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Improving Refrigerant Flow Analysis and Diagnostic Reasoning among BTLED-IA 3 Students Through a Metacognitive Diagnostic Problem-Based Learning Approach with Realia Integration

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ABSTRACT

Understanding refrigerant flow, pressure–temperature relationships, and component functions is a core competency in Domestic Refrigeration and Air-Conditioning (DomRAC), yet students often struggle because these processes cannot be directly observed. This classroom-based action research examined written-test performance and diagnostic task outcomes among 20 third-year Bachelor of Technology and Livelihood Education–Industrial Arts (BTLED-IA) students at Davao Oriental State University following a four-week Metacognitive Diagnostic Problem-Based Learning (MD-PBL) intervention with realia integration. Using a single-group pre-test/post-test design, the intervention combined instructor think-aloud modeling, team diagnostic rotations following a Plan, Test, Monitor, and Fix Proposal sequence with an actual air-conditioning unit, manifold gauge, and diagnostic scenario cards, a defense symposium, and reflection journals. Data were gathered through content-validated 20-item written tests and four-point analytic rubrics for scenario analysis, practical demonstration, diagnostic defense, and reflection journals, and were analyzed using means, standard deviations, percentages, a paired-samples t-test, and Cohen's dz. Mean written-test scores increased from 10.95 (SD = 1.54; 54.75%) to 18.35 (SD = 1.04; 91.75%), a gain of 7.40 points, $t(19) = 15.85$, $p < .001$, $dz = 3.54$. Reported weighted rubric means were 3.78 for scenario analysis, 3.62 for demonstration, 3.38 for the defense symposium, and 3.56 for reflection journals, with planning, monitoring, and evaluation each rated 3.75. These ratings describe assessed performance rather than improvement from baseline. The written-test increase was associated with the intervention period, but the absence of a control group, unestablished test-form equivalence, and the lack of a reported reliability coefficient limit causal interpretation. The MD-PBL approach offers a structured, low-cost instructional sequence for further classroom use and evaluation in refrigeration and air-conditioning education.

Keywords: *metacognitive diagnostic problem-based learning, refrigerant flow, diagnostic reasoning, realia, BTLED-Industrial Arts, action research*

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INTRODUCTION

Understanding refrigerant flow, pressure–temperature relationships, and the functions of refrigeration system components is a fundamental competency in the Domestic Refrigeration and Air-Conditioning (DomRAC) course. The Technical Education and Skills Development Authority (TESDA) DomRAC Servicing NC II Training Regulations emphasize that learners should demonstrate competence in analyzing refrigeration system operation, interpreting pressure conditions, and applying theoretical concepts during laboratory activities and competency assessment. Students nevertheless often find refrigerant flow and refrigeration cycle operation difficult because many system processes cannot be directly observed. Laboratory-based instruction using an actual refrigeration system improves students' understanding of refrigerant flow and system behavior by connecting theory with practice (Shehadi, 2020), and authentic, experience-based learning has been reported to enhance students' conceptual understanding of air-conditioning systems compared with conventional classroom instruction (Ismail et al., 2025).

Classroom observations among third-year Bachelor of Technology and Livelihood Education major in Industrial Arts (BTLED-IA) students at Davao Oriental State University revealed similar difficulties. Although a functional window-type air-conditioning unit was available during laboratory instruction and students had been exposed to technical materials, including educational videos, many students struggled to analyze refrigerant flow, interpret pressure changes, and explain the functions of major components. Students could physically identify the compressor, condenser, expansion device, and evaporator, but had difficulty explaining refrigerant movement through the cycle, identifying where pressure increases and decreases, interpreting manifold gauge readings, and relating these changes to component functions. A baseline pre-test administered to 20 students yielded a mean score of 10.95 out of 20 (54.75%), interpreted as Did Not Meet Expectations, indicating that exposure to instructional materials and laboratory realia alone was insufficient without structured learning support.

A WHY–WHY instructional diagnosis was used to organize possible explanations for this difficulty. Two priority instructional needs within the teachers' influence were identified: insufficient explicit cognitive scaffolding during realia-based laboratory learning, since students could see the equipment but could not visualize how invisible refrigerant changes pressure during the cycle; and gaps in prerequisite heating, ventilation, and air-conditioning (HVAC) knowledge, as students entered the program from different senior high school strands with uneven exposure to refrigeration concepts. A congested curriculum was noted as a contextual factor beyond the teachers' control. These factors were treated as instructional priorities rather than verified causes, and the study did not test whether senior high school strand caused the observed differences.

Research in technical and vocational education suggests that instructional approaches integrating problem-based learning and metacognitive strategies enhance analytical thinking, conceptual understanding, and problem-solving (Ferdiansyah et al., 2023; Rivas et al., 2022). In response, this study developed the Metacognitive Diagnostic Problem-Based Learning (MD-PBL) Approach with Realia Integration, which combines metacognitive reflection, problem-based diagnostic tasks, and hands-on laboratory activities using an actual air-conditioning unit and diagnostic scenario cards. Specifically, the study addressed four questions: (a) What were the students' levels of understanding of refrigerant flow and pressure changes before and after the implementation of the MD-PBL Approach? (b) Was there a statistically significant difference between the pre-test and post-test scores? (c) What levels of performance did students demonstrate in refrigeration system scenario analysis, practical demonstration using a manifold gauge, and diagnostic presentation and defense? and (d) What level of metacognitive awareness was demonstrated in students' reflection journals? The study may benefit students preparing for advanced HVAC courses, teachers seeking a structured and low-cost instructional framework, schools aiming to maximize existing laboratory equipment, and future researchers in technical-vocational education.

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Literature Review

Metacognitive Learning Strategies in Technical and Vocational Education

Metacognition refers to learners' awareness and regulation of their own cognitive processes through planning, monitoring, and evaluating learning (Flavell, 1979). Stanton et al. (2021) emphasized that metacognition enhances learning by enabling students to monitor, regulate, and evaluate their thinking, resulting in improved academic performance and more effective learning strategies. Learners with well-developed metacognitive skills are better able to identify knowledge gaps, select appropriate strategies, and adjust their approaches, and despite the difficulty of observing metacognitive processes, structured metacognitive activities in classroom instruction are recommended to promote meaningful learning and conceptual understanding.

Rivas et al. (2022) similarly highlighted that metacognitive strategies help learners plan, monitor, and evaluate their understanding, thereby promoting deeper conceptual learning and critical thinking. Integrating metacognitive strategies into instruction enhances learners' ability to analyze concepts, reflect on their understanding, and apply knowledge in meaningful situations. These strategies are particularly relevant in technical and vocational education, where learners must interpret technical concepts and apply them in authentic contexts such as the diagnosis of refrigeration system behavior.

Problem-Based Learning in HVAC and Technical-Vocational Education

Problem-based learning engages learners with authentic, ill-structured problems that require them to integrate knowledge and develop evidence-based explanations (Barrows, 1986). Ferdiansyah et al. (2023) developed a problem-based blended learning model for vocational education and reported high validity, practicality, and effectiveness in improving learning outcomes. Engaging learners in authentic problem-solving activities enhanced their analytical thinking, problem-solving skills, and conceptual understanding by enabling them to relate theoretical knowledge to practical applications.

In refrigeration and air-conditioning education, Made and Ambiyar (2023) applied a problem-based learning approach using an air-conditioning simulator in a control system course and reported improved learning outcomes, as well as gains in analytical thinking, innovation, discipline, and communication. Engaging learners in realistic problem situations allowed them to connect theoretical concepts with actual system operation, supporting the development of technical competencies. These findings suggest that diagnostic problems grounded in real equipment can serve as productive contexts for learning refrigeration concepts.

Realia-Based and Experiential Learning

Experiential learning holds that meaningful learning occurs through a cycle of concrete experience, reflective observation, abstract conceptualization, and active experimentation (Kolb, 1984). Mendoza (2024) emphasized that experiential learning remains essential in technical-vocational teacher education because hands-on experiences strengthen technical competencies and bridge theoretical knowledge with practical application. Direct engagement in authentic learning activities enables learners to develop technical proficiency, critical thinking, and the practical skills required in vocational fields.

Authentic instructional materials support this process. Ahmadova (2026) found that realia-based instruction, in which learners interact directly with real objects rather than relying solely on textbooks, improved learning outcomes, classroom engagement, and motivation, and promoted deeper understanding. In the Philippine refrigeration education context, trainers and instructional devices have been developed to give learners direct access to working systems, including a domestic refrigerator trainer for beginner technicians (Bajet & Bajet, 2014) and a dual-evaporator air-conditioning trainer with a heating system (Dadivas et al., 2025). These principles are applicable to technical and vocational education, where interaction with actual equipment can make complex concepts more accessible.

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Learning Challenges in Refrigeration and Air-Conditioning Education

Students in refrigeration and air-conditioning programs require meaningful laboratory experiences to understand refrigeration cycle operation and thermodynamic principles. Shehadi (2020) explained that understanding refrigerant flow, pressure behavior, and temperature changes requires learners to relate theoretical concepts to the actual operation of a system. Through laboratory instruction using an actual refrigeration training unit, students were able to observe cycle processes, interpret pressure and temperature measurements, and compare theoretical principles with actual system performance, which improved their visualization of system operation.

Ismail et al. (2025) likewise found that students who participated in experience-based learning of air-conditioning building systems demonstrated better conceptual understanding than those who received conventional classroom instruction alone. Direct exposure to actual systems enabled learners to connect theory with observation and to visualize system operation. Together, these studies indicate that refrigeration concepts remain difficult when instruction relies mainly on conventional methods, and that structured interaction with real equipment can help address this difficulty.

Theoretical Framework

The study was anchored on three complementary theories. Metacognitive Learning Theory (Flavell, 1979) guided students to analyze refrigerant flow, pressure behavior, temperature changes, and component functions through prediction, observation, reflection, and evaluation. The Problem-Based Learning framework (Barrows, 1986) informed the use of guided diagnostic scenarios requiring students to analyze system conditions, interpret readings, and formulate evidence-based explanations. Experiential Learning Theory (Kolb, 1984) supported direct interaction with an actual window-type air-conditioning unit and manifold gauge so that students could connect concepts with observable system behavior.

Within the MD-PBL Approach, metacognitive strategies were embedded through think-aloud demonstrations, guided questioning, and reflective activities, consistent with structured teaching frameworks in which the teacher first models the reasoning process before gradually releasing responsibility to learners (Fisher & Frey, 2014). Problem-based diagnostic tasks and collaborative rotations then required students to apply that reasoning to realistic HVAC situations, while reflection journals and the defense symposium made their thinking visible. Collectively, these perspectives provided the rationale for integrating metacognitive regulation, authentic problem solving, and experiential learning in a single instructional sequence.

Research Gap and Conceptual Framework

The reviewed literature shows that metacognitive learning, problem-based learning, experiential learning, and realia-based instruction each contribute to conceptual understanding and technical competence (Ferdiansyah et al., 2023; Mendoza, 2024; Rivas et al., 2022; Stanton et al., 2021). Studies in refrigeration education have emphasized laboratory exposure and experience-based learning (Ismail et al., 2025; Shehadi, 2020) or problem-based learning with simulators (Made & Ambiyar, 2023), but fewer have combined explicit metacognitive scaffolding, problem-based diagnostic tasks, and realia in a structured sequence for pre-service technology and livelihood education students. This study addressed that need through the MD-PBL Approach with Realia Integration.

Figure 1 presents the conceptual framework of the study. The MD-PBL intervention with realia, consisting of metacognitive modeling in Week 1, team diagnostic rotations in Weeks 2–3, and a defense symposium with reflection in Week 4, supports the learning processes of Plan, Test, Monitor, and Fix Proposal, the use of actual equipment and diagnostic evidence, and the explanation and checking of reasoning. These processes lead to three assessed outcomes: written understanding, measured through a pre-test and post-test; diagnostic performance, assessed through post-intervention performance rubrics; and metacognitive awareness, assessed through rubric-rated reflection journals. The arrows represent the instructional rationale rather than confirmed causal

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relationships; mediation was not tested, and only written understanding was measured before and after the intervention.

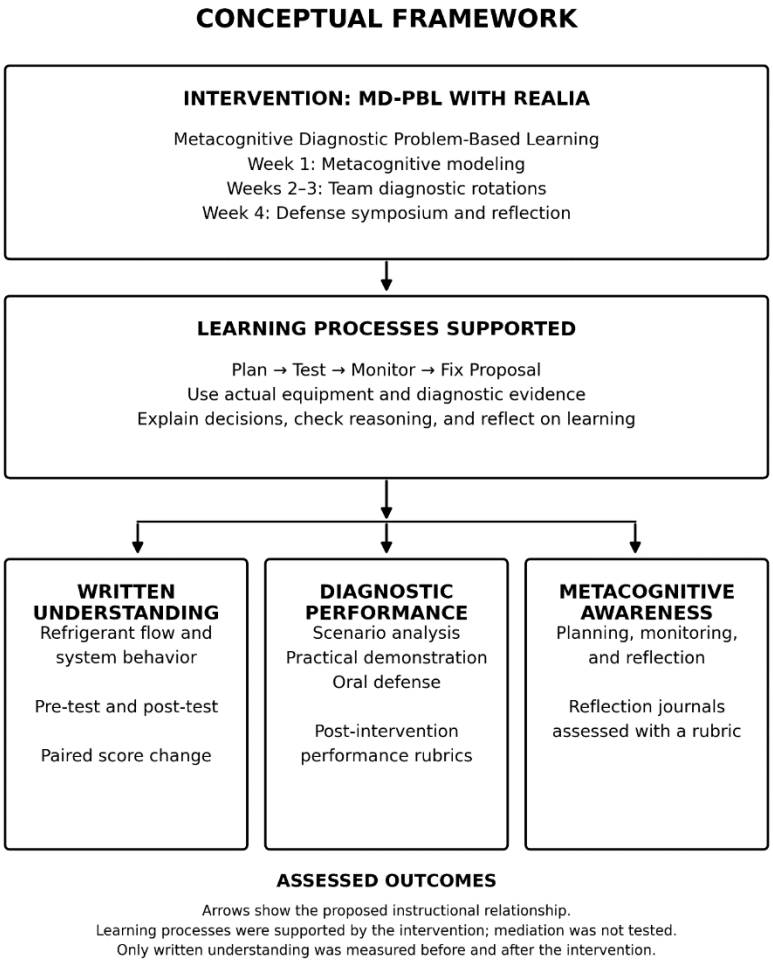


Figure 1. *Conceptual Framework of the Study*

METHODS

Research Design

The study used classroom-based action research with a quantitative single-group pre-test/post-test comparison. The classroom inquiry followed the action research cycle of planning, implementation (acting), observation, and reflection (Mertler, 2016). Written tests provided paired scores for the same students, while rubric-based assessments described performance in scenario analysis, demonstration, group presentation, and reflection. These complementary sources addressed different research questions and were not treated as interchangeable measures of improvement.

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Research Locale

The study was conducted in the Industrial Arts laboratory of the Faculty of Teacher Education, Davao Oriental State University, Philippines, during the first semester of Academic Year 2025–2026. The intervention was implemented within the regular DomRAC course using a functional window-type air-conditioning unit available in the laboratory, together with a manifold gauge, diagnostic scenario cards, guided worksheets, and reflection journals. Classes met on Tuesdays and Thursdays from 3:30 to 5:30 p.m.

Participants and Sampling Technique

The participants were 20 third-year BTLED-IA students (10 male and 10 female) in one intact DomRAC class. The class was purposively selected because its learning needs matched the focus of the intervention. As an intact class rather than a randomly selected sample, the findings are interpreted within the participating classroom. The intervention formed part of regular classroom instruction, and score records used alphanumeric participant codes.

Research Instrument

Five instruments were used. The written pre-test and post-test each consisted of 20 multiple-choice items on refrigeration component functions, refrigerant flow, pressure–temperature relationships, and diagnostic reasoning, scored 1 for a correct and 0 for an incorrect answer (maximum score of 20). Written-test results were interpreted using the following scale: 0.81–1.00 (81%–100%), Outstanding; 0.61–0.80, Fairly Satisfactory; 0.41–0.60, Did Not Meet Expectations; 0.21–0.40, Needs Improvement; and 0.00–0.20, Poor. The two forms contained different items and ordering.

Four analytic rubrics with four-point scales assessed performance: the Scenario Analysis Sheet and rubric (system data summary, component analysis, refrigerant flow sequence, system explanation, and reflection); the Demonstration Rubric (gauge setup accuracy, pressure reading accuracy, diagnostic reasoning, safety and tool handling, and procedural flow); the Defense Symposium Rubric (diagnostic accuracy, metacognitive reasoning, use of evidence, communication and teamwork, TESDA-based solution, and defense response); and the Reflection Journal Rubric (planning reflection, monitoring awareness, evaluation/self-correction, technical understanding, and clarity of writing). Rubric means were interpreted as 3.50–4.00, Outstanding; 2.50–3.49, Very Satisfactory; 1.50–2.49, Satisfactory; and 1.00–1.49, Needs Improvement. Each criterion carried an unequal weight printed in the instrument. All instruments underwent expert content validation by three validators; no internal consistency coefficient, completed inter-rater agreement statistic, or test-form equivalence analysis was reported.

Data Gathering Procedure

The intervention was implemented over four weeks in three phases (Table 1). In Week 1, students were oriented to the purpose and structure of the MD-PBL Approach, foundational concepts were reviewed, the pre-test was administered, and the instructor conducted a think-aloud demonstration using the laboratory air-conditioning unit to model how to read a manifold gauge, observe temperature behavior, and analyze refrigerant flow and pressure changes. In Weeks 2–3, students worked in small groups at diagnostic stations equipped with the air-conditioning unit, a manifold gauge, and scenario cards presenting simplified system conditions, selected readings, and guided questions. Each task followed four steps: Plan (formulating an initial explanation and prediction), Test (gathering observations and measurements under supervision and examining scenario data), Monitor (comparing predictions with evidence and identifying inconsistencies), and Fix Proposal (revising explanations and proposing an evidence-based diagnostic response without repairing or modifying the equipment). The instructor facilitated through probing questions rather than direct answers. In Week 4, groups presented their diagnostic analyses in a defense symposium, completed reflections, and took the post-test.

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Table 1. *Four-Week Implementation of the MD-PBL Approach with Realia Integration*

Phase	Key activities	Assessment evidence
Phase 1: Metacognitive modeling (Week 1)	Orientation; review of foundational concepts; pre-test; instructor think-aloud demonstration of manifold gauge reading, temperature observation, and refrigerant flow analysis	Written pre-test; initial reflections
Phase 2: Team diagnostic rotations (Weeks 2–3)	Small-group stations with air-conditioning unit, manifold gauge, and scenario cards; Plan → Test → Monitor → Fix Proposal; instructor probing questions and feedback	Scenario analysis sheets; demonstration ratings; reflection journals
Phase 3: Defense symposium and reflection (Week 4)	Group presentation and defense of diagnostic analyses; reflection; post-test; consolidation of scores and outputs	Defense symposium ratings; reflection journals; written post-test

Data Analysis

Written-test totals were summarized using means, sample standard deviations, and percentage scores, and item proportions correct were computed. Individual pre-test and post-test totals were paired by participant code and compared using a paired-samples t-test at the .05 level, with Cohen's dz computed as the mean difference divided by the standard deviation of the differences. Rubric criteria were summarized using criterion means, and weighted overall rubric means were computed as the sum of each criterion mean multiplied by its printed criterion weight. Only the written scores were used for inferential comparison; rubric ratings were interpreted descriptively because comparable baseline rubric ratings were not collected. Planning, monitoring, and evaluation journal criteria were interpreted as the most direct evidence of metacognitive awareness, while technical understanding and writing clarity were treated as supporting criteria.

Ethical Consideration

Participation was voluntary, and students were informed of the purpose, procedures, and objectives of the study before data collection. Alphanumeric participant codes were used in score records, and names were excluded from quantitative reporting. Data were used solely for academic and research purposes. Laboratory safety orientation and close supervision were provided during hands-on diagnostics, and activities were to be suspended immediately if unsafe practices were observed.

RESULTS AND DISCUSSION

Students' Understanding Before and After the MD-PBL Approach

Before the intervention, the students obtained a mean written-test score of 10.95 out of 20 (54.75%), interpreted as Did Not Meet Expectations. Pre-test item proportions ranged from 0.25 to 0.85. The lowest-performing items addressed the misconception that low pressure always means low temperature (0.25), the component primarily responsible for rejecting heat (0.35), the highest level of understanding during system observation (0.35), and the location of subcooled liquid, high suction pressure with low cooling capacity, and ice formation on the evaporator coil (0.40 each). These results identify initial difficulty with the assessed concepts but do not establish its causes.

After the intervention, the mean score was 18.35 out of 20 (91.75%), interpreted as Outstanding. Post-test item proportions ranged from 0.75 to 1.00, and four items, on interpreting low suction with slightly elevated discharge pressure, why refrigerant absorbs heat in the evaporator, why heat must be rejected in the condenser, and correct understanding of the refrigerant cycle, were answered correctly by all 20 students. As shown in Table 2, six pre-test items fell in the Needs Improvement range and seven in Did Not Meet Expectations, whereas 17 post-test items were Outstanding and none fell below Fairly Satisfactory. Because the two forms contained different items, these item-level results describe performance on each form rather than item-by-item improvement.

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Table 2. *Distribution of Written-Test Items by Proportion Correct*

Proportion corrects	Descriptive interpretation	Pre-test items	Post-test items
0.81–1.00	Outstanding	1	17
0.61–0.80	Fairly Satisfactory	6	3
0.41–0.60	Did Not Meet Expectations	7	0
0.21–0.40	Needs Improvement	6	0
0.00–0.20	Poor	0	0
Overall mean		0.55 (54.75%)	0.92 (91.75%)

Note. Counts were derived from the reported item proportions of the 20-item pre-test and post-test. The two forms contained different items.

These results are consistent with studies reporting that structured interaction with actual refrigeration equipment helps learners visualize system operation and relate theory to observed behavior (Ismail et al., 2025; Shehadi, 2020). The lowest-performing pre-test items involved relationships among pressure, temperature, phase, and component function, precisely the invisible processes that students could not infer from simply viewing the realia. The MD-PBL design addressed this by pairing realia with explicit modeling and guided prediction, in line with structured teaching approaches that make expert reasoning visible before learners apply it independently (Fisher & Frey, 2014).

Difference Between Pre-Test and Post-Test Scores

Table 3 presents the paired comparison of written-test scores. The mean increased by 7.40 points, equivalent to 37 percentage points, and the paired-samples t-test indicated a statistically significant difference, $t(19) = 15.85$, $p < .001$. The null hypothesis of no mean difference was therefore rejected. Cohen's dz of 3.54 indicated a large standardized difference relative to the variability of individual score changes.

Table 3. *Paired-Samples Comparison of Written-Test Scores (n = 20)*

Assessment	M	SD	%	Mean difference	t	df	p	Cohen's dz
Pre-test	10.95	1.54	54.75					
Post-test	18.35	1.04	91.75					
Post-test minus pre-test				7.40	15.85	19	< .001	3.54

The direction of this result agrees with evidence that problem-based learning improves analytical thinking and learning outcomes in vocational education (Ferdiansyah et al., 2023; Made & Ambiyar, 2023) and that metacognitive strategies support deeper conceptual understanding (Rivas et al., 2022; Stanton et al., 2021). However, the single-group design without a control group means that the increase cannot be attributed solely to the intervention; regular instruction, familiarity with assessment, or other experiences during the period may also have contributed. In addition, although both test forms underwent content validation, their equivalence in difficulty was not established, so differences between the forms may also have contributed to the observed increase.

Performance in Diagnostic Activities

Table 4 presents the rubric ratings. In scenario analysis, system data summary and component analysis each received 3.95, refrigerant flow sequence and system explanation 3.65, and reflection 3.55, all Outstanding, with a weighted overall mean of 3.78 (Outstanding). In the practical demonstration using a manifold gauge, pressure reading accuracy and diagnostic reasoning each received 4.00 and safety and tool handling 3.80 (Outstanding), while gauge setup accuracy (3.20) and procedural flow (3.00) were Very Satisfactory; the weighted mean was 3.62 (Outstanding). These lower-rated procedural criteria identify areas for further guided practice.

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Table 4. *Ratings in Scenario Analysis, Demonstration, Defense Symposium, and Reflection Journals*

Criterion	Weight	Mean	Interpretation
Scenario analysis			
System data summary	20%	3.95	Outstanding
Component analysis	30%	3.95	Outstanding
Refrigerant flow sequence	15%	3.65	Outstanding
System explanation	15%	3.65	Outstanding
Reflection	20%	3.55	Outstanding
Weighted mean		3.78	Outstanding
Practical demonstration using a manifold gauge			
Gauge setup accuracy	25%	3.20	Very Satisfactory
Pressure reading accuracy	25%	4.00	Outstanding
Diagnostic reasoning	20%	4.00	Outstanding
Safety and tool handling	15%	3.80	Outstanding
Procedural flow	15%	3.00	Very Satisfactory
Weighted mean		3.62	Outstanding
Defense symposium (group level)			
Diagnostic accuracy	30%	3.50	Outstanding
Metacognitive reasoning	20%	3.40	Very Satisfactory
Use of evidence	15%	3.75	Outstanding
Communication and teamwork	15%	3.25	Very Satisfactory
TESDA-based solution	10%	3.00	Very Satisfactory
Defense response	10%	3.00	Very Satisfactory
Weighted mean		3.38	Very Satisfactory
Reflection journals			
Planning reflection	25%	3.75	Outstanding
Monitoring awareness	25%	3.75	Outstanding
Evaluation/self-correction	20%	3.75	Outstanding
Technical understanding	20%	3.00	Very Satisfactory
Clarity of writing	10%	3.30	Very Satisfactory
Weighted mean		3.56	Outstanding

Note. Four-point scale: 3.50–4.00 = Outstanding; 2.50–3.49 = Very Satisfactory; 1.50–2.49 = Satisfactory; 1.00–1.49 = Needs Improvement. Ratings were collected after participation in the activities; no baseline rubric ratings were collected.

In the defense symposium, use of evidence (3.75) and diagnostic accuracy (3.50) were Outstanding, while metacognitive reasoning (3.40), communication and teamwork (3.25), TESDA-based solution (3.00), and defense response (3.00) were Very Satisfactory, yielding a weighted mean of 3.38 (Very Satisfactory). Students were thus able to ground their diagnostic conclusions in evidence, but proposing standards-aligned solutions and responding to questioning remained less developed. These patterns are consistent with the view that authentic problem-solving with real systems strengthens the connection between theory and practice (Made & Ambiyar, 2023; Mendoza, 2024). Because comparable baseline ratings were not collected, these results describe performance demonstrated after participation in the activities rather than improvement. Defense ratings were group-level scores and should not be interpreted as individual gains.

Metacognitive Awareness in Reflection Journals

In the reflection journals, planning reflection, monitoring awareness, and evaluation/self-correction each received 3.75 (Outstanding). These criteria provide the most direct evidence of metacognitive awareness in students' reflective outputs and indicate that students documented how they planned their work, monitored their understanding, and revised their explanations when evidence contradicted their predictions, consistent with the planning, monitoring, and evaluation processes described in metacognitive theory (Flavell, 1979; Stanton et al., 2021). Technical understanding received the lowest rating (3.00) and clarity of writing 3.30, both Very Satisfactory, indicating that accurate explanation of refrigeration concepts in writing deserves continued attention.

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The weighted journal mean was 3.56 (Outstanding). This overall value describes reflective output quality and is not a comprehensive measure of metacognition; without baseline ratings, an increase in metacognitive awareness cannot be established.

Taken together, the higher written-test scores and favorable task ratings suggest that the MD-PBL sequence warrants further classroom evaluation. Modeling made expert reasoning explicit, rotations provided structured opportunities to interpret evidence, and journals and presentations documented students' explanations, consistent with the theoretical rationale of metacognitive, problem-based, and experiential learning (Barrows, 1986; Flavell, 1979; Kolb, 1984). The evidence, however, does not isolate the contribution of modeling, realia, collaboration, or reflection. The teacher-researchers also observed that some students initially struggled with interpreting pressure–temperature relationships, that more confident learners tended to dominate some group discussions, and that limited laboratory time constrained extended reflection, which required adjustments in pacing and facilitation.

CONCLUSION

The participating class obtained substantially higher written-test scores after the four-week MD-PBL intervention with realia integration, with the mean increasing from 10.95 (54.75%) to 18.35 (91.75%) and a statistically significant paired difference, $t(19) = 15.85$, $p < .001$, $dz = 3.54$. This finding supports an association between the intervention period and written-test performance within this class. Ratings for scenario analysis, practical demonstration, the defense symposium, and reflection journals were in the Outstanding to Very Satisfactory range, with planning, monitoring, and evaluation evident in students' reflections, while gauge setup, procedural flow, standards-aligned solutions, defense responses, and written technical explanation emerged as areas needing further support.

Because the study used a single intact class without a control group, the equivalence of the test forms was not established, no instrument reliability coefficient was reported, and comparable baseline rubric ratings were not collected, the findings do not establish the causal effectiveness of the intervention or improvement in practical skills or metacognitive awareness. The study nonetheless contributes a structured and low-cost instructional sequence that integrates explicit metacognitive modeling, problem-based diagnostic tasks, and existing laboratory realia, which can guide further classroom implementation and evaluation in refrigeration and air-conditioning education.

Recommendation

HVAC and Industrial Arts instructors may continue to use diagnostic scenario activities, guided worksheets, reflection journals, and realia-based laboratory instruction in refrigeration and air-conditioning classes, refining these materials based on students' learning needs. In future implementations, more structured scaffolding may be provided for complex diagnostic tasks, especially gauge setup and procedural flow; clearer group roles may be established to promote balanced participation; and additional time may be allocated for reflection and defense activities. Instruction may also give greater attention to standards-aligned solutions and to accurate written explanation of refrigeration concepts.

The department and school administrators may support the sustained use of the approach by strengthening laboratory resources, faculty development, and collaborative learning activities, and by maintaining scenario cards, worksheets, and measurement tools for repeated use. The approach may be adapted for higher year levels through advanced troubleshooting, electrical diagnostics, and preventive maintenance tasks, and for settings with limited equipment through scenario cards and printed worksheets.

Future researchers may evaluate the MD-PBL Approach using a comparison group, equivalent or anchored pre-test and post-test forms, reported reliability coefficients, documented rater procedures, and baseline rubric ratings, and may examine individual performance, retention, and transfer over longer periods.

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