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Enhancing Workforce Skills in Industry 4.0 through an E-Book on KUKA Robot Control and Maintenance

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Abstract

This study aimed to develop, evaluate, and determine the efficiency and effectiveness of an e-book on KUKA industrial robot control and maintenance. The e-book was designed to support both theoretical understanding and hands-on competencies, addressing the growing need for skilled personnel in the context of Industry 4.0. Its structure comprised five instructional units, instructional videos, end-of-unit tests, and reference materials. The quality of the e-book was assessed by five experts in content and instructional media, who rated it at a high level of quality (content: $\bar{x}$ = 4.34, SD = 0.51; media: $\bar{x}$ = 4.33, SD = 0.57). Efficiency analysis yielded E1/E2 = 85.13/81.13, exceeding the 80/80 standard. Effectiveness testing showed that post-test scores ($\bar{x}$ = 186.60, SD = 8.09) were significantly higher than their pre-test scores ($\bar{x}$ = 126.07, SD = 13.07), with results significant at the .001 level. These findings confirm the e-book's effectiveness in enhancing learning achievement. The study highlights the value of digital learning platforms in robotics education and workforce development. The e-book offers a flexible resource that extends learning beyond face-to-face training and effectively strengthens technical competencies for industrial robotics.

Keywords: Industry 4.0, KUKA robot, E-Book, Enhancing skills

Introduction

The adoption of industrial robots is widely recognized as a key enabler of smart manufacturing under the Industry 4.0 framework. Industrial robots are no longer confined to simple pick-and-place or assembly tasks; rather, they are increasingly integrated into flexible, precise, and adaptive production systems. To meet these evolving demands, robot control systems have significantly advanced, encompassing real-time data analytics, user-friendly programming interfaces, and seamless interoperability with industrial networks (Bilancia et al., 2023; Soori et al., 2024). Beyond control, maintenance has emerged as a critical factor influencing system

availability and cost-effectiveness. Traditional corrective and preventive maintenance strategies are being replaced by predictive approaches that leverage sensor data, machine learning algorithms, and Industrial Internet of Things (IIoT) platforms to anticipate anomalies and optimize repair schedules. Predictive maintenance reduces unplanned downtime, improves asset utilization, and extends robot lifespan (Bilancia et al., 2023; Soori et al., 2023; Rahman et al., 2023; Soori et al., 2024; Qiu et al., 2025; Wojtulewicz & Chaber, 2025).

Globally, the robotics market is expanding rapidly, driven by Industry 4.0, Artificial Intelligence (AI), and IoT. Industrial robots have become indispensable in sectors such as automotive, electronics, and logistics, while service robots are emerging as key drivers of growth, addressing challenges such as aging populations, labor shortages, and the demand for efficiency in service delivery and household tasks (International Federation of Robotics: IFR, 2023). However, challenges remain in research and development, interoperability standards, local production capacity, and workforce reskilling (Lamsam & Insawath, 2024). In Thailand's manufacturing sector, robotics and automation are playing an increasingly important role due to labor shortages, heightened safety requirements, and government policies such as Thailand 4.0. Small and Medium-sized Enterprises (SMEs), in particular, are adopting robots to replace human labor in hazardous or labor-intensive environments. The declining cost of robotic technologies has further enhanced accessibility. Nevertheless, successful implementation requires workforce upskilling and reskilling to ensure effective operation (International Labour Organization, 2024).

Recognizing this need, the Bachelor of Technical Education Program in Electronics and Automation Engineering at Rajamangala University of Technology Thanyaburi has prioritized human resource development in industrial robotics. Instruction and training in this field have primarily been delivered in face-to-face and onsite formats. However, for greater effectiveness, supplementary learning media and instructional materials in the form of digital learning platforms are essential. Such platforms enable anytime, anywhere access, allowing learners to study in advance or review theoretical concepts, technical skills, and practical exercises. Essalih et al. (2025) reported that digital learning platforms and innovative training approaches can enhance competencies and help address labor shortages. Increasing research highlights the importance of digital education and training platforms in meeting these challenges. For example, Arents and Greitans (2022) emphasized that AI- and IoT-enabled intelligent robotic systems can only achieve their full potential if engineers and operators possess sufficient competencies. Similarly, Wojtulewicz and Chaber (2025) demonstrated that embedding predictive diagnostics within control systems through industrial protocols not only improves system reliability but also creates valuable experiential learning opportunities for robotics education. Soori et al. (2023) further showed that maintenance training based on machine learning, integrating real-world sensor data, can effectively present predictive maintenance concepts without the need for additional hardware. Complementary research underscores that combining machine learning, digital twin simulations, and predictive maintenance enhances robotic precision, minimizes downtime, and reduces costs, while simultaneously fostering human–robot collaboration and ensuring workplace safety (Bilancia et al., 2023). On a broader scale, Qiu et al. (2025) identified IoT and IIoT as critical enablers of smart manufacturing, providing real-time connectivity, flexible production, and predictive maintenance, though challenges remain regarding cybersecurity, interoperability, and workforce skills.

In this context, the development of an interactive e-book on industrial robot control and basic maintenance of KUKA robots accessible anytime and anywhere represents a timely and valuable initiative. Such a resource can provide structured knowledge on robot programming, control commands, and safety measures, while also introducing predictive maintenance strategies aligned with Industry 4.0 practices. By integrating theoretical foundations with practical case studies, this e-book is designed to serve both as a training tool and as a reference document for engineers, technicians, and operators. Ultimately, this initiative is expected to contribute to the development of a skilled workforce capable of driving Thailand's transition toward smart manufacturing.

Methodology

This study employed a research and development (R&D) design, aiming to create, validate, and implement an instructional electronic book (e-book) on KUKA industrial robot control and basic maintenance. The development process followed a structured sequence aligned with the National Skill Standard program in Mechatronic and Industrial Robotics Technician Level 1 (Course code: 1020024190201) (Department of Skill Development: DSD 2025), ensuring that the training content corresponded to recognized industrial competencies. The methodology comprised five main phases: (1) content analysis, (2) instructional material development, (3) e-book creation, (4) quality validation, and (5) implementation and effectiveness testing.

Research Objectives

The methodology of this study was guided by three main objectives. The first objective was to develop an e-book designed for teaching KUKA industrial robot control and basic maintenance. The second objective was to evaluate the quality of the e-book, with a particular focus on content accuracy and the appropriateness of its instructional media design. Finally, the third objective was to assess the effectiveness of the e-book in enhancing learners' knowledge and practical competencies related to industrial robot operation and maintenance.

Development Procedures

Content Analysis

Relevant documents, standards, and curricular frameworks were reviewed to ensure consistency with professional competencies. In particular, the National Skill Standard for Mechatronics and Industrial Robotics Technician Level 1 was employed as a primary reference. We selected only the Industrial Robotics part for the e-book creation. Based on this standard, the instructional content was systematically organized into five units. The first unit focused on industrial safety practices, including the proper use of protective equipment, interpretation of safety symbols, hazard prevention measures, and basic first aid. The second unit addressed the fundamentals of industrial robotics, covering definitions, significance, types of robots, and their benefits in modern industry. The third unit introduced KUKA robot components and control systems, such as configuration, the SmartPAD, SmartHMI, controllers, and motion systems. The fourth unit emphasized the programming of KUKA robots for applied tasks, including trajectory programming, pick-and-place operations, and shape drawing. Finally, the fifth unit concentrated on preventive maintenance and troubleshooting, which encompassed inspection procedures, maintenance checklists, scheduling, error detection, and corrective actions to ensure the reliability and longevity of the robotic system.

Structure and Content of Learning Units

Instructional units were developed into learning sheets with clear behavioral objectives, summarized content, illustrations, and structured exercises. Drafts were reviewed for accuracy, clarity, and alignment with learning goals.

Assessment Development

Achievement tests were designed to measure learning outcomes across all units. Content validity was verified by five experts using the Item-Objective Congruence (IOC) index. Items with IOC values above 0.50 were retained, while those below were revised according to expert feedback. A total of 230 items were initially developed, and validated items were used in subsequent evaluations.

E-book Production

The e-book was structured with standard components, including a cover, preface, table of contents, instructional units, end-of-unit tests, references, and back cover. To enhance understanding and practical engagement, the e-book also incorporates three instructional video clips, covering introductory guidance, programming demonstrations, and step-by-step maintenance procedures. In addition, end-of-unit tests and corresponding answer keys were provided to assess and reinforce learners' knowledge, while references were included to support the academic credibility of the material. Together, these components ensured that both theoretical and practical aspects of industrial robot control and maintenance were comprehensively addressed. Video editing was performed using CapCut, with resolution optimized at 1080p for online distribution.

Figure 1. Example of an e-book

Quality Validation

We collaborated with industrial robotics experts and instructional media specialists in digital learning, with five experts in each field. Content and media evaluation data were collected using structured assessment forms, and the results were analyzed through mean scores ($\bar{x}$) and standard deviations (SD).

Content Quality

The e-book content was evaluated by five experts in robotics and industrial education. Assessment criteria included clarity of objectives, accuracy, comprehensiveness, appropriateness of sequencing, and engagement of content. Ratings were provided using a 5-point Likert scale, ranging from 1 (least appropriate) to 5 (most appropriate).

Instructional Media Quality

The instructional media design was validated by five experts in educational technology. The evaluation criteria included clarity of presentation, appropriateness of text and visuals, creativity, interactivity, and alignment with pedagogical principles. Mean scores and standard deviation were calculated to determine the quality level, interpreted according to a five-level scale (from "least appropriate" to "most appropriate").

Population and Sample

The sample group consisted of 15 participants purposively selected from a robotics training program. These participants were individuals with an interest in the field who voluntarily applied for training in industrial robot control and maintenance in response to the program's admission announcement.

Data Collection and Analysis

In Thai educational research, the efficiency of instructional packages is typically assessed using two indices: E1 and E2. E1 (process efficiency) reflects learners' performance during instruction, based on formative assessments or practice, while E2 (outcome efficiency) measures performance after instruction through post-tests or performance tests. The standard criterion, known as 80/80, indicates that effective packages should achieve at least 80% in both indices (Brahmawong, 2013). Subsequently, learning effectiveness was examined by comparing learning achievement, in which pre-tests and post-tests were administered to the sample group (Latimier et al., 2019).

Figure 2. The learning environment during the training

Results and Analysis

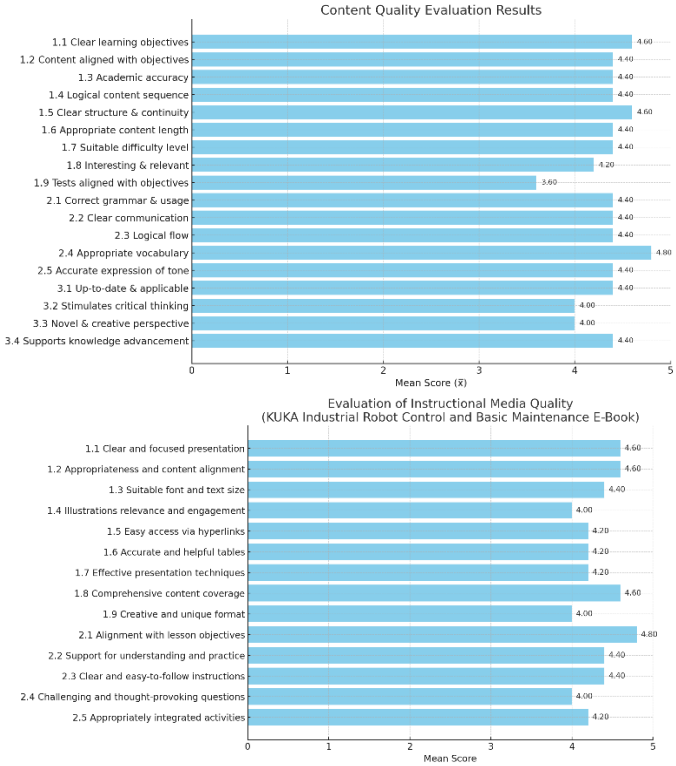
The research aimed to develop, evaluate, and determine the efficiency and effectiveness of an e-book on KUKA industrial robot control and maintenance. The outcomes of the study are summarized as follows:

Content Quality

Five experts evaluated the e-book's content across criteria such as clarity of learning objectives, accuracy, sequencing, and language use. The results indicated an overall mean score of 4.34 (SD = 0.51), corresponding to a "high" level of quality. The highest-rated items included clarity of learning objectives ($\bar{x}$ = 4.60, SD = 0.49) and logical content structure ($\bar{x}$ = 4.60, SD = 0.49). This suggests that the content was accurate, well-organized, and suitable for the target learners.

Instructional Media Quality

The e-book's media design was also evaluated by five experts. The results yielded an overall mean score of 4.33 (SD = 0.57), also at a "high" level of quality. The strongest features were clarity of presentation ($\bar{x}$ = 4.60, SD = 0.49), relevance of media to content ($\bar{x}$ = 4.60, SD = 0.49), and alignment of activities with learning objectives ($\bar{x}$ = 4.80, SD = 0.40). These findings confirm that the media components effectively supported learning, engagement, and comprehension.



(a) Content quality evaluation results (b) Instructional media quality results

Figure 3. Content and instructional media quality results

Efficiency and Effectiveness Analysis

The test scores collected before training, the scores from end-of-unit assessments, and the post-training achievement test scores were used to evaluate both the efficiency and effectiveness of the training program on KUKA industrial robot control and basic maintenance, as shown in Table 1.

Table 1
Pre-test, end-of-unit test, and post-test scores of training achievement on KUKA industrial robot control and maintenance

Participant	The Pre-Test of Training Achievement Scores (230)	Scores from Unit Tests (Points)						The Post-Test of Training Achievement Scores (230)
		Unit 1 (30)	Unit 2 (60)	Unit 3 (50)	Unit 4 (40)	Unit 5 (50)	Total (230)	
1	122	25	40	46	33	40	184	180
2	131	21	49	40	35	42	187	181
3	121	18	53	46	37	44	198	182
4	132	25	53	44	34	47	203	183
5	132	20	55	42	37	44	198	186
6	128	21	57	46	37	43	204	182
7	145	22	57	47	39	46	211	190
8	122	28	51	44	35	45	203	184
9	131	20	51	43	29	47	190	188
10	101	19	48	41	30	39	177	185
11	153	20	56	45	33	45	199	214
12	112	22	57	43	32	46	200	187
13	131	18	50	44	30	45	187	185
14	111	25	54	45	32	40	196	188
15	119	21	57	42	36	44	200	184
Total	**1891**	**325**	**788**	**658**	**509**	**657**	**2937**	**2799**
Average	**126.07**	**–**	**–**	**–**	**–**	**–**	**195.80**	**186.60**

Table 2
Efficiency of the development of the E-Book on KUKA industrial robot control and maintenance

Item	Number of Training participants	Full Score	Mean Score	Percentage	Criterion (%)
Scores from end-of-unit tests (five units) (E1)	15	230	195.80	85.13	80
Scores from the achievement test (E2)	15	230	186.60	81.13	80

Training participants' performance data were analyzed to determine the efficiency of the e-book using the 80/80 criterion. Results revealed an E1 score of 85.13% (process efficiency) and an E2 score of 81.13% (outcome efficiency) as shown in Table 2. Both indices exceeded the 80/80 standard, confirming that the e-book enabled learners to perform successfully during learning activities and achieve the intended learning outcomes in both theoretical and practical aspects.

Table 3
Paired sample t-test results of training achievement (N = 15)

Test	Mean ($\bar{x}$)	SD	t	df	p-value
Pre-test	126.07	13.07			
Post-test	186.60	8.09	21.64	14	< .001 ***

*** p < .001

The results indicate that learners' post-test scores ($\bar{x}$ = 186.60) were significantly higher than their pre-test scores ($\bar{x}$ = 126.07). The difference was statistically significant at the .001 level, suggesting that the instructional e-book on KUKA industrial robot control and basic maintenance was effective in enhancing learning achievement.

Discussion

The findings of this study demonstrate that the developed e-book on KUKA industrial robot control and maintenance achieved high quality and effectiveness. Expert evaluations confirmed its clarity, accuracy, and suitability for learners, while efficiency scores (E1 = 85.13%, E2 = 81.13%) exceeded the 80/80 standard. Moreover, post-test scores were significantly higher than pre-test scores ($t = 21.64$, $p < .001$), indicating that the e-book effectively enhanced both theoretical understanding and practical competencies. These results align with broader research emphasizing the importance of digital learning platforms in preparing a skilled workforce for Industry 4.0. Essalih et al. (2025) highlighted the role of such platforms in addressing labor shortages and improving competencies, while Arents and Greitans (2022) stressed that AI- and IoT-enabled robotic systems require operators with sufficient technical skills. Similarly, Soori et al. (2023) demonstrated that integrating machine learning and predictive maintenance concepts into training improves both system reliability and hands-on learning. By providing accessible, structured materials that integrate safety, programming, and maintenance practices, this e-book supports workforce development and complements initiatives such as Thailand 4.0, which emphasize digitalization and smart manufacturing.

Conclusion

This study developed and evaluated an e-book on KUKA industrial robot control and basic maintenance, with results showing high quality in both content and instructional media. Efficiency analysis (E1 = 85.13%, E2 = 81.13%) exceeded the 80/80 criterion, and learners' post-test scores were significantly higher than their pre-test scores, confirming the effectiveness of the e-book in enhancing learning achievement. The outcomes demonstrate that structured digital learning resources can strengthen learners' knowledge, skills, and competencies, particularly in areas crucial to Industry 4.0. By integrating theoretical content with practical applications, the e-book provides a flexible and accessible tool for workforce preparation. Overall, the study supports the adoption of digital instructional materials as an essential complement to traditional training in robotics education and vocational development.

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