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The Effectiveness of the HVAC Escape Room in Enhancing Active Engagement and Mastery of the Fundamentals of VRF Systems and VRF Piping among Vocational College Students

Ruhaini Linda Bin Jamil*, Siti Zahira Binti Yusof, Eryanie Binti Kaimi, Al-Muhammad Haris Ikhwan bin Mahizan, Mohamad Indra Fitri bin Mohamad Saney

Refrigeration and Air-Conditioning Technology Programme, Sungai Buloh Vocational College, Jalan Kuala Selangor, U20, Shah Alam, 40160 Selangor, MALAYSIA

*Corresponding author email: RuhainiLinda@kvsbkpm.edu.my

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Abstract

Practical training in refrigeration and air-conditioning depends on access to equipment, and vocational workshops rarely have enough of it. At the Refrigeration and Air-Conditioning Workshop of Sungai Buloh Vocational College a single Variable Refrigerant Flow (VRF) unit serves an entire class, so structured observation found that only six of 30 students were actively engaged at any moment while the remaining 24 waited their turn. This action research evaluated the HVAC Escape Room, a teacher-built gamified activity of five rotating stations covering component identification, a crossword code-breaker, piping-route sketching, a video quiz and a hands-on pipe-measurement task, designed to convert waiting time into structured learning. Thirty Diploma students took part in one Kemmis and McTaggart action research cycle. Twenty-four students completed both a 20-item pre-test and an equivalent post-test, and a ten-item perception questionnaire was administered afterwards. Mean scores rose from 12.17 to 18.30 out of 20, a gain of 6.13 marks or 30.65 percentage points, while the median rose from 12 to 19 and the minimum score rose from 6 to 11. Perceptions were uniformly positive, with an overall mean of 4.60 on a five-point scale, highest for enjoyment and lowest for systematic task completion. Because the design used a single intact group with no control group, no inferential test and no delayed post-test, these results describe change within one cohort rather than establishing a causal or durable effect. They nonetheless suggest that a low-cost gamified activity can make productive use of unavoidable waiting time in equipment-constrained workshops.

Keywords: Educational escape room, gamification, student engagement, VRF systems, vocational education, action research

1. Introduction

Technical and Vocational Education and Training (TVET) in Malaysia is built on competency-based assessment, in which students must demonstrate mastery through performance rather than through recall alone. The Diploma in Refrigeration and Air-Conditioning Technology reflects this orientation: the greater part of the programme is delivered in the workshop, and a graduate's employability rests on demonstrated skill with real equipment. Practical sessions are therefore not a supplement to the curriculum but its core.

One of the more demanding courses in the programme concerns Variable Refrigerant Flow (VRF) systems. A VRF installation modulates refrigerant flow to several indoor units from a single outdoor condensing unit, and its piping network, which combines liquid and gas lines, Refnet joints and branch selectors, requires students to reason about system layout as well as to handle tools. Mastery of the fundamentals of VRF systems and VRF piping therefore combines conceptual understanding with psychomotor skill, and both are best developed at the equipment itself.

*Corresponding author: RuhainiLinda@kvsbkpm.edu.my

The obstacle is access. Equipment shortfalls are a structural condition of vocational workshops rather than an occasional inconvenience: studies of workshop and laboratory management in vocational education document formal rationing systems such as lending cards, scheduled rotations and budget-constrained procurement planning, precisely because the machine-to-student ratio is habitually low (Ardian et al., 2020). Research on how refrigeration and air-conditioning students experience their practicum similarly identifies the preparation and conditions of practice sessions, not student ability, as the limiting factor in what learners take away from them (Berman et al., 2020).

When a class must share one machine, the immediate consequence is waiting. Waiting time is not neutral: engagement in vocational education is unstable, varies systematically between learner profiles, and can decline over a programme rather than accumulate (Niittylahti et al., 2023). Emotional engagement, meaning how students relate to peers and teachers and how committed they feel, is itself a predictor of the behavioural engagement that shows up as on-task activity (Sureda García et al., 2021). A student standing idle at the back of a workshop is therefore not merely losing practice minutes; the idling itself works against the disposition that practice depends on.

The instructional case for filling that time is well established. A meta-analysis of 225 studies across science, engineering and mathematics found that active learning raises examination performance and substantially reduces failure rates relative to lecturing (Freeman et al., 2014). Cognitive load theory supplies the mechanism: working memory is severely limited, and instructional design works by removing load that is extraneous to the learning goal so that the remaining capacity can be spent on the material itself (Sweller et al., 2019). Any activity intended to occupy waiting students must therefore be structured around the target content rather than merely keeping them busy.

One common response to equipment scarcity is to substitute a simulation. The evidence supports this only partially. A meta-analysis of 46 studies of virtual laboratories in engineering education reported a moderate positive effect overall but concluded explicitly that virtual laboratories cannot fully replace physical hands-on work and function best as a supplement to it (Li & Liang, 2024). A direct comparison in a vocational school of virtual simulation against real hands-on practice, both supported by instructional video, reached a similar conclusion about where substitutes fall short (Qi et al., 2026). Substitution is thus a partial answer; the real unit still has to be reached.

Gamification offers a different route, one that supplements rather than substitutes. A meta-analysis of gamified learning found positive effects on cognitive, motivational and behavioural outcomes, with the size of the effect moderated by how the activity is designed rather than by whether it is called a game (Sailer & Homner, 2020). Systematic review evidence indicates that gamification raises engagement with structured programmes (Looyestyn et al., 2017), and controlled implementations report gains in both engagement and performance (Poondej & Lerdpornkulrat, 2020; Wang et al., 2022). Digital educational games have been shown to raise motivation for learning, with learning engagement mediating the effect (Li et al., 2024).

Within TVET specifically, a systematic review by Malaysian authors maps what gamification and game-based learning have and have not achieved in vocational settings and identifies engagement as their most consistently reported benefit (Dahalan et al., 2024). Malaysian evidence is encouraging: a gamification technique raised student engagement at a Malaysian polytechnic (Ab. Rahman et al., 2018), and a control-and-experimental study in Malaysian TVET reported gains in both engagement and test performance for the gamified group (Abu Samah et al., 2022). Comparable work exists on gamified interaction design for vocational teaching (Ma & Li, 2024), on digital gamification for engineering content (Uluskan, 2024), and on game creation as a vocational pedagogy (Li & Wang, 2025).

A particular form of gamification is the educational escape room, in which learners work in teams to solve a sequence of content-based puzzles under time pressure. A systematic review of the format establishes its design conventions, namely small teams, a bounded time limit, and puzzles whose solution requires the target content rather than incidental cleverness, and warns that the game goal must be reachable only through the educational goal (Veldkamp et al., 2020). A meta-analysis of 22 empirical studies reports a large effect on knowledge gain and a moderate effect on attitudes (Kim et al., 2024). In engineering education specifically, a randomised controlled trial with 326 participants found escape-room students outperformed lecture students on knowledge acquisition (Gordillo & López-Fernández, 2024), and a department-wide, station-based engineering escape room combining CAD, electronics and laboratory tasks demonstrated that the format scales to hands-on technical content (Scandurra & Ciofi, 2023).

This evidence must be read alongside its qualifications. A deliberately sceptical review concluded that much of the escape-room literature reports enthusiasm and self-reported outcomes rather than robust learning evidence (Taraldsen et al., 2022). A meta-analysis paired with a synthesis of qualitative data surfaced negative student experiences that quantitative summaries conceal, including indifference, waning interest and unhealthy competition (Bai et al., 2020). A fourteen-week longitudinal study found that the benefit of gamification declines after roughly four weeks as novelty wears off, before partially recovering with familiarity (Rodrigues et al., 2022). Most pointedly, an interprofessional escape room in medical education produced no statistically significant short-term knowledge gain over conventional teaching despite high enjoyment ratings, although a one-month follow-up did favour the escape room (Stange et al., 2026). Enjoyment and learning are not the same outcome, and a single-session study is exposed to the novelty effect.

Locally, teacher-built low-cost teaching aids have a credible record in Malaysian vocational education. Mini aquaponic models, for example, were developed and validated by an expert panel precisely because students lacked access to the real installation (Lutfi et al., 2022). The closest precedent to the present study is a quasi-experiment at a Malaysian institution in which game-based learning in a vehicle air-conditioning course improved both cognitive and affective outcomes among 30 vocational students (Azizan et al., 2021). That study shares the same discipline family, a comparable cohort size and a comparable instructional problem.

The gap this study addresses is nonetheless specific. The escape-room literature is concentrated in higher education and in disciplines where the content is predominantly conceptual; where it reaches technical subjects, the activity typically replaces a lecture. What has not been examined is the use of a gamified station activity as a deliberate companion to scarce equipment, running alongside the practical rotation so that the students who are waiting are learning the same content as the students at the machine. No published education study on the teaching of VRF systems could be located at all. This study therefore reports a first practitioner account of that arrangement.

Accordingly, this action research evaluates the HVAC Escape Room, a teacher-built gamified station activity, in a Malaysian vocational college workshop. It sets out to identify the level of student engagement before and after the implementation of the activity, to evaluate the change in students' knowledge of the fundamentals of VRF systems and VRF piping following the intervention, and to examine students' perceptions of and interest in learning these topics through the HVAC Escape Room.

2. Methodology

2.1 Research Design

This study employed an action research approach directed at a concrete problem encountered in the researcher's own teaching: students were unable to engage with practical work because a single Variable Refrigerant Flow (VRF) unit had to serve an entire class. The study adapted the Kemmis and McTaggart (1988) action research model, which proceeds through four phases: planning, acting, observing and reflecting. One complete cycle was carried out.

The design is a single-group pre-test and post-test arrangement without a control group. This is stated plainly here because it governs how the results in Section 3 may be read: the study describes change within one intact cohort and is not able to attribute that change to the intervention alone. The limitations of practitioner-led action research, including the concentration of teaching, observation and assessment roles in one person, are recognised in the Malaysian literature (Moktar et al., 2025) and are revisited in Section 4.

2.2 Study Setting and Participants

The study was conducted at the Refrigeration and Air-Conditioning Workshop of Sungai Buloh Vocational College, Selangor, during practical sessions on the Fundamentals of VRF Systems and VRF Piping.

Thirty students enrolled in the Diploma in Refrigeration and Air-Conditioning Technology programme took part in the intervention. Of these, 24 completed both the pre-test and the post-test and form the sample for the test-score analysis reported in Section 3.2; the perception questionnaire was completed by the same 24 students. Participants were selected purposively as the intact class taking the course at the time of the study.

2.3 Baseline Diagnosis

Before designing the intervention, a baseline diagnosis was carried out to establish what was actually limiting learning. Two instruments were used.

Structured observation

The researcher observed practical sessions using a self-developed observation form recording the number of students taking part in practical activity, the number waiting for a turn, mobile-phone use, level of attention, and participation in learning activities.

Diagnostic test

A diagnostic test was administered to establish students' initial mastery of the fundamental concepts of VRF systems and VRF piping. This test also served as the pre-test for the intervention.

The baseline findings, reported in Section 3.1, indicated that the constraint was structural rather than attitudinal: opportunities to take part in practical work were unequal, available session time was not being used productively by most of the class, and students had difficulty connecting theoretical content to the equipment they could not reach. The working assumption formulated from this diagnosis was that if waiting time could be filled with a structured, content-aligned activity, both engagement and mastery would improve.

2.4 The HVAC Escape Room Intervention

The HVAC Escape Room is a teacher-built gamified activity in which small groups rotate through five stations, each holding a task that must be solved using the target content. It was designed to run alongside the practical rotation, so that students away from the VRF unit were working on the same subject matter as those at it. All materials were prepared by the researcher from printed cards, worksheets and a video link; no equipment was purchased and no change was made to the curriculum.

Each of the five sections addressed a distinct curricular outcome. In the first, Identify the VRF Components, students named the main VRF system components and stated their functions from pictures and component cards. The second, The Code Breaker, required them to complete a crossword puzzle on VRF terminology from the instructions provided. In the third, VRF Piping, students sketched the piping route, identified the Refnet, labelled the gas and liquid pipes and completed the piping diagram. The fourth, Let's Explore the VRF System, asked them to watch a video through the link provided and answer the accompanying quiz questions. The fifth, VRF Pipe Measurement Practical, was carried out on the actual VRF unit, where students measured the diameters of the gas and liquid pipes.

The final section deliberately returned students to the real unit. The activity was designed as a companion to the equipment rather than a substitute for it.

2.5 Research Instruments

Three instruments were used to collect data.

2.5.1 Pre-Test

The pre-test comprised 20 multiple-choice questions on the fundamentals of VRF systems and VRF piping, administered before the intervention to establish each student's initial level of knowledge.

2.5.2 Post-Test

The post-test was administered immediately after the HVAC Escape Room activities and used a set of 20 questions equivalent in content and difficulty to the pre-test.

2.5.3 Perception Questionnaire

A ten-item questionnaire using a five-point Likert scale was administered through Google Forms to assess students' perceptions of and interest in the activity. The items covered enjoyment, interest in learning through gamification, active involvement, group cooperation, understanding of VRF systems and VRF piping, systematic task completion, motivation, the usefulness of the activity materials, and the suitability of the activity for the topic.

2.6 Implementation Procedure

The action research proceeded in a fixed sequence. It began with initial observation and problem identification, followed by administration of the pre-test. The HVAC Escape Room was then implemented across its five activity sections, during which student engagement was observed and recorded on the checklist. Once all groups had completed the stations the post-test was administered, followed by the perception questionnaire, and the cycle closed with data analysis and reflection. Students were divided into small groups and rotated through the five stations within a single teaching and learning session.

2.7 Data Analysis

Data from the pre-test, post-test, observation form and perception questionnaire were analysed using descriptive statistics: frequencies, percentages, means and medians. No inferential test was conducted, because the study did not include a control group and individual paired score data were not retained for statistical testing. The consequences of this choice for the interpretation of the results are addressed in Section 4.

2.8 Research Ethics

The study was conducted in accordance with research ethics principles. Respondents' informed consent was obtained before data collection and participation was voluntary, with no coercion to take part or to complete any instrument. Respondents' identities were not recorded and results are reported in aggregate, so no individual student can be identified. Data were recorded and analysed transparently, without alteration or selective omission. Students' safety and well-being were prioritised throughout the activity, particularly during the practical section conducted on the VRF unit.

3. Results

Results are reported in three parts: the baseline diagnosis that motivated the intervention, the change in test performance, and students' perceptions of the activity. All figures are descriptive.

3.1 Baseline Engagement and Diagnostic Findings

Structured observation of practical sessions found that the workshop held only one VRF unit for the whole class. In practice this allowed six of the 30 students to carry out practical work at any given moment, while the remaining 24 waited for a turn. Figure 1 shows the resulting distribution.

Figure 1. Student participation during VRF practical teaching and learning activities

Students who were waiting were observed to be largely off task, with mobile-phone use and declining attention recorded on the observation form. The analysis of these findings indicated that the problem was not primarily one of student ability or motivation. Rather, opportunities to take part in practical work were unequal, session time was not being used productively by most of the class, active participation was limited, motivation declined over the session, and students had difficulty connecting theoretical content to an application they could not physically reach.

The diagnostic test confirmed a correspondingly low baseline level of mastery, with a mean of 12.17 out of 20 and a lowest score of 6. Taken together, the two instruments indicated that the required response was not additional theoretical explanation but a way of occupying the 80 per cent of the class who were, at any moment, learning nothing.

3.2 Pre-Test and Post-Test Performance

Twenty-four students completed both the pre-test and the post-test. Table 1 summarises their performance.

Table 1. Comparison of pre-test and post-test performance

Statistic	Pre-test	Post-test	Change
Number of respondents	24	24	–
Mean score (max. 20)	12.17	18.30	+6.13 marks
Mean percentage	60.85%	91.50%	+30.65 percentage points
Median	12	19	+7 marks
Score range	6–18	11–20	Minimum rose from 6 to 11

The mean score rose from 12.17 to 18.30 out of 20, an increase of 6.13 marks or 30.65 percentage points. The median rose from 12 to 19, indicating that at least half the cohort scored 19 or above after the intervention. The score range narrowed and shifted upward, from 6–18 before to 11–20 after; the rise in the minimum score from 6 to 11 indicates that the lowest-performing students improved, rather than the group mean being carried by the strongest performers. Figure 2 presents the mean and median comparison.

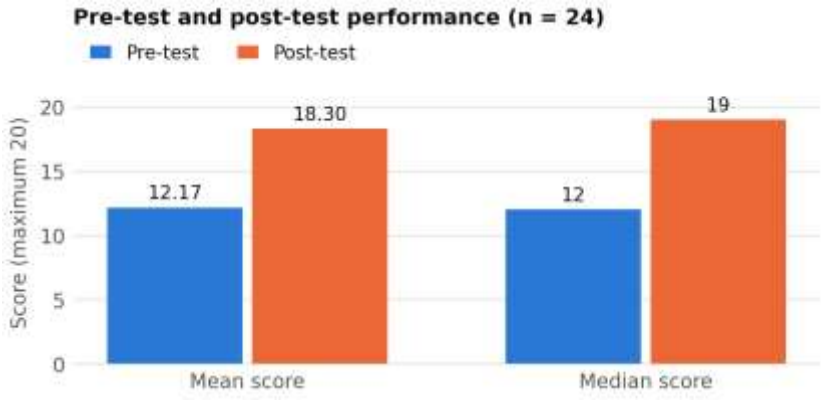

Figure 2. Comparison of mean and median scores for the pre-test and post-test

These are descriptive comparisons for a single group. No standard deviation, inferential test or effect size is reported, so the improvement cannot be described as statistically significant.

3.3 Students' Perceptions of the Intervention

The perception questionnaire returned uniformly positive responses, with an overall mean of 4.60 on the five-point scale. Figure 3 shows the mean for each item.

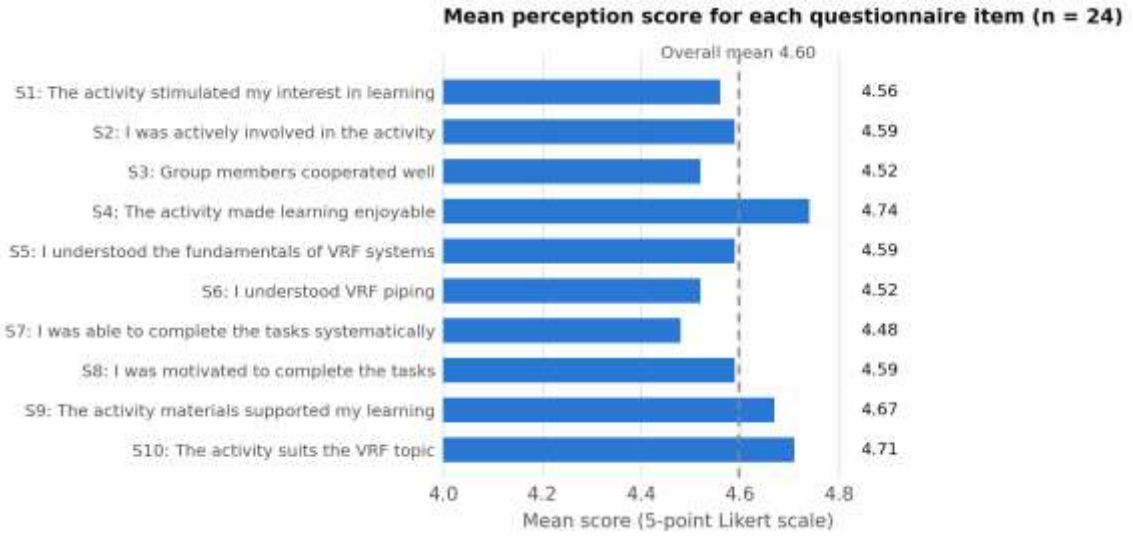

Figure 3. Mean perception scores for each questionnaire item

The highest-rated item, which stated that the activity made learning more enjoyable, recorded a mean of 4.74. The activity materials also received strong endorsement at 4.67, and the suitability of the activity for the VRF topic scored 4.71. Although every item recorded a high mean, the lowest was the ability to complete tasks systematically, at 4.48, followed by group cooperation and understanding of VRF piping at 4.52 each. The relative position of these items, rather than their absolute values, is what is informative: it suggests that the activity was more successful in generating enjoyment than in structuring how students worked through the tasks.

These data are self-reported and were collected immediately after the activity.

3.4 Constraints Observed During Implementation

Several constraints were recorded during implementation: only one VRF unit was available for the practical section; teaching and learning time was limited; sufficient activity materials had to be prepared for every group; and careful time management was required to ensure that all groups completed all five sections. Dividing students into groups and organising the tasks as stations was what made it possible to work within these constraints.

4. Discussion

This study examined whether a teacher-built gamified station activity could convert unavoidable waiting time in an equipment-constrained workshop into structured learning. Mean scores rose from 12.17 to 18.30 out of 20, the median from 12 to 19, and the weakest performance in the cohort improved markedly, with the minimum score rising from 6 to 11. Perceptions were uniformly positive, with an overall mean of 4.60 on a five-point scale. It should be stated at the outset that these figures describe change within a single intact group tested before and after, without a control group and without inferential testing. They are read here as an encouraging practitioner signal, not as evidence of a causal effect.

The direction of the change is nonetheless consistent with the mechanism the intervention was designed around. The baseline observation established that 24 of 30 students were disengaged at any given moment, not because the content was beyond them but because there was nothing for them to do. Replacing idle waiting with structured tasks is precisely the substitution that the active-learning literature supports: across 225 studies in science, engineering and mathematics, active engagement with content outperformed passive reception (Freeman et al., 2014). The gain reported here is what one would expect when roughly 80 per cent of a class moves from no learning activity to a designed one.

How the activity was designed matters more than the fact that it was a game. Reviews of educational escape rooms are explicit that the game goal must be reachable only through the educational goal, or the puzzles become decorative (Veldkamp et al., 2020), and meta-analytic evidence indicates that the effect of gamification is moderated by design rather than being a property of gamification as such (Sailer & Homner, 2020). The five sections here were each tied to a specific curricular outcome (component identification, terminology, piping-route logic, system operation and pipe measurement), and the fifth section returned students to the actual VRF unit. The structure also kept extraneous load low by giving each station one bounded task rather than an open problem, which is what cognitive load theory recommends when working memory is the binding constraint (Sweller et al., 2019).

The station-and-rotation arrangement is worth separating from the escape-room framing. A department-wide engineering escape room built on the same principle of parallel stations, with teams rotating between them and several involving real laboratory equipment, demonstrated that the format can carry hands-on technical content at scale, while honestly reporting that students' stated motivation to take part was largely social (Scandurra & Ciofi, 2023). In the present case the rotation was not a stylistic choice but the solution to the underlying problem: with one machine and thirty students, parallel stations are what allow the whole class to be occupied with VRF content simultaneously.

The perception data point in the same direction while revealing a boundary. The highest-rated item was enjoyment (4.74) and the lowest was the ability to complete tasks systematically (4.48). That pattern is informative rather than incidental: it suggests the activity succeeded in affect before it succeeded in procedural structure, which is consistent with reviews finding that escape rooms reliably generate enthusiasm while their learning evidence remains thinner (Taraldsen et al., 2022). It also echoes the qualitative synthesis that surfaced indifference, waning interest and competitive pressure behind otherwise positive averages (Bai et al., 2020). The lowest-rated item is the one the next action-research cycle should act on, most likely by tightening the sequencing instructions and the time allocation per station.

A gamified activity of this kind should be understood as a companion to the equipment, not a replacement for it. Meta-analytic evidence on virtual laboratories in engineering education reports a moderate positive effect while concluding explicitly that they cannot fully substitute for physical hands-on work (Li & Liang, 2024), and a direct vocational-school comparison of virtual simulation against real hands-on practice reaches the same conclusion (Qi et al., 2026). This is why the fifth station retained measurement on the real unit. The claim available from this study is that the escape room made the waiting productive, not that it taught what the machine teaches.

The practical case rests on cost and reproducibility. The materials were prepared by the teacher from printed cards, worksheets, a crossword and a video link, and the intervention required no procurement, no new software licence and no change to the curriculum. This matters because equipment scarcity in vocational workshops is a budget condition rather than a scheduling one (Ardian et al., 2020; Berman et al., 2020), and interventions that require capital cannot address it. The Malaysian record for teacher-built low-cost aids developed in response to exactly this constraint is established (Lutfi et al., 2022), as is the effectiveness of gamification in Malaysian TVET and polytechnic settings (Ab. Rahman et al., 2018; Abu Samah et al., 2022; Dahalan et al., 2024). The nearest published precedent, a game-based module in a vehicle air-conditioning course with a comparable cohort, reported gains in both cognitive and affective outcomes (Azizan et al., 2021), and the present results are consistent with it.

Several limitations bear directly on how far these findings travel. First, the design used a single intact group with no control group, so the improvement cannot be separated from repeated exposure to the content, from the pre-test itself acting as a rehearsal, or from the additional teacher attention the cohort received. Second, only descriptive statistics are reported; no inferential test, standard deviation or effect size was computed, so the 6.13-mark gain cannot be described as statistically significant. Third, 30 students took part in the activity but 24 completed both tests, and the six-student difference is unexplained, which introduces a possible attrition bias. Fourth, the researcher designed the intervention, taught the cohort, conducted the observation and marked the tests, a concentration of roles that is a recognised constraint of teacher-led action research in Malaysia alongside workload and sole-researcher data collection (Moktar et al., 2025). Fifth, the perception data are self-reported and were collected immediately after an enjoyable activity. Sixth, and most consequentially, measurement was immediate: a fourteen-week study found gamification's benefit declines after about four weeks as novelty fades (Rodrigues et al., 2022), and an escape room in medical education produced no significant short-term knowledge gain over conventional teaching despite high enjoyment, with the advantage appearing only at one-month follow-up (Stange et al., 2026). A single-session post-test cannot distinguish learning from novelty.

5. Conclusion

This action research asked whether the waiting time created by a single shared Variable Refrigerant Flow unit could be turned into structured learning through a teacher-built gamified station activity. Baseline observation confirmed that only a small minority of the class could work at the unit at any one time while the majority, having nothing assigned to them, drifted off task. After the intervention, knowledge scores improved substantially, the improvement reached the weakest performers rather than resting on the strongest, and student perceptions were uniformly favourable, strongest on enjoyment and weakest on working through the tasks systematically. The study therefore concludes that structured occupation of waiting time is associated with improved mastery of the fundamentals of VRF systems and VRF piping in this cohort, an association consistent with what the wider evidence on active learning and well-designed gamification would predict, though not a demonstration of proven effectiveness. Its original contribution lies in how the activity was positioned: where educational escape rooms are ordinarily built to replace a lecture, this one was built to accompany scarce equipment, running in parallel with the practical rotation and returning learners to the real unit at its final station, so that it supplements hands-on work rather than substituting for it.

For institutions working under the same constraint, the waiting portion of a practical session should be timetabled as instructional time with its own prepared materials, built from the same curricular outcomes as the practical task and closing at the equipment itself; and because students rated systematic working lower than every other aspect of the activity, station instructions and the time allowed at each station should be specified explicitly before the design is adopted elsewhere. These recommendations are bounded by the study's limitations: a single intact group with no comparison group, descriptive statistics only, an unexplained shortfall between those who took part and those who completed both tests, a researcher who designed, taught, observed and marked, self-reported perception data gathered immediately after an enjoyable session, and no measure of retention beyond it. A second cycle should therefore adopt a quasi-experimental design with a comparison group, report dispersion, an inferential test and an effect size, add a delayed post-test to separate durable learning from novelty, and use independent marking; wider trials across other equipment-constrained topics, other colleges and cohorts of differing prior attainment would then establish whether the benefit belongs to the design or to this teacher and this class.

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Conflict of Interest

The author declares no conflict of interest.

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