Upskilling and reskilling for engineering workforce: implementing an automated manufacturing 4.0 technology training course

Sasithorn Chookaew & Suppachai Howimanporn

King Mongkut's University of Technology North Bangkok
Bangkok, Thailand

ABSTRACT: In today's world of rapid technological advancement, engineers constantly need to upskill and reskill for a successful career. Industry 4.0 technologies are essential for engineers who must have up-to-date knowledge of automation and data exchange in manufacturing, such as cyber-physical systems, the Internet of things, cloud technology and the smart factory. However, many training courses fail to provide the required knowledge due to a lack of strategies to motivate engineers to learn and engage with new technology practices. In view of this, a training course has been designed and implemented to improve the performance of engineering workforce in industrial remote control. A programmable logic controller (PLC) has been used to collect sensor data and send it to databases through open platform communications unified architecture (OPC-UA). This enabled data analysis and visualisation in real time, and supported more significant decision-making in the automated industrial manufacturing process. The results from the course, including feedback from the trainees, indicated that active training can enhance engineers' performance and their perception on technology.

Keywords: Manufacturing education, engineering education, lifelong learning

INTRODUCTION

Engineering education and continuous training play a key role in engaging and motivating engineers to reskill and upskill through actual practice with emphasis on problem solving based on new and emerging technology knowledge and skills. Especially, the 4.0 Industrial Revolution (4IR or Industry 4.0) technology is essential for engineers' understanding of current automation and data exchange trends in manufacturing, such as cyber-physical systems (CPS), the Internet of things (IoT), cloud and cognitive computing, and the smart factory.

In previous studies, researchers focused on lifelong learning with flexible training courses for industrial learning [1][2]. The aim was to ensure quality learning outcomes and also to create a culture where communication and collaboration are highly valued and respected by all stakeholders including the industry, education sector and the trainee. [1][2].

Fung advocated for education and industry to work closer together [3]. Enterprises play an increasingly significant role in education and training. Therefore, educational institutions should be agile and innovative to keep pace with the accelerating rate of change in the world, and prepare responsive and practical workforce with appropriate skills.

Doherty and Stephens proposed reskilling and upskilling programmes with faster, shorter learning and experiential training [4]. They argued it is required due to constant technological advancements and changes, and an increasing demand for highly competent trainers and experts to facilitate the upskilling of those employed in manufacturing [4].

In this study, the emphasis was on implementing a course for upskilling and reskilling that connects the educational system with lifelong learning. Such a course could build up engineers' confidence with a more robust understanding of the industry. The next step was to evaluate the proposed approach, including engineers' performance and their perceptions of attending training activity. Accordingly, the following two research questions were formulated:

- RQ1: Do engineers who participate in training activities improve their learning performance?
- RQ2: What is the engineers' perception of the training activities in terms of learning new technologies?

AUTOMATED MANUFACTURING 4.0 TECHNOLOGY

Engineering education is a lifelong learning activity of engineers. However, not all of them engage in it with the same intensity. Some engineers have seen their skills depleted, while industrial demands stay the same or increase.

This situation has caused some professionals to review their careers, and raised questions regarding reskilling and upskilling to expend one's career and progress as an engineer. Continuous learning opportunities can help engineers retain and upgrade their performance. However, in this endeavour, knowledge of Industry Revolution 4.0 technologies are needed including cyber-physical systems, making production systems modular and changeable based on data resources, and adaptive to highly customised products [5].

Many studies proposed an intelligent and agile system based on smart communication for monitoring and control with industrial communication using Node-RED [6-8]. Node-RED is a development tool for connecting hardware devices, application programming interfaces and on-line services. It has a browser-based editor to enable wiring together flows using the wide range of nodes in the palette. The industrial flows automation created in the Node-RED tool and a programmable logic controller (PLC) can be stored, imported and exported for information-sharing as a dashboard in the gateway connected with the open platform communications unified architecture (OPC-UA) [9].

Therefore, a learning module in a training course could offer a method to remote control a general industrial robot (multi-axis controllers) in industrial automation. This module could provide a robot through the industrial Internet of things (IoT) for interface input from the robot operator. The operator could program or move robots remotely and share information via the freeboard Web platform. The outcome could control the position, speed and acceleration, and then display the operating status.

In this study, the PLC was used to collect sensor data. After collecting the data, the PLC sent it to databases through OPC-UA, enabling data analysis and visualisation in real time, thereby supporting more significant decision-making in the industrial automated manufacturing process. After that, all data were live data in the dashboard with Node-RED that allowed showing the graphic interface through which the user could visually interact with the system via mobile devices, as shown in Figure 1.

Figure 1: The conceptual framework of Industry 4.0 technology.

DEVELOPMENT OF TRAINING ACTIVITY

The following three training modules were developed to drive learning activity in three days within the training course for engineers:

Module I: preparation of the fundamental concepts. The core concepts are basic knowledge of industrial robots' remote control capability and of real time mandatory to control any process and actuation in industrial applications. This module point to Industry 4.0 technologies that allow production lines to communicate regardless of location, time zone, platform or other factors. The ability to access data from home or from anywhere else with cloud computing allows engineers to be more flexible in the workplace.

Module II: practice the tasks. The active learning pedagogy and industrial applications were employed to widen and support engineers' work skills. This module shows that it is important to combine concepts, practice, and include active tasks that intertwine the challenges of applying theory to problem solving in industry. In addition, the dashboard node allowed users to create a screen for monitoring and control via graphs and buttons, devices, machines and sensors, then to configure the data display and access to it via the mobile Web. In this module, engineers were divided into groups in order to perform hands-on activity.

Module III: presentation of the outcome. In this module, a video recording of the trainees' presentation was used as the engineer's learning strategy.

The trainer was a university instructor with industrial experience who conducted the three-day training activities. During the course, manufacturing process concepts were introduced to better connect real-world phenomena and motivate trainees. The engineers practiced in various conditions and many situations. They shared knowledge and worked together to present the mission of the training activity. Then, a group of engineers prepared a presentation for about 30 minutes to show their control project with Node-RED via a mobile device, as shown in Figure 2 and Figure 3.

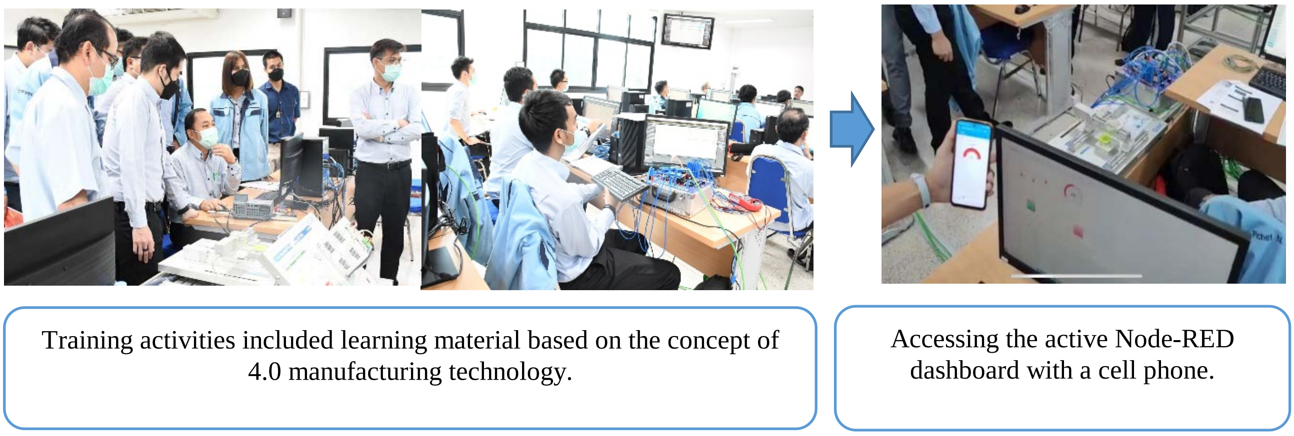

Figure 2: Training activities.

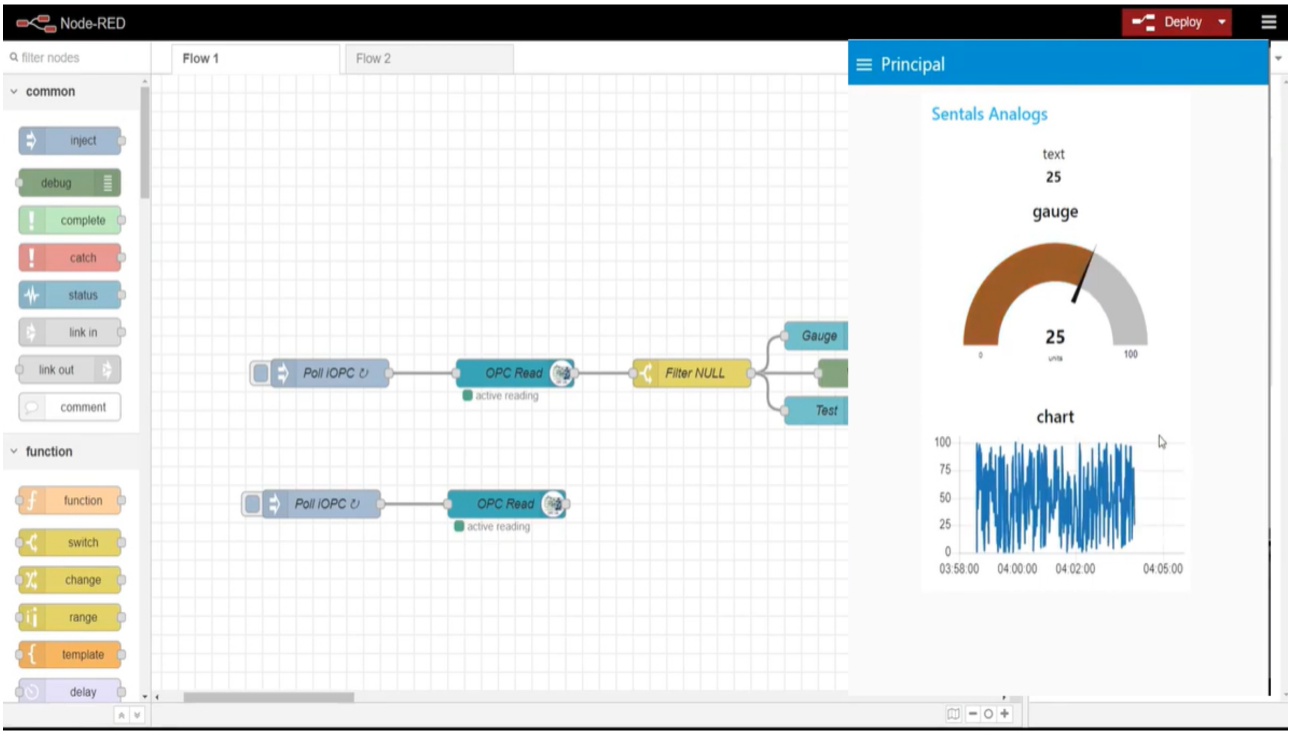

Figure 3: A screen shot of the Node-RED flow and dashboard.

RESEARCH METHODOLOGY

A quasi-experiment with a one-group pre- post-test design was adopted to examine engineers' learning performance in the training activity. For the study, 27 engineers were recruited (two females and 25 males) aged 23-50 from one enterprise in Thailand. Most engineers had background in several engineering disciplines, including electrical, electronics, mechatronics, mechanical and computer engineering.

The participants attended hands-on activities covering 4.0 technology in manufacturing in three days. At the beginning, they were asked to complete a pre-test to measure their prior knowledge (30 minutes). Then they participated in the training activities based on the three modules described above. The engineers were divided into seven groups (2-3 people per group). After the activities, their learning performance was evaluated. To assess the effectiveness of the training, a post-test was administered to the engineers, including 30 multiple-choice questions. In addition, a perception survey was conducted to gauge the participants' views on their training experience.

RESULTS

To determine the learning performance level in this study, a paired-samples *t*-test was used to find significant differences in means between the pre-test and post-test results of this training. The test revealed significant differences in learning performance ($p < 0.05$), as shown in Table 1.

Table 1: The paired-samples *t*-test of engineers' learning performance.

Before training (n = 27)		After training (n = 27)		df	*t*	*p*
M	SD	M	SD			
8.70	2.72	23.04	3.39	26	19.03	0.000*

$*p < 0.05$

In addition, group performance scores in learning tasks were calculated in percentages. Eighty percent or more was an excellent performance, 60-79% was a good performance, and less than 60% was classed as fail in this training course. Overall, most of the groups reached the excellent level scoring 80% or more, as shown in Figure 4.

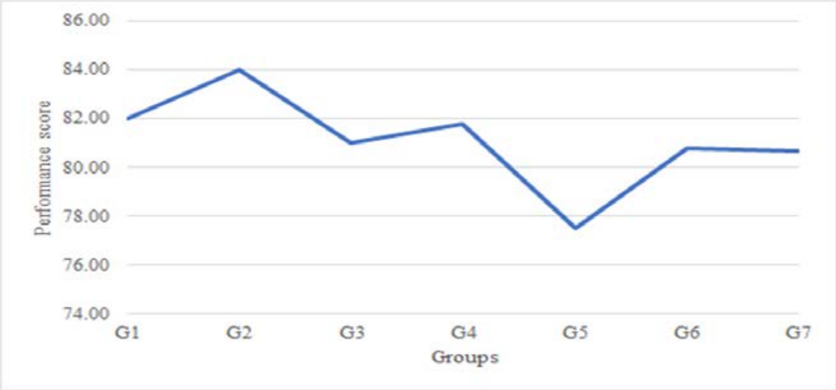

Figure 4: Group performance scores in percentages.

Table 2 below shows three dimensions of the engineers' satisfaction towards the course, including the training process, activities and usefulness. The results show that the engineers were satisfied at the highest level with the training course overall (M = 4.57, SD = 0.53). They expressed the highest level of satisfaction about the usefulness of the training (M = 4.68, SD = 0.46), the training process (M = 4.54, SD = 0.52), and also the training activities (M = 4.49, SD = 0.58) were rated at the highest level.

Table 2: The engineers' satisfaction with the training course.

Items	M	SD	Interpretation
Satisfaction with the training process	4.54	0.52	Highest
Satisfaction with the training activities	4.49	0.58	Highest
Satisfaction with the usefulness of the training workshop	4.68	0.46	Highest
Overall	4.57	0.53	Highest

To further investigate the engineers' perceptions of the training activity, the following four questions were included in the feedback survey.

The first question (Q1) was: *Why using 4.0 technology is important to the industry?* Many of the participants strongly agreed that 4.0 technology is important to the industry, and recognised the transformation change needed in the engineering learning process, for example:

- *The increasing demand to bring automated machines to use in the production line brings more efficient results, especially when Industry 4.0-related technologies are used.*
- *The industry wants higher quality products with lower cost processes, with less machine downtime and the ability to make more products faster.*

The second (Q2) was: *What was Industry 4.0 technology included in this course, and how was it related to your career?* Industry 4.0 technologies are being incorporated into manufacturing operations through digitalisation, thereby transforming the manufacturing process. As industry production lines overlap with digitisation, this has consequences for the engineer's work area; for example:

- *After I graduated from college, I found great opportunities to develop skills in the engineering field. This course was a great way to access new technology and other resources that can help enhance my confidence and the usage of technology in the industry.*
- *This course has increased my skills, particularly the actual use of new technology tools and access to data sources were beneficial.*

The third (Q3) was: *Do you think this learning process can improve your knowledge?* Most participants preferred this course over other training. They provided feedback on every aspect of the training: concepts, practice, technology and the trainer that positively impacted on the overall training process; for example:

- *This course was built on problem-based and actual experiential learning situations demonstrated in the course content and practice via projects tasks.*
- *This training was a relatively advanced course, with many learning approaches used to drive training activity. The competent trainer created a course according to the industrial requirements.*

The fourth (Q4) was: *Do you think this course can help you in upskilling and reskilling?* All participants agreed that the course could help upskill and reskill, and that it enabled them to perform the given tasks with understanding based on the learned concepts, for example:

- *I need to learn new knowledge and skills related to the engineering field, and this course helped me understand new concepts and transfer engineering knowledge into practice; upgrading my skills in this course was a great step in my career development.*
- *I liked this training course as it was a good form of retraining in new technology related to my work; I think it is important to continue learning after graduation. The idea of working Industry 4.0 technologies appeals very strongly to me.*

These positive comments indicate the participants' satisfaction who seemingly enjoyed this alternative learning experience. This training course was compelling for them as it provided the much needed reskilling and upskilling in Industry 4.0 technologies with learning activities based on real-world industrial technology.

CONCLUSIONS

With the Forth Industrial Revolution now flourishing, enterprises may choose to recruit a new workforce for the newly created jobs. Alternatively, they may also reskill and upskill the existing workforce to prepare them for new technologies. In this article, the authors outlined a training course based on Industry 4.0 technologies in view of the upskilling and reskilling alternative. This course was aimed at professionals with an engineering degree who needed training in Industry 4.0 technologies.

Upskilling is concerned with providing new skills to engineers in the field, while reskilling refers to upgrading their pre-existing knowledge and skills for different jobs. The performance of engineers in the course outlined in this article was very high indicating their real engagement and motivation. For the participants, the training course was an excellent opportunity for learning novel technological solutions to manufacturing factory problems.

Despite the learning opportunities in this specific course, further co-operation between educational institutions and industry is essential in developing the engineering workforce's knowledge and skills required in the 21st Century. One alternative could be professional development programme prepared by both the industry and educational institutions, and addressing the needs and preferences of the industry while incorporating a proper pedagogical framework. [10]. It is critical to recognise that partnerships between educational institutions and the industry sector are essential to provide up-to-date knowledge, materials, technology, consultation and development facilities, and to achieve their objectives more effectively.

ACKNOWLEDGEMENTS

This research was funded by King Mongkut's University of Technology North Bangkok, Thailand. Contract no. KMUTNB-65-BASIC-08.

REFERENCES

1. Penesis, I., Barnes Katersky, R., Kilpatrick, S., Symes, M. and León de la Barra, B.A., Reskilling the manufacturing workforce and developing capabilities for the future. *Australasian J. of Engng Educ*, 22, **1**, 14-22 (2017).
2. Xu, S., Zhang, M. and Hou, L., Formulating a learner model for evaluating construction workers' learning ability during safety training. *Safety Science*, 116, 97-107 (2019).
3. Fung, M., *Developing a Robust System for Upskilling and Reskilling the Workforce: Lessons from the Skills Future Movement in Singapore*. In: Anticipating and Preparing for Emerging Skills and Jobs. Singapore: Springer, 321-327 (2020).
4. Doherty, O. and Stephens, S., The skill needs of the manufacturing industry: can higher education keep up? *Education+Training*. 63, **4**, 632-646 (2021).
5. Zheng, T., Ardolino, M., Bacchetti, A. and Perona, M., The applications of Industry 4.0 technologies in manufacturing context: a systematic literature review. *Inter J. of Production Research*, 59, **6**, 1922-1954 (2021).
6. Tabaa, M., Chouri, B., Saadaoui, S. and Alami, K., Industrial communication based on Modbus and node-RED. *Procedia Computer Science*, 130, 583-588 (2018).
7. Sicari, S., Rizzardi, A. and Coen-Porisini, A., Smart transport and logistics: a node-RED implementation. *Internet Technol. Letters*, 2, **2** (2019).
8. Nițulescu, I.V. and Korodi, A., Supervisory control and data acquisition approach in node-RED. *Application and Discussions. IoT*, 1, **1**, 76-91 (2020).

9. Chuquimarca, L., Asencio, A., Torres, W., Bustos, S., Sánchez, J. and Saldaña, C., *Evaluation of Data Transfer from PLC to Cloud Platforms-Based Real-Time Monitoring Using the Industrial Internet of Things*. In: Information and Knowledge in Internet of Things, Springer, Cham, 331-344 (2022).
10. Lawanto, O., Uziak, J., Villanueva, I. and Scheaffer, M., Continuing engineering education: a needs assessment for the introduction of a graduate certificate programme. *Global J. of Engng. Educ.,* 19, **3**, 186-193 (2017).

BIOGRAPHIES

Sasithorn Chookeaw is currently an assistant professor at the Department of Teacher Training in mechanical engineering in the Faculty of Technical Education at King Mongkut's University of Technology North Bangkok, Thailand. She received a BSc degree in technology education and an MSc degree in computer and information technology from King Mongkut's University of Technology Thonburi, Bangkok, Thailand, in 2005 and 2008 respectively. She received a PhD degree in science and technology education from Mahidol University, Bangkok, Thailand, in 2015. She is interested in technology-enhanced learning, technology in engineering education, personalised learning, professional development and training, educational robotics, and industrial education.

Suppachai Howimanporn is currently an assistant professor with a major in mechatronics engineering in the Department of Teacher Training in Mechanical Engineering in the Faculty of Technical Education at King Mongkut's University of Technology North Bangkok, Thailand. He received his BEng in electrical engineering, and a MEng in control engineering from King Mongkut's Institute of Technology Ladkrabang, Thailand, in 1999 and 2004, respectively. In 2014, he received DEng degree in mechatronics from the School of Engineering and Technology at the Asian Institute of Technology, Thailand. He is a professional trainer in automated control systems for many industries. He is interested in optimisation algorithms in control systems, industrial robotics, automation system and mechatronics engineering.