Development and Efficiency Evaluation of an Experimental Inverter Air Conditioner System for Training.

Tritthaporn Kaew Sook[1] and Niran Watchrodom[1]

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Abstract

The objectives of this research were: (1) to develop and determine the efficiency of an inverter air conditioning system training unit, and (2) to study student learning achievement and satisfaction towards the developed training unit. The sample group consisted of 30 undergraduate students enrolled in the Refrigeration and Air Conditioning course. The research instruments included the inverter air conditioning training unit with accompanying laboratory manuals, a learning achievement test, and a satisfaction questionnaire. Data was analyzed using mean, standard deviation, dependent samples t-test, and the E_1/E_2 efficiency formula.

The results of the research revealed that: (1) the efficiency of the developed inverter air conditioning training unit was 80.08/83.33, which met the established 80/80 criteria; (2) the students' post-test scores were significantly higher than their pre-test scores at a 0.01 level of statistical significance; and (3) the students' satisfaction with the training unit and the learning method was at a high level. These findings indicate that the developed training unit is an effective instructional tool for practical application in related courses.

Keywords: efficiency, experimental set construction, Learning Achievement, inverter air conditioning system

[1] Department of Mechanical Engineering, Faculty of Industrial Education,
Rajamangala University of Technology Suvarnabhumi
*Corresponding Author.; E-mail address: niran.w@rmutsb.ac.th

Introduction

The educational challenges in 21st century Thailand extend beyond ensuring equitable access for all learners. A paramount objective is to enhance educational value by fostering student well-being alongside the development of high-efficiency skills applicable to real-world contexts (Thanalertsomboon, 2021). Amid rapid social shifts and technological disruptions, educational management must prioritize transformative learning to cultivate student competencies essential for navigating the modern era (Panumat et al., 2021). This alignment supports the "Thailand 4.0" policy, which drives national progress through innovation across various sectors, including Education 4.0 and Industry 4.0 (Paitoon, 2016). Consequently, modernizing the education system is a critical factor in human capital development and national advancement.

The transition toward a digital society has profoundly influenced consumption patterns and energy utilization (Department of Alternative Energy Development and Efficiency, 2020). Currently, rising temperatures in Thailand have led to a significant increase in the installation of air-conditioning systems. Statistical data reveal that over 60% of total energy consumption in industrial sectors and residential buildings is attributed to refrigeration and air-conditioning systems. In response, modern households are increasingly adopting inverter technology to optimize energy efficiency (Niran, 2018). Nevertheless, the pedagogical delivery of "Refrigeration and Air Conditioning Laboratory" courses faces substantial environmental and infrastructural challenges.

A primary concern is the inadequacy of experimental tools and equipment, particularly regarding the complex control systems and electronic circuitry of inverter technologies. Many educational institutions lack modern demonstration kits that align with current industry standards and curricular objectives, resulting in a mismatch between instructional activities and required technical skills. Furthermore, insufficient instructional media adversely affects student achievement. Theoretical instruction alone is insufficient for students to internalize abstract concepts that are not visible to the naked eye. The absence of practical laboratory kits deprives learners of the opportunity to simultaneously develop cognitive and psychomotor skills in simulated environments.

To address these critical issues, this study aims to develop an "Inverter Air Conditioning System Experimental Kit" as an effective instructional medium. This apparatus is designed to simulate authentic operational scenarios, enabling students to engage in deep learning and achieve concrete learning outcomes. Ultimately, this innovation seeks to modernize educational quality and ensure its relevance to contemporary technological advancements.

Objectives

1. To develop and determine the efficiency of the Inverter Air Conditioning System.

2. To compare the academic achievement of students before and after using the Inverter Air Conditioning System Experimental Kit.

3. To evaluate student satisfaction regarding the implementation of the developed Inverter Air Conditioning System Experimental Kit.

Conceptual Framework

The conceptual framework for this study is based on a Research and Development (R&D) model, structured as follows:

1. Independent Variable: Implementation of Problem-Based Learning (PBL) integrated with the developed Inverter Air Conditioning System Experimental Kit and accompanying worksheets.

2. Dependent Variables: Efficiency of the Experimental Kit based on the established criteria, Academic Achievement of student's post-implementation and Student Satisfaction regarding the use of the experimental kit and instructional worksheets.

Hypotheses

1. The quality and appropriateness of the developed inverter air conditioning instructional worksheets were evaluated by a panel of experts.

2. The developed inverter air conditioning system experimental kit achieved the specified efficiency criteria.

3. Students who learned through problem-based learning (PBL) combined with the developed experimental kit had significantly higher post-test scores than pre-test scores.

Methodology

This study focused on the development and efficiency evaluation of an inverter air conditioning system experimental kit. A systematic approach was adopted to ensure the validity and effectiveness of the instructional materials, including phases of design, expert validation, implementation, and evaluation. The detailed research procedures are presented as follows:

1. Research Procedures and Efficiency Evaluation

The research and development process was conducted through five systematic phases as follows:

1.1 Design Phase: This stage involved a comprehensive review of relevant literature, existing research, and inverter air conditioning theories. The data collected were synthesized to develop instructional worksheets, prioritizing structural detail, clarity, and ease of comprehension for the learners.

1.2 Expert Evaluation: The developed experimental kit and accompanying worksheets were submitted to a panel of five experts. Using a standardized suitability assessment form, the experts evaluated the academic and technical quality of the media. Feedback and suggestions provided were subsequently utilized to refine and finalize the instructional tools.

1.3 Implementation: The validated instructional materials were implemented with a sample group of 30 undergraduate students.

1.4 Evaluation: The efficiency of the experimental kit was determined using the E_1/E_2 efficiency formula. Furthermore, student satisfaction levels regarding the use of the kit were assessed.

1.5 Conclusion: Statistical analysis was conducted to interpret the data and draw conclusions in accordance with the research objectives and hypotheses.

2.. Population and Sample

The sample for this research comprised 30 undergraduate students majoring in Mechanical Engineering within the Faculty of Industrial Education at Raja Mangala University of Technology Suvarnabhumi, Shambari Center. These participants were enrolled in the Refrigeration and Air Conditioning Laboratory course during the first semester of the 2022 academic year. The sample was selected through purposive sampling.

3. Research Instruments

3.1 Inverter Air Conditioning System Experimental Kit: Technical Specifications: Cooling capacity of 11,942 BTU/hr.; power consumption of

1,000 Watts; operating current of 4.8 Amperes; utilizing R32 refrigerant.

3.2 Operational Worksheets: A series of five instructional modules were developed

1. Installation of small-scale air conditioning systems.

2. Refrigerant cycle analysis.

3. Evacuation (vacuuming) and refrigerant charging procedures.

4. Electrical circuitry for inverter-based air conditioners.

5. Diagnostic and troubleshooting techniques for inverter systems.

3.3 Evaluation Forms: These include a quality assessment form for expert review and a student satisfaction questionnaire utilizing a 5-point Likert scale.

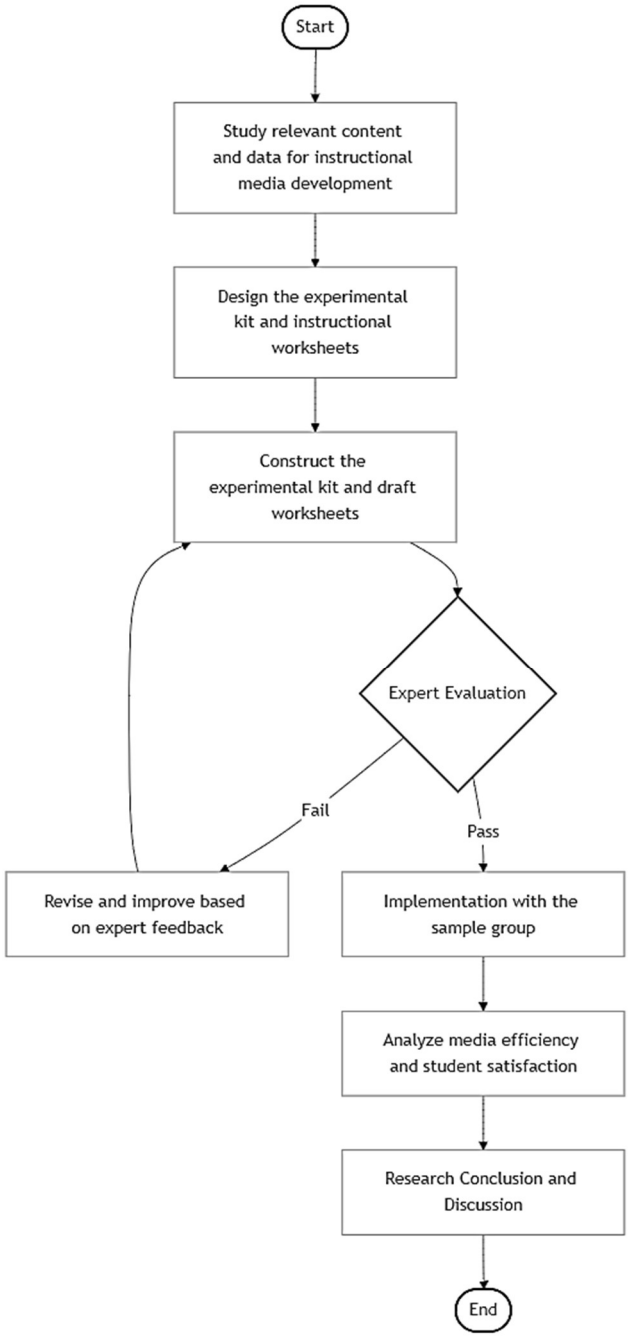


Figure 1: Research Action Plan.

4. Achievement Test Development

To measure the instructional efficacy of the experimental kit, an academic achievement test was developed through the following steps:

- A Table of Specifications (TOS) was established to align core content with behavioral learning objectives.

- A 10-item assessment tool was constructed, serving as both a Pre-test and Post-test to quantify the knowledge gain and skill advancement of the learners.

5. Data Collection

Data collection was conducted in sequential steps. Initially, the instructional materials were evaluated by experts. Subsequently, the materials were implemented with the sample group over a period of three weeks. Data collected included process scores during learning (E1), post-test scores (E2), and students' satisfaction ratings. These data were then analyzed for further interpretation.



Figure 2: Front view of the experimental kit.



Figure 3: Rear aspect of the developed experimental kit

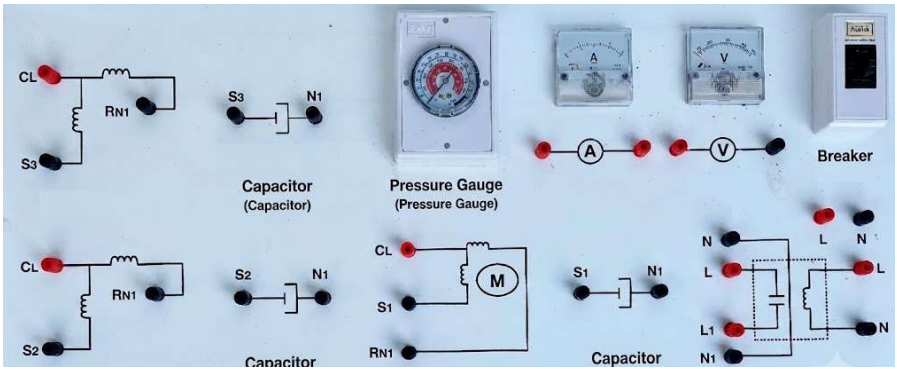


Figure 4: Electrical circuit diagram.

Results and discussion

The implementation of the Inverter Air Conditioning Training System within the Refrige-ration and Air Conditioning Laboratory curriculum yielded significant findings. The apparatus underwent a dual-stage validation process: a technical review by five subject matter experts and a satisfaction survey involving a cohort of 30 students. Additionally, the pedagogical efficiency of the accompanying job sheets was rigorously calculated.

1. Statistical Framework To process the gathered data, the following analytical tools were utilized:

1.1 Descriptive Statistics, the fundamental quantitative data were analyzed using:

1) Arithmetic Mean ($\bar{x}$): This metric was employed to identify the central tendency of the evaluation scores, calculated via the formula

$$\bar{x} = \frac{\sum x}{N} \quad (1\text{-}1)$$

When

$\bar{x}$ Mean score

$\sum x$ Total summation of the group scores.

N Total sample size

2. Standard Deviation (S): The variability and dispersion of the evaluation scores were computed utilizing the following equation 1-2

$$S = \sqrt{\frac{N\sum x^2 - \left(\sum x\right)^2}{N\left(N-1\right)}} \quad (1\text{-}2)$$

When

S Sample standard deviation

x Individual evaluation scores.

$\sum x$ Summation of the respective values.

N Total number of respondents.

1.2 Psychometric Evaluation of the Research Instrument.

The item discrimination index yields coefficients ranging between -1.00 and 1.00, which are mathematically classified into positive values (0.01 to 1.00) and negative values (-1.00 to -0.01). The interpretation of this statistical metric governs the validation and retention of each instrument item based on the following criteria:

- Positive Coefficients (0.01 to 1.00): A positive index demonstrates that the item exhibits adequate discriminative power. This signifies that the specific question effectively measures the intended construct and aligns precisely with the research objectives, confirming its suitability for final application.

- Negative Coefficients (-1.00 to -0.01): Conversely, a negative value indicates a severe deficiency in discriminative capacity. This implies that the item fails to assess the designated objective properly, thereby necessitating the immediate exclusion of the question from the evaluation tool.

- Zero Index (0.00): A value of zero reflects a complete lack of discriminative ability. Items falling into this category are deemed ineffective and should either be permanently discarded or undergo comprehensive revision prior to subsequent utilization.

1.3 Content Validity Evaluation

To ensure the research instruments precisely aligned with the defined curricular domains, the content validity of both the academic achievement test and the learning attitude scale was rigorously evaluated. This verification process was executed utilizing the Index of Item-Objective Congruence (IOC) in accordance with Equation (1-3)

$$IOC = \frac{\sum R}{N} \quad (1\text{-}3)$$

When

IOC The congruence index among test items, behavioral objectives, and content.

$\sum R$ Sum of expert evaluation scores.

N Number of evaluating experts.

1.4 Instructional Efficiency E_1 / E_2

The evaluation of the training system E_1 / E_2 utilized the efficiency framework, setting the benchmark at 80/80 for both Applied Knowledge (A) and Transferred Knowledge (T). This standard serves to compare process learning scores against final summative outcomes. While criteria can range from 70/70 for fundamental levels to 90/90 for advanced cohorts, the 80/80 threshold was selected to match the specific complexity of this subject.

E_1 (Process Efficiency): The percentage of the mean score derived from in-class formative assignments, including laboratory job sheets, practical exercises, and quizzes. These values can be calculated using the following equations:

$$E_1 = \frac{\overline{x_1}}{N_1} \times 100 \quad (1\text{-}4)$$

When

E_1 Process Efficiency

$\overline{x}$ The average score obtained from all formative activities and job sheets.

N_1 The total parallel score possible from those continuous assessments.

E_2 (Product Efficiency): The percentage of the mean score achieved from the final post-test administered upon course completion. Calculated via the following equations:

$$E_2 = \frac{\overline{x_2}}{N_2} \times 100 \quad (1\text{-}4)$$

When

E_2 Product Efficiency

$\overline{x_2}$ The cumulative score of all participants from the summative post-test.

N_2 The total number of students within the cohort.

2. Expert Validation Outcomes.

To ascertain the suitability of the inverter air conditioning training apparatus and the integrated laboratory job sheets, a comprehensive evaluation was executed by a panel of five subject matter experts. The research instrument incorporated a 5-point Likert rating scale to capture expert feedback, which was subsequently quantified and categorized into five hierarchical levels of appropriateness. The statistical mean thresholds for data interpretation were defined as follows

4.50 – 5.00: Highly Appropriate

3.50 – 4.49: Appropriate

2.50 – 3.49: Moderately Appropriate

1.50 – 2.44: Inappropriate

0.0 – 1.44: Highly Inappropriate

Table 1 Expert evaluation results for the laboratory worksheet.

Evaluation Items	$\overline{x}$	SD	**Qualitative Level**
1. The worksheets are appropriately designed for the learners' level.	4.60	0.55	Highly Appropriate
2. The worksheet enhances practical skills in air conditioning electrical wiring.	4.60	0.55	Highly Appropriate
3. The visual appeal and engagement of the worksheet.	3.80	0.84	Appropriate
4. Alignment between the worksheet and the learning objectives.	4.00	0.71	Appropriate
5. Appropriateness of technical terminology.	4.20	0.84	Appropriate

Table 1 Expert evaluation results for the laboratory worksheet. (Continued)

Evaluation Items	$\overline{x}$	SD	Qualitative Level

Table 1 (Continued).

Evaluation Items	$\bar{x}$	SD	Qualitative Level
6. Structural clarity and layout layout of the worksheet.	3.80	0.45	Appropriate
7. Overall suitability of the worksheet format.	4.20	0.84	Appropriate
8. Clarity of the step-by-step instructions provided on the sheet.	4.00	0.71	Appropriate
9. The worksheet effectively stimulates students' learning processes.	4.00	0.71	Appropriate
10. Logical sequencing of the tasks and procedures within the worksheet.	4.40	0.55	Appropriate
The overall mean score ($\bar{x}$)	4.16	0.34	

According to the statistical data presented in table 1 indicates that the laboratory worksheet achieved an overall mean score ($\bar{x}$) of 4.16(S.D. = 0.34), verifying that the developed in-structional materials are statistically appropria

Table 2 Expert evaluation results for the experimental setup.

Evaluation Items	$\bar{x}$	$S.D.$	Qualitative Level
1. Appropriateness of the physical dimensions of the experimental setup.	4.60	0.55	Highly Appropriate
2. Ergonomic design and aesthetic appeal that motivate learning.	4.60	0.55	Highly Appropriate
3. Suitability of the component positioning and layout.	3.60	0.89	Appropriate
4. Structural durability and robustness of the training unit.	3.80	0.84	Appropriate
5. Quality and appropriateness of the materials used in construction.	4.20	0.84	Appropriate
6. Ease of equipment maintenance and servicing.	3.80	0.45	Appropriate
7. Alignment between the experimental setup and the laboratory sheets.	4.20	0.84	Appropriate
8. Practicality and convenience of the experimental setup process.	4.00	0.45	Appropriate
9. Operational safety features during experimental procedures.	4.00	0.84	Appropriate
10. Academic and pedagogical value of the experimental setup.	4.60	0.55	Highly Appropriate
The overall mean score ($\bar{x}$)	4.14	0.37	

Table 2 indicates that the experimental setup achieved an overall mean score ($\bar{x}$) of 4.14 (S.D. 0.37), verifying that the developed hardware is statistically Appropriate.

3. Efficiency Evaluation of the laboratory worksheets.

The developed laboratory worksheets were implemented with a sample cohort of 30 students (N = 30). The empirical scores obtained from both continuous assessments and final evaluations were statistically analyzed to determine the instructional efficiency (E_1 / E_2) based on the participants' academic achievements. The corresponding statistical outcomes are detailed in Tables 3 and 4.

Table 3 Student academic progress and process efficiency (E_1) from laboratory worksheets.

laboratory worksheets	$\sum x$	$\bar{x}$	S.D.	E_1
Topic 1	222	7.40	0.62	73.33
Topic 2	245	8.17	0.37	81.00
Topic 3	246	8.20	0.40	81.33
Topic 4	248	8.27	0.44	82.00
Overall Process Efficiency				80.08

The empirical data in Table 3 indicate that the student cohort (N = 30) achieved an average score of 80.08% across all four laboratory assignments, successfully surpassing the predefined 80% efficiency benchmark.

Table 4 Student academic achievement (E_2)

laboratory worksheets	$\sum x$	$\bar{x}$	S.D.	E_1
Topic 5	250	8.33	0.47	83.33
Overall Process Efficiency				83.33

The data in Table 4 reveal that the student sample (N = 30) achieved a mean score of 83.33% on the final laboratory task, successfully exceeding the established 80% threshold. Conclusively, the empirical findings consolidated from Tables 3 and 4 indicate that the developed instructional worksheets for the inverter air conditioning training apparatus yielded an overall efficiency (E_1 / E_2) of 80.08/83.33. This outcome statistically surpassed the predefined 80/80 efficiency benchmark, confirming the pedagogical effectiveness of the developed materials.

4. Efficiency Evaluation of the Inverter Air Conditioning Training Apparatus.

The instructional efficiency of the developed training apparatus was determined by analyzing the proportional relationship between the percentage scores obtained from the formative (continuous) and summative (post-learning) assessments. These statistical values are detailed in Table 5.

Table 5 Percentage Scores of Formative and Summative Assessments.

Score	Formative Score	Summative Score
Percentage (%)	77.66	81.66

Based on the empirical evidence in Table 5, the instructional efficiency ratio of the developed inverter air conditioning training apparatus was determined to be 77.66/81.66, demonstrating statistical consistency with the pedagogical framework.

5. Student Satisfaction and Pedagogical Outcomes

The developed instructional worksheets and training apparatus were deployed with a sample cohort of 30 undergraduate students en-rolled in the Refrigeration and Air Conditioning Laboratory course. Post-implementation assessments revealed substantial formative progression in the students' learning

outcomes. Furthermore, the evaluation of student perception indicated that the overall satisfaction toward the training apparatus was sustained at a high level.

Table 6 Student Satisfaction Evaluation Results.

Evaluation Items	$\bar{x}$	$S.D.$
1. The laboratory worksheets are appropriately designed for the learner's level.	4.60	0.54
2. The tasks effectively enhance circuit assembly and system-level skills.	4.60	0.54
3. Aesthetic appeal and overall interest in the instructional materials.	4.40	0.54
4. Direct alignment between the worksheets and intended learning objectives.	4.40	0.54
5. Technical accuracy and grammatical correctness of the language used.	3.60	0.54
6. Clarity and legibility of the worksheet formatting.	3.80	0.44
7. Layout appropriateness and professional presentation of the materials.	4.00	0.70
8. Clarity and precision of the step-by-step procedural instructions.	3.80	0.44
9. The worksheet structure stimulates and engages the students' learning process.	4.20	0.83
10. Appropriate chronological sequencing of the assigned laboratory tasks.	4.80	0.44
The overall mean score	4.22	0.37

According to the empirical data in Table 6, the student satisfaction evaluation regarding the deve-loped laboratory worksheets yielded an overall mean score ($\bar{x}$) of 4.22 (S.D. = 0.37). This statistical outcome demonstrates that the learners' perception toward the instructional materials sits securely within the high satisfaction level.

Conclusion

This research presented the design, development, and efficiency evaluation of an instructional training apparatus along with its corre-sponding laboratory worksheets. Based on the empirical findings, the research outcomes can be concluded and discussed as follows:

1. Expert Evaluation Outcomes.

The suitability of the developed inverter air conditioning training apparatus and worksheets was assessed by a panel of five experts using a 5-point Likert scale. The evaluation revealed that the laboratory worksheets achieved an overall mean score ($\bar{x}$) of 4.16, while the training apparatus secured a mean score of 4.14. Both components were statistically interpreted within the "High" suitability tier. This confirms that the mechanical and pedagogical design of the training system meets professional and academic standards.

2. Efficiency Evaluation of the Laboratory worksheets.

The implementation of the worksheets with a sample cohort of 30 students demonstrated

that the process efficiency (E_1), derived from the progression scores of Job Sheets 1–4, averaged 80.08%. Furthermore, the product efficiency (E_2), evaluated from the achievement score of Job Sheet 5, reached 83.33%. Consequently, the efficiency ratio of the developed job sheets was established at 80.08/83.33, successfully surpassing the predefined 80/80 performance benchmark.

3. Efficiency Evaluation of the Inverter Air Conditioning Training Apparatus.

The operational efficiency of the inverter air conditioning training apparatus was assessed based on the students' academic achievements. The average score obtained from the formative (during-learning) assessment was 77.66%, which then increased to 81.66% in the summative (post-learning) assessment. This yielded an overall apparatus efficiency ratio of 77.66/81.66, confirming its pedagogical effectiveness in driving student learning progression.

4. Student Satisfaction and Outcomes

Following the instructional integration within the Refrigeration and Air Conditioning Laboratory course, the students demonstrated substantial learning development. The evaluation of student perception indicated that the learners were highly satisfied with the developed materials, yielding a composite satisfaction mean score of 4.22, which falls securely within the "High" satisfaction tier.

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Reference

Ananacha, T., Rattanabanlue, A., & Watcharodom, N. (2024). Enhancement of split-type air conditioner by improving the cooling system for residence. International Journal of Science and Innovative Technology, 7(1), 89–99.

Hiranyapanich, K. (2005). Development of an experimental kit for digital signal processor (DSP) microprocessor interfacing [master’s thesis, King Mongkut's Institute of Technology Ladkrabang].

Jantrakul, W. (1987). Guidelines for designing instructional media: Demonstration equipment. Journal of Vocational Education, 12(3), 45–52.

Jantrakul, W. (2009). Instructional package design, construction, and efficiency evaluation: How to make it logical. Technical Education Journal for the Masses, (July-September), King Mongkut's University of Technology North Bangkok.

Maneewan, D., Nuangpirom, P., & Akatimagool, S. (2016). Development of an instructional package on waveguide iris circuits. Faculty of Industrial Education, King Mongkut's University of Technology North Bangkok.

Moasawang, W., Soontornganokpong, W., & Suwanjan, P. (2013). An experimental kit for LCD color television receivers. Faculty of Industrial Education, King Mongkut's Institute of Technology Ladkrabang.

Naknaka, P. (2009). Educational research course materials. Faculty of Education, Suan Dusit Rajabhat University.

Chinatrakul, R. (1995). Educational research methods. Faculty of Industrial Education, King Mongkut's Institute of Technology Ladkrabang.

Taweerat, P. (2010). Research methods in behavioral and social sciences. Bureau of Educational and Psychological Testing, Srinakharinwirot University Prasarnmit.

Phonrak, A., & Akatimagool, S. (2013). Construction and efficiency evaluation of a training package on microcontrollers and basic robot applications. Faculty of Industrial Education, King Mongkut's University of Technology North Bangkok.

Ruangsuwan, C. (1990). Educational technology: Theory and research. Odien Store Publishing.

Treeronathanakul, P. (1998). Practical teaching methods. King Mongkut's University of Technology Thonburi Press.

Watchrodom, N. (2018). Coefficient of performance increase for split-type air conditioners using heat loss