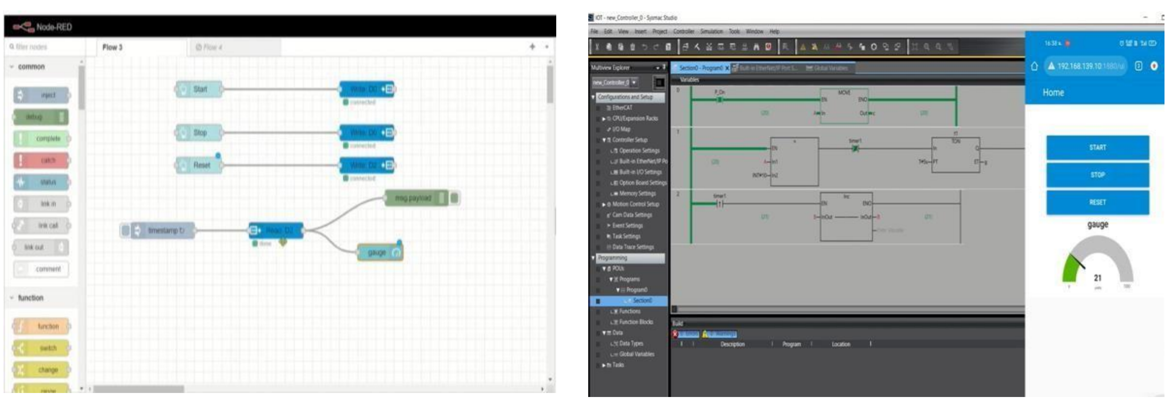
The professional development training program was implemented in a three-day workshop (a total of 28 hours). The designed training activities were separated into three days based on three learning modules as follows:

Day 1: At the beginning of engineering teacher professional development training, they participate in the preparation module with motivation learning and receive information related to the smart manufacturing concept, as shown in Figure 2.

Figure 2. The training participation of engineering teacher.

Day 2: they practiced with an SMS kit in the practice module. A worksheet is an important tool that engineering teachers use in training activities to answer questions and complete a task following a learning topic and activity. They used Sysmac Studio software of the programmable logic controller or PLC to collect sensor data from the SMS kit and then program it to control the process. After collecting data, PLC will send data to databases (Figure 3 a) through OPC-UA, allowing data analysis and visualization in real-time, supporting more significant decision-making for the smart manufacturing process.

After that, all data were created live data dashboard with Node-RED (Figure 3 b) that shows the graphic interface through which the user can visually interact with the system via mobile device. After completing each task, they evaluated performance with the knowledge and skills checklist to ensure that engineering teachers in the learning process use the training. Data were recorded through self-assessment by the participants.



(a) (b)

Figure 3. The screen shot of (a) Node-RED flow (b) Sysmac Studio and dashboard.

Day 3: Last day, they were randomly selected to showcase in the presentation module for discussion and knowledge sharing. Then, they take an engagement questionnaire.

5. Results

5.1 Engineering Teachers' Performance

The performance checklist is an instrument used to assess and provide the outcome of engineering teachers' success or failure whose performances are evaluated in the training course. The total performance score of 0–100 is according to these meanings: score ≥ 80 at an excellent level, = 79-70 at a good level, =69-60 at an acceptable level, =59-50 at a marginal level, and ≤ 49 at inadequate levels. Figure 6 shows that most engineering teachers' performance is excellent (M= 85.10, S.D.=5.65). However, only one engineering teacher has a performance score of less than 70 (acceptable level).

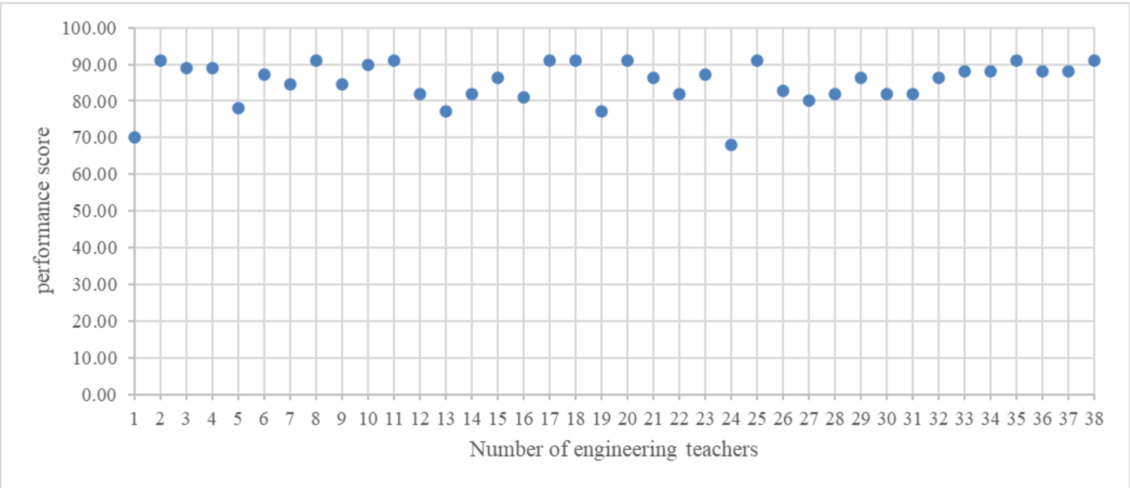


Figure 4. The engineering teachers' performance.

5.2 Engineering Teachers' Engagement

The second research objective is to evaluate engineering teachers' engagement in training activities. It consists of 11 items that could be scored on a 5-point Likert scale from 1 (Strongly disagree) to 5 (Strongly agree). When analysing the engagement questionnaire, descriptive statistics are used to describe mean scores, where 1–1.5 represents "strongly disagree," 1.51–2.50 represents "disagree," 2.51–3.50 represents "neutral," 3.51–4.00 means "agree," and 4.01–5.00 represent "strongly agree." For the result of engineering teachers' engagement in training activities, see Table 1.

Table 1. *Result of the engineering teachers' engagement in training activities*

Item	Mean	S.D.	Remark
Behavioral Engagement	*4.18*	*0.90*	*Agree*
1. I can participate and work in a training activity.	4.27	0.79	Agree
2. I attempt to define and discuss the task.	4.24	0.82	Agree
3. I think an environment is not a barrier to my learning.	4.03	1.05	Agree
Cognitive Engagement	*4.09*	*0.99*	*Agree*
4. I think the smart manufacturing system learning kit improves my thinking process and work related to the learning factory paradigm.	4.49	0.64	Agree
5. When I am unsure about the concept in training, I always consult a mentor.	3.86	0.99	Agree
6. When the problem occurs, I attempt to find the solution myself.	4.00	1.04	Agree
7. I always plan before operating in an activity with the smart manufacturing system learning kit.	4.00	1.09	Agree
Emotional Engagement	*4.26*	*0.85*	*Agree*
8. I think I can apply the smart manufacturing system learning kit in my teaching	4.16	0.85	Agree

9. I feel that the smart manufacturing system learning kit is a challenge for me.	4.24	0.88	Agree
10. I prefer the smart manufacturing system learning kit.	4.27	0.79	Agree
11. I think the smart manufacturing system learning kit gives me the knowledge and has a connecting learning factory paradigm as well.	4.38	0.85	Agree

In table 1, the engineering teachers' behavioral engagement dimension (M= 4.18, S.D. = 0.90), they interested in training activity, while the engineering teachers' emotional engagement dimensions were agreed (M= 4.09, S.D. = 0.99), and the engineering teachers' cognitive engagement dimensions were agreed (M= 4.26, S.D. = 0.85), respectively.

In addition, semi-structured interviews about how to think training activities served as the research method used in this study. Three participants selected who have outstanding were interviewed individually. The interviews lasted approximately 5 to 10 min. In this group of engineering teachers, the common view was that they all acknowledged their engagement in training activities with a positive attitude as follows:

Engineering teacher A: *"I think this training is an opportunity to open new technology to practice learning that they found most efficient in their vocational development into industrial 4.0."*

Engineering teacher B: *"I usually feel nervous about new technology because it is challenging to learn and teach, but I learned this course; I think it is easy if I have learning material to connect concepts and practices."*

Engineering teacher C: *"When I do many tasks in the training module, I have always been lazy. I think that I do not remember any content, but I try to pass it. At last, I can do it. However, I think this training takes a short time."*

6. Conclusions and Limitations

This study is an important mechanism for the engineering teachers' professional development, providing opportunities for learning any employable new skills related to STEM education. The finding has examined engineering teachers' performance and engagement in professional development training using a smart manufacturing system learning kit. To encourage the capacity to interconnect learning and the teaching/transferring of the engineering teacher. In addition, the organization is aware of professional development and capitalizes on developing teachers who function as potential workers and create new pedagogical practices.

The critical discovery limitation from this study is an unsatisfied demand number of learning kits in activities that impact individual engineering teachers' perception of the activity they have participated in the training. In addition, the research design and the participants' sample size limit robust statistical analysis and results to an extent.

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