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PAPER

Improving Problem-Solving Skills and Learning Retention in a Thai Electrical Circuit Laboratory Using Flipped Classroom, Augmented Reality, and Microlearning

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ABSTRACT

This study aimed to develop and evaluate a flipped, microlearning, and augmented reality model to enhance undergraduate engineering students' conceptual understanding and problem-solving skills in an electrical circuit laboratory course. The participants consisted of 43 first-year engineering students, divided into an experimental group ($n = 21$) and a control group ($n = 22$). The experimental group was instructed using the integrated model, while the control group received traditional instruction. Research instruments included a learning achievement test, a problem-solving skills rubric, and a satisfaction questionnaire, all of which demonstrated acceptable validity and reliability. Data were analyzed using multivariate analysis of variance (MANOVA) and mixed ANOVA. The findings indicated that students in the experimental group significantly outperformed those in the control group in both learning achievement ($p < .05$) and problem-solving skills ($p < .01$). In addition, the experimental group demonstrated greater learning retention at two weeks after instruction. These results suggest that integrating augmented reality and microlearning within a flipped classroom framework effectively supports conceptual understanding and enhances problem-solving skills in engineering education. The integrated model provides a practical instructional approach for improving laboratory-based learning in science and engineering contexts. This study extends existing research by providing an instructional framework that supports both cognitive and experiential learning in higher education.

KEYWORDS

augmented reality, electrical circuit laboratory, flipped classroom, learning achievement, microlearning, problem-solving skills

1 INTRODUCTION

Thailand's higher education system has long emphasized student-centered approaches to promote natural learning and holistic student development [1].

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However, as society evolves into the digital age, the characteristics of Gen Z students have changed significantly. Today's students are proficient with digital technology, think independently, and are highly self-reliant. These changes demand corresponding updates to instructional methods.

This study focused on first-year engineering students enrolled in the Electrical Circuit Laboratory (ECL) course at Rajamangala University of Technology Thanyaburi (RMUTT). Teaching practical fundamental electrical circuits to novice engineering students presents persistent challenges [2]. The ECL course integrates theory and practice in large classes of 20–40 students with diverse educational backgrounds, including high school graduates and students from vocational certificate programs. The ECL course also serves as a foundation for advanced studies in electrical circuits. Traditional teaching methods such as demonstrations and lectures may no longer adequately meet the expectations of either lecturers or students.

Blended learning (BL), which integrates online technology to enhance traditional learning, has been proposed as a solution [3]–[4]. BL creates a student-centered environment that allows students to develop and learn at their own pace. In 2007, Bergmann and Sams pioneered the flipped classroom (FC) concept, which reverses traditional instructor-student roles across in-class and out-of-class activities [5]. The four pillars of FC are a flexible environment, a learning culture, intentional content, and a professional instructor [6]. Research across higher education disciplines has consistently reported that FC significantly enhances students' knowledge and skills [7].

Another promising educational innovation is augmented reality (AR), which combines real and virtual worlds through devices such as webcams, computers, and software [8]. AR creates immersive, technology-assisted learning experiences that allow students to interact with 2D and 3D images alongside the physical world [9]. Studies have reported that AR effectively attracts attention, fosters positive attitudes, increases motivation, and enhances learning through hands-on visualization of abstract theoretical concepts [10], [11].

Also making its way is microlearning, which consists of short learning exercises delivered via technologies such as videos, tests, infographics, and other interactive learning modules [12]. Microlearning entails breaking down information into smaller pieces that students can learn within 5 to 15 minutes [13].

Although FC, AR, and microlearning have been studied extensively in higher education [14], [15], most research lacks an integrated teaching model that combines all three approaches to enhance learning achievement and problem-solving skills in engineering practical courses. The Thai RMUTT ECL course requires both skills and cognitive knowledge for long-term retention, applying theoretical knowledge to solve real-world electrical circuit problems, and success in future advanced courses.

The current investigation is based on three theories that complement each other. According to constructivist theory, the flipped learning concept is appropriate because students are able to gain knowledge and use it while working within small groups in class. The principle of cognitive load theory explains the use of microlearning because it allows splitting large topics into small chunks and thus reducing unnecessary load. The last theory—experiential learning—provides the basis for the process of problem-solving through the CIRER cycle.

Therefore, this study integrates three complementary theoretical perspectives: constructivist theory, cognitive load theory, and experiential learning [16]. Constructivism emphasizes that students actively construct knowledge through FC, engaging with outside-classroom content before class and applying it during in-class activities. AR with microlearning can motivate students and reduce extraneous cognitive load [17]. The proposed FLIP-MAR model focuses the learning process on hands-on experience [18], allowing students to transform existing knowledge by engaging in new activities, thereby acquiring new knowledge, problem-solving skills, and attitudes toward electrical circuits.

2 METHODS

The research framework (see Figure 1) integrates blended learning, flipped classroom, AR, and microlearning to enhance learning achievement (LA) and problem-solving skills (PSS) in the ECL course.

Fig. 1. The research framework

2.1 Research scope

The content scope covered the ECL course (0-3-1 credits, 3 practical hours/week) for undergraduate students in the Faculty of Industrial Education and the Faculty of Engineering at RMUTT. The focus was on five learning units: (1) reading 4-band and 5-band resistor color codes, (2) using a multimeter, (3) series circuits, (4) parallel circuits, and (5) combination circuits [19]. Data were collected from December 2025 to January 2026 (academic year 2025, semester 2).

2.2 Population

The population consisted of 238 first-year undergraduate students across five engineering majors (Electrical, Mechanical, Industrial, Computer, and Electronic Engineering) at RMUTT's Faculty of Industrial Education. The sample consisted of 43 first-year electrical engineering students enrolled in the ECL course. Cluster random sampling was used to select Electrical Engineering as the representative major, followed by simple random sampling to assign Section 1 (n = 21) to the experimental group (FLIP-MAR model) and Section 2 (n = 22) to the control group (traditional teaching) [20].

2.3 Variables

Independent variable: teaching method (traditional vs. FLIP-MAR). Dependent variables: LA (learning achievement) measured by a 45-item multiple-choice test, and PSS (problem-solving skills) assessed using a 5-item analytic rubric.

2.4 Research instruments

FLIP-MAR learning model. Developed using the ADDIE framework (Analysis, Design, Development, Implementation, Evaluation) [21]. The model integrates a flipped classroom (pre-class online content and in-class active learning), augmented reality (marker-based AR e-book), and microlearning (short, focused modules of 5–15 minutes) (see Figure 2). Five experts in instructional design, measurement and evaluation, and information technology assessed the model's quality and appropriateness using a 5-point Likert scale (1 = very low, 5 = excellent). The overall mean was 4.53 (SD = 0.50), indicating excellent performance.

Fig. 2. The experiment plan

AR ECL e-book. Developed following the ADDIE model. The e-book contains five learning units across nine class sessions. It uses marker-based AR: students scan images in the book with their Android smartphones to trigger 2D/3D animations, circuit visualizations, and explanatory videos. Five experts in instructional design and educational technology evaluated the e-book's quality using the same 5-point scale. The overall mean was 4.53 (SD = 0.50), excellent.

Learning achievement test. A 45-item multiple-choice test with five options per item, aligned with the learning objectives of the five units. Content validity was assessed by five experts in measurement and evaluation using the Index of Congruence (IOC). Items with IOC ≥ 0.5 were retained. The test was then piloted with 30 senior engineering students who had completed the course. Reliability was calculated using the Kuder-Richardson 20 (KR-20) formula, requiring a coefficient ≥ 0.8. Item difficulty (p) was set between 0.2 and 0.8; discrimination index (r) was set ≥ 0.2. The final test had a reliability of 0.887, difficulty ranging from 0.33 to 0.80, and discrimination ranging from 0.23 to 0.56, all meeting the required standards.

Problem-solving skills (PSS) rubric. A 5-item analytic rubric based on the CIRER cycle (Clarify, Investigate, Research, Evaluate, Reflect) [22]. Each item was scored on a 0–4 scale (0 = no demonstration, 4 = excellent). Two instructors and electrical circuit laboratory experts assessed inter-rater reliability (IRR) using Cronbach's alpha of the intra-class correlation coefficient (ICC) on 20 practical assignments from the previous academic year. The IRR values ranged from 0.943 to 0.991, well above the minimum threshold of 0.7 [23].

Satisfaction questionnaire. A 34-item questionnaire across seven components: content and learning activities, problem-solving skills development, AR e-book design, preparation activities, inside-classroom activities, outside-classroom activities, and overall model satisfaction. Items were rated on a 5-point Likert scale. Five experts in instructional design assessed content validity using IOC; all items had IOC between 0.94 and 1.00.

2.5 Procedures

The study was conducted in three phases.

Phase 1 (Design and Development). The research team reviewed literature on blended learning, flipped classrooms, AR, and microlearning [24]. The FLIP-MAR model was drafted and reviewed by experts. The AR e-book was developed using ADDIE, with microlearning design principles (each module ≤ 15 minutes). The LA test, PSS rubric, and satisfaction questionnaire were developed and validated as described above.

Phase 2 (Experiment). After obtaining ethics approval and informed consent, all participants completed a pre-test (LA test) via Google Forms. The control group received traditional instruction: in-class lectures, demonstrations, and individual lab work with a printed manual. The experimental group used the FLIP-MAR model: before each class, students studied AR e-book modules and short videos (microlearning). During class, they engaged in collaborative problem-solving using the CIRER cycle, hands-on lab activities, and peer discussions. Both groups had nine class sessions (3 hours each) over six weeks (January–February 2026). Immediately after the final session, both groups completed the same LA post-test and a practical circuit problem (assessed with the PSS rubric). Two weeks later, a retention test (same LA test) was administered.

Phase 3 (Data Analysis). Descriptive statistics (means, standard deviations, frequencies) were computed. MANOVA was used to compare LA and PSS between groups. A mixed ANOVA (repeated measures) examined LA changes across three time points (pre-, post-, and retention). One-sample t-tests compared satisfaction scores against the benchmark (3.50 = high). All assumptions (normality, homogeneity of variance, and covariance) were checked and met.

2.6 AI tools

During manuscript preparation, the authors used Google Translate to assist in translation from Thai to English. No generative AI was used for data analysis or interpretation.

3 RESULTS

3.1 The FLIP-MAR model components

The model includes the **CIRER problem-solving cycle** (see Figure 3):

- **C (Clarify)** – Understand the problem, identify components, and scope [25].
- **I (Investigate)** – Analyze circuit structure and relationships [26].
- **R (Research)** – Seek additional knowledge from AR e-books, videos, or online resources [27].
- **E (Evaluate)** – Verify solution practicality and accuracy [28]. *Problem-Based Learning for Engineering Education: Developing the Engineers of the Future*. Routledge.
- **R (Reflect)** – Reflect on the process and apply it to new problems [29].

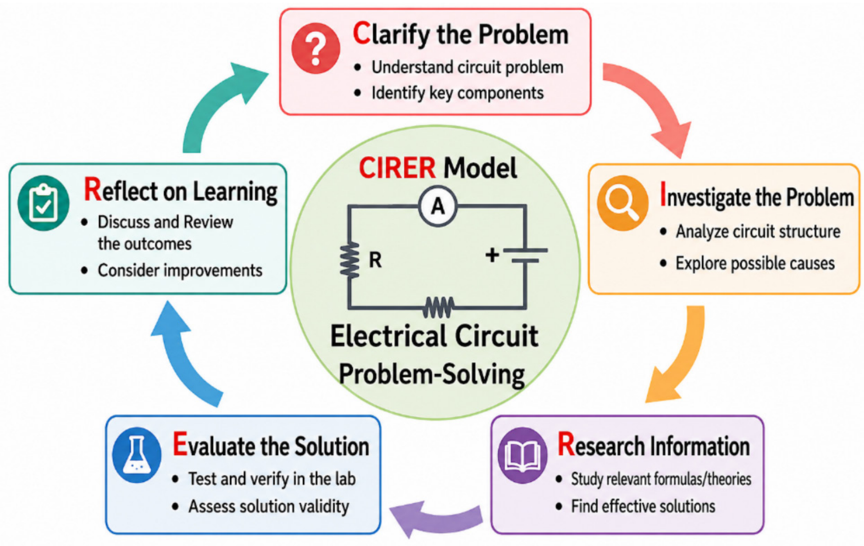

Fig. 3. CIRER cycle used in the FLIP-MAR learning model

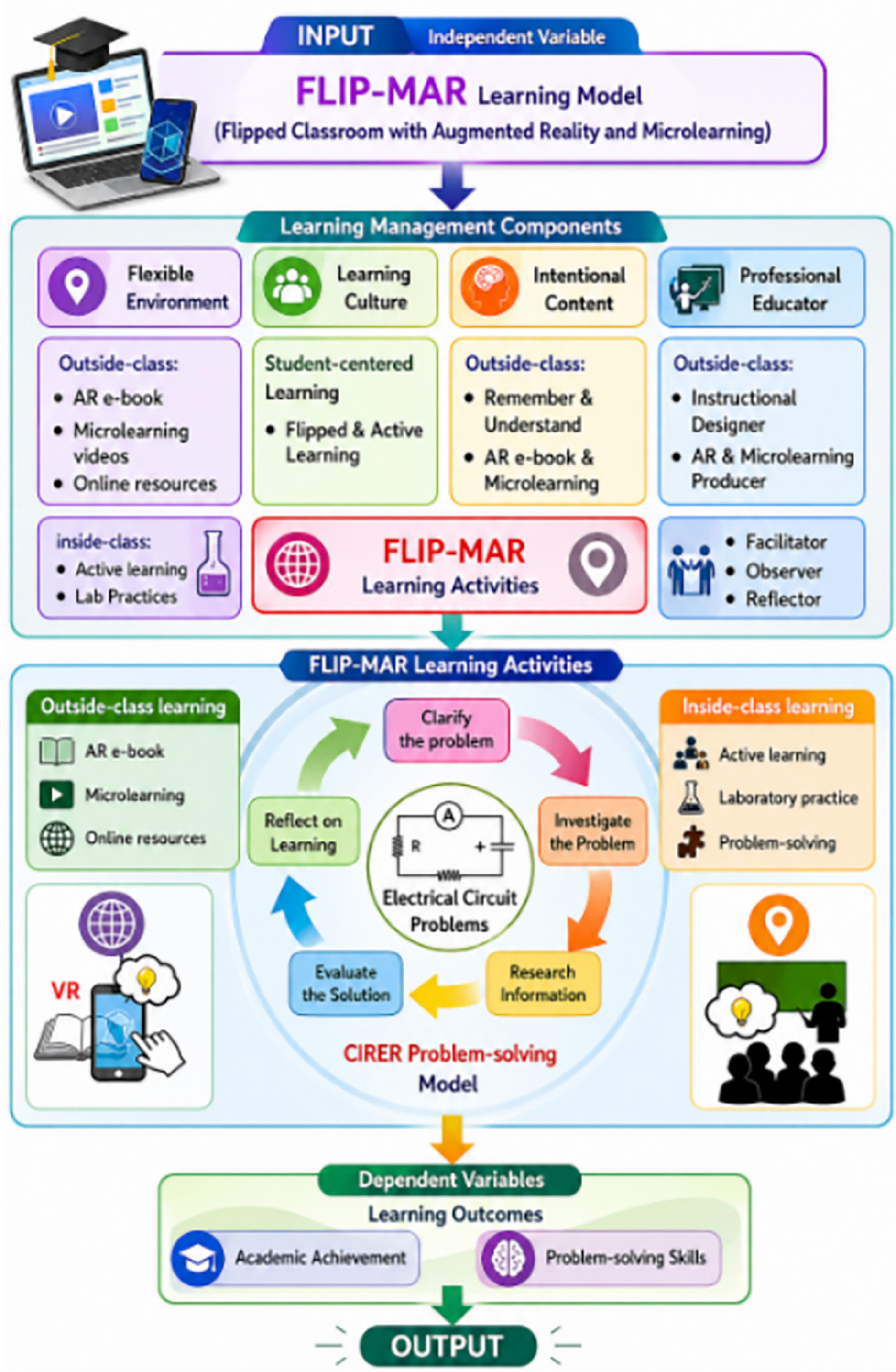

Fig. 4. The FLIP-MAR learning model

The full FLIP-MAR model (see Figure 4) integrates FC pillars (flexible environment, learning culture, intentional content, and professional educator) with microlearning components (microcontent, flexible learning, knowledge retention, outcome-oriented learning, and performance & skills development).

Expert evaluation yielded a total mean of 4.79 (SD = 0.41), indicating excellent performance based on the meta-evaluation standards for utility, feasibility, propriety, and accuracy [30]. Table 1 summarizes the results.

Table 1. Expert quality assessment of the FLIP-MAR learning model (n = 5)

Standard	Mean (M)	SD	Level
Propriety (Ethics & Standards)	4.82	0.39	Excellent
Utility (Practical Value)	4.68	0.48	Excellent
Feasibility (Practicality)	4.80	0.41	Excellent
Accuracy (Technical Soundness)	4.85	0.37	Excellent
Total	4.79	0.41	Excellent

The model achieved an overall mean of 4.79 (SD = 0.41), interpreted as excellent, confirming its high quality and appropriateness for implementation.

3.2 Learning achievement and problem-solving skills (MANOVA)

A multivariate analysis of variance revealed a statistically significant effect of teaching method (Wilks' $\lambda = 0.128$, $F(2, 40) = 136.3$, $p < .001$, $\eta^2 = 0.872$). Univariate follow-up tests showed that FLIP-MAR students scored significantly higher on both LA (M = 34.10, SE = 0.99 vs. 30.82, SE = 0.97; $p < .05$) and PSS (M = 48.99, SE = 0.34 vs. 40.28, SE = 0.41; $p < .01$) compared to the control group. Table 2 summarizes the MANOVA results.

Table 2. MANOVA for teaching method on LA and PSS (n = 43)

Dependent Variable	F(1, 41)	p	η^2
Learning achievement	5.558	.023	.119
Problem-solving skills	270.931	.000	.869

3.3 Learning retention (Mixed ANOVA)

Repeated measures analysis (Greenhouse-Geisser) showed a significant interaction between time and teaching method ($F(1.594, 65.372) = 20.790$, $p < .001$, $\eta^2 = 0.336$). The FLIP-MAR group maintained higher scores across the pre-test (M=19.57, SD = 1.28), post-test (M = 34.10, SD = 0.99), and two-week retention test (M = 38.88, SD = 1.14). The control group improved from pre-test (M = 19.27) to post-test (M = 30.82) but did not fully retain those gains at the two-week retention test (M = 27.18), whereas the FLIP-MAR group continued to improve from post-test (M = 34.10) to retention (M = 38.88).

3.4 Student satisfaction

Students in the experimental group (n = 18) reported overall satisfaction at the highest level (M = 4.26, SD = 0.71 on a 5-point scale). The highest-rated individual item was "Flipped classroom preparation" (M = 4.44, SD = 0.71). All components exceeded the "high" benchmark (≥3.50). Table 3 presents the mean scores for each of the seven main components.

Table 3. Student satisfaction with the FLIP-MAR model (n = 18)

Component	M	SD	Level
1. Content & learning activities	4.32	0.69	Highest
2. Problem-solving skills development	4.26	0.64	Highest
3. AR e-book design & quality	4.24	0.71	Highest
4. Preparation activities (FLIP-MAR)	4.24	0.69	Highest
5. Inside-classroom activities	4.32	0.69	Highest
6. Outside-classroom activities	4.27	0.68	Highest
7. Overall FLIP-MAR model	4.24	0.79	Highest

4 DISCUSSION

The FLIP-MAR approach had a profound positive impact on students' LA, PSS, and learning retention when compared with conventional pedagogy. This effect is based on the synergetic interplay of the components of this innovative learning approach.

Firstly, the flipped classroom learning model fosters cognitive engagement, active learning, and constructivist principles. In particular, through transferring direct instruction to preparatory classwork, in-class activities become problem-centered and experimental. This point was previously mentioned in several scientific works, including [7] and [31].

Secondly, AR technology is seen as situated scaffolding, which facilitates learning by providing a visualization of complex circuit concepts in 2D and 3D. This is supported by multiple studies reporting the efficacy of AR technology for deepening comprehension and motivation among students [10], [11]. For instance, according to the recent work of Hui et al. [32], marker-based AR contributes to problem-based learning in technical disciplines.

Thirdly, microlearning decreases cognitive load on students and promotes effective knowledge retention. In agreement with other research, the FLIP-MAR participants showed higher retention levels after two weeks [17], [33]. Additionally, this learning technique appeals to Gen Z students due to efficiency in using digital content [34].

Fourth, the CIRER cycle directly strengthens problem-solving skills. The structured inquiry steps (clarify, investigate, research, evaluate, reflect) gave students a clear framework for tackling circuit problems. This supports recent work on mobile-facilitated problem-solving [26] and scaffolding in STEM. The CIRER cycle extends traditional problem-based learning by embedding reflection as a distinct, final step, which likely contributed to the observed retention gains.

Fifth, the large effect size (partial $\eta^2 = 0.872$) indicates that about 87% of the variance in LA and PSS outcomes is attributable to the FLIP-MAR intervention—a highly practical significance. This exceeds effect sizes reported in studies examining FC alone (typically $\eta^2 = 0.20–0.40$) or AR alone ($\eta^2 = 0.15–0.35$), suggesting that the integration produces a multiplier effect.

Compared to other recent integrated models—such as AR with problem-based learning (Hui et al., 2024) [32] or flipped classroom with microlearning [35]—the FLIP-MAR model is unique in combining all three components within a single, theory-driven framework. The inclusion of the CIRER cycle provides a cognitive scaffold that may explain the sustained retention beyond immediate post-test gains.

Unlike other research studies that focused on FC, AR, or microlearning separately, this study proves that when FC, AR, and microlearning are applied as a whole, their results are more successful.

5 CONCLUSION

The proposed FLIP-MAR approach represents an effective theoretical model for improving learning effectiveness, solving problems, and retaining knowledge. This approach is based on the CIRER problem-solving cycle and focuses on the needs of digital-age students. This innovative educational approach is based on a learner-centered educational paradigm.

5.1 Practical implications

The Thai engineering education system can employ the FLIP-MAR approach without incurring huge costs on infrastructure since the AR e-book operates on common Android mobile phones. Teachers should spend one-third of classroom teaching time on microlearning lessons prior to class and two-thirds on in-class activities in the form of the CIRER cycle. It is advised that faculty members take faculty development workshops before the implementation of the approach regarding the creation of AR markers and brief videos. Where learning resources are scarce, microlearning elements should be provided using free applications such as YouTube and Google Forms, while AR should be integrated progressively.

5.2 Limitations and future research

Several limitations are worth noting. Firstly, the research took place in one particular institution, which makes it difficult to generalize about different settings. Secondly, while the number of participants (n = 43) was quite small, it was enough to perform MANOVA. Thirdly, the impact of students' digital literacy skills and socio-economic status on the ability to use AR applications was not taken into account. Finally, the period during which participants were able to retain knowledge was only two weeks long.

Future research should be focused on: (1) generalizing the model of FLIP-MAR in different universities and in various engineering specializations (mechanical engineering, civil engineering, computer engineering); (2) using bigger samples with stratified randomization; (3) analyzing the impact of prior knowledge and Internet connection; (4) measuring retention within 3–6 months after the end of the course; (5) applying the model to non-laboratory lessons, for example, theoretical engineering or math lessons; and (6) determining the minimum amount of microlearning needed in a flipped classroom model.

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