

Gamification-Based Learning Management Integrated with Microscale Chemistry Experiments on Factors Affecting the Rate of Chemical Reactions to Enhance Learning Achievement and Scientific Competency of Eleventh Grade Students

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〈 Abstract 〉

This study aimed to (1) develop a learning management plan based on gamification integrated with microscale chemistry experiments in the unit *Factors Affecting the Rate of Chemical Reactions* for Grade 11 students, (2) examine learning achievement, and (3) assess changes in scientific competency. The study employed a one-group pretest-posttest design. The sample comprised 50 Grade 11 students from Montfort College, Chiang Mai Province, during the second semester of the 2024 academic year, selected through purposive sampling and organized into 10 heterogeneous groups for instruction. Learning activities were designed using gamification principles and microscale chemistry experiments and implemented through four lesson plans over twelve class periods. Research instruments included lesson plans, experimental kits, a performance assessment rubric, and a scientific competency assessment adapted from the PISA 2018 framework. Data were analyzed using descriptive statistics (mean, standard deviation, and percentage). A one-sample Wilcoxon signed-rank test (using the 10 groups as the unit of analysis) was used to test whether group learning achievement exceeded the 70% criterion, and the Wilcoxon signed-rank test for paired samples was used to compare students' pre- and post-instruction scientific competency scores. The results indicated that the developed learning management

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plan demonstrated good to very good quality. Students achieved an average learning outcome of 87.67 percent, which was significantly higher than the 70 percent criterion ($p = .001$). Furthermore, students' scientific competency improved significantly from pre- to post-instruction ($p = .016$), with problem- solving showing the highest post-test mean score ($\bar{x} = 4.11$, S.D. = 0.73).

* Key words : Gamification, Microscale Chemistry, Scientific Competency, Learning Achievement

I. Introduction

In the 21st century, rapid and continuous advancements in technology and information have driven the world into an era of innovation that emphasizes creativity and the application of knowledge to solve complex problems. In response, Thailand has launched the *Thailand 4.0* policy, which aims to drive the economy through innovation, reduce dependency on natural resources, and transition toward developed-country status. Achieving these goals requires prioritizing human resource development, particularly by fostering scientific competencies, which form the foundation for logical reasoning, inquiry, experimentation, data analysis, and systematic communication. These skills are essential for life in the modern world and play a crucial role in enabling sustainable innovation.

Enhancing students' scientific competencies has therefore become a central mission of contemporary Thai education. The focus lies in equipping learners with knowledge and understanding that can be appropriately applied to real-world contexts, while also enabling them to engage in lifelong learning and collaborate creatively with others. Promoting such competencies requires learner-centered instructional models that create environments conducive to hands-on practice, analytical thinking, and systematic problem-solving.

Education for All emphasizes equitable education for every child, regardless of disability, nationality, religion, ethnicity, or geographic location, ensuring that all learners receive appropriate basic education. However, in Thailand—as in many other countries—traditional teaching methods remain predominant, often emphasizing rote memorization for examinations. This approach has been criticized for failing to foster genuine interest or deep understanding among students. Consequently, instructional approaches should emphasize active learning, experiential problem-solving, and analytical thinking to cultivate systematic scientific skills (Samarn Rattanasakorn, 2007).

As part of their teaching responsibilities, the researcher was assigned to teach Grade 11 chemistry at Montfort College, Chiang Mai, and surveyed students' attitudes toward the subject. The results indicated that most students perceived chemistry as difficult and unappealing, primarily because they could not relate the content to their daily lives. This perception hindered their ability to develop problem-solving skills applicable to real-world situations. To address this issue, the researcher initially employed STEM education, integrating knowledge from science, technology, engineering, and mathematics to foster analytical and creative problem-solving skills. Nevertheless, the

implementation revealed limitations, such as insufficient diversity of learning contexts, weak connections to students' real-life experiences, and time constraints during classroom activities. These limitations restricted the potential of STEM education to fully address students' needs, particularly regarding the development of scientific competencies, which are essential in the 21st century.

To overcome these challenges, the researcher adopted *microscale chemistry experiments* as a teaching technique. This approach uses minimal amounts of chemicals, ensuring high safety, cost-effectiveness, and time efficiency, while allowing experiments to be designed in ways that connect directly to real-world contexts. In particular, for the unit *Factors Affecting the Rate of Chemical Reactions*, which is abstract in nature, microscale experiments enable students to better understand phenomena and reaction mechanisms through hands-on practice, systematic observation, and guided discussion. Such processes significantly enhance analytical thinking skills (Wooster, 2007).

In addition, the researcher integrated gamification into instruction. Prior studies indicate that gamification effectively enhances motivation, engagement, and enjoyment, encouraging students to collaborate, exchange ideas, and work toward common goals—attributes essential to developing scientific competencies (Chanat Poondet & Thanita Lertpornkulrat, 2016). This approach also aligns with learner-centered education by fostering active participation and systematic learning.

Accordingly, the researcher sought to develop a learning model that integrates gamification with microscale chemistry experiments to make instructional activities more engaging and effective. Designed activities emphasize students' active participation in classroom experiments, connecting learning with real-life experiences while fostering analytical thinking, problem-solving, and teamwork. Microscale experiments further offer several advantages, including reduced time, high safety, minimal materials, low cost, and the possibility of multiple repetitions without imposing excessive burdens on teachers or students. By combining gamification with microscale chemistry, the proposed instructional design aims to strengthen students' scientific competencies, particularly in questioning, planning and conducting experiments, using tools safely, collecting and interpreting data, and communicating logically. Ultimately, this integration supports the national curriculum's goal of cultivating learners with scientific competencies and improving learning achievement in chemistry.

II. Research Objectives

1. To develop a learning management plan that integrates gamification with microscale chemistry experiments in the chemistry unit *Factors Affecting the Rate of Chemical Reactions* for Grade 11 students at Montfort College.

2. To investigate the learning achievement of Grade 11 students taught through gamification integrated with microscale chemistry experiments in the aforementioned chemistry unit.

3. To examine the development of Grade 11 students' scientific competencies through the application of gamification integrated with microscale chemistry experiments in the aforementioned chemistry unit.

III. Research Hypotheses

1. Grade 11 students taught through gamification integrated with microscale chemistry experiments in the chemistry unit *Factors Affecting the Rate of Chemical Reactions* will achieve an average learning outcome that meets or exceeds the 70 percent minimum standard specified by the Office of the Basic Education Commission (2014) and in line with Bloom's (1976) criteria.

2. Grade 11 students taught through gamification integrated with microscale chemistry experiments will show statistically significant improvement in scientific competency, as measured by the PISA 2018-based 25-item Likert self-assessment (six sub-indicators: scientific understanding, scientific problem-solving, scientific reading and writing, scientific responsiveness, research skills, and scientific communication), when comparing pre- and post-instruction results.

IV. Definitions of Terms

1. **Gamification-Based Instruction** Refers to learning activities designed by the researcher that integrate game mechanics into the instructional process to enhance motivation, engagement, and interest. The instructional sequence comprises five stages: (1) lesson introduction, (2) knowledge exploration, (3) knowledge explanation, (4) hands-on practice, and (5) summary and evaluation. These stages are combined with eight game elements adapted from Zimbrick (2013, p.78) and Chanat Poondet & Thanita

Lertpornkulrat (2016, p. 332): (1) goals, (2) rules, (3) scoring, (4) levels, (5) time constraints, (6) competition, (7) leaderboards, and (8) rewards.

2. Gamification-Integrated Instruction with Microscale Chemistry Experiments Refers to lesson plans that merge gamification elements with chemistry experiments conducted using microscale techniques. Microscale chemistry involves using much smaller quantities of chemicals than conventional practice—typically 0.05–1.0 g of reagents and < 25 cm³ of solutions, compared with 5–100 g and 100–500 cm³ in standard procedures. Specialized microscale equipment or adapted laboratory tools may be used. This approach is concise, safe, cost-effective, and feasible within limited class time. It also encourages student participation and develops scientific competencies such as analytical thinking, problem-solving, tool use, and scientific communication.

3. Learning Achievement Denotes students' ability to produce a laboratory report on *Factors Affecting the Rate of Chemical Reactions*, assessed with a researcher-developed five-level rubric. The rubric was adapted from the assessment framework of the *Education and Knowledge Construction* course at Montfort College and validated by experts. Instructors assessed group work against six criteria: (1) completeness of introductory information (objectives, rationale, scope, planning, and advance decisions); (2) accuracy and sufficiency of background information and planning principles; (3) correctness and completeness of operational procedures; (4) clarity and systematic presentation of results and conclusions; (5) appropriateness and appeal of evaluation-related content; and (6) timeliness.

4. Scientific Competency Scientific Competency refers to students' ability to apply scientific knowledge, skills, and reasoning to explain natural phenomena, evaluate and design scientific investigations, and interpret scientific data for real-world problem solving. This construct is grounded in the PISA 2018 scientific literacy framework, which comprises three core domains: (1) Explaining Phenomena Scientifically, (2) Evaluating and Designing Scientific Enquiry, and (3) Interpreting Data and Evidence Scientifically. In this study, scientific competency was measured using a researcher-developed, Likert-type self-assessment instrument consisting of 25 items, rated on a five-point scale (1 = very low to 5 = very high). The instrument was reviewed by experts and aligned with the PISA 2018 framework. To operationalize the three PISA domains more precisely within the context of classroom chemistry learning, the assessment items were organized into six sub-indicators:

- (1) scientific understanding,
- (2) scientific problem-solving skills,
- (3) scientific reading and writing,

- (4) scientific responsiveness,
- (5) research skills, and
- (6) scientific communication.

These six sub-indicators collectively represent students' scientific competency in terms of knowledge application, inquiry processes, data interpretation, and scientific communication. Content validity of the instrument was confirmed through expert review, yielding an Index of Item-Objective Congruence (IOC) of 0.94, and internal consistency reliability was high (Cronbach's alpha = 0.85).

V. Related Literature

Principles of Gamification

Chiewanan and Chiarawattanasuk (2018) emphasized that gamification can effectively shape behavior through active participation, sustained engagement, and reinforcement. Successful gamification repeatedly elicits desired outcomes until they become automatic and habitual. Rewards provide consistent reinforcement, sustaining newly acquired behaviors and promoting continuous learning.

Laisakul (2019) proposed two essential principles:

1. Game Mechanics—interactive features such as points, levels, leaderboards, challenges, badges, and achievements that generate enjoyment and challenge, while being adaptable to non-game contexts.
2. Game Drivers—human needs stimulated by gameplay, such as the desire for rewards, achievement, recognition, social belonging, self-expression, and competition. These drivers sustain motivation and reinforce behavior over time.

In summary, gamification is a powerful approach to motivation and behavioral reinforcement. When well-structured, it fosters sustained interest, active engagement, and effective learning.

Meesuk (2015) integrated gamification into Grade 10 science-program classrooms. The results revealed continuous learner engagement, higher satisfaction, and increased enjoyment due to hands-on practice, self-directed inquiry, and peer collaboration.

Chaiyasiri (2019) studied Grade 10 students using blended learning combined with

gamification. The findings showed significantly increased motivation, particularly when instruction followed clear stages: motivational warm-up, cognitive challenge, explanation and demonstration, task performance, and reflection. Positive reinforcement through rewards further enhanced engagement and created a supportive learning environment.

Promharaj (2021) developed a 5E inquiry-based learning plan with a genetics board game for Grade 10 students. The plan achieved an efficiency level of $E1/E2 = 77.32/83.23$, surpassing the 75/75 criterion. Post-test results showed problem-solving skills significantly above 70% ($p < .05$). The study confirmed that integrating inquiry-based instruction with game elements effectively enhanced interest, engagement, and systematic thinking.

Lutfi et al. (2023) created *Hydrocarbons Chem-Rush*, a gamified learning tool for Indonesian high school students. Results indicated that students in the gamification group outperformed controls in achievement, motivation, participation, and knowledge retention, demonstrating the effectiveness of well-designed educational games.

VI. Microscale Chemistry Experiments

Microscale chemistry was introduced in 1983 and first applied at the college level before spreading to secondary and tertiary institutions across the United States, with over 400 adopting it (Szafran, Singh, & Pike, 1989). Its popularity stems from advantages such as time efficiency, safety, and cost savings, as well as reduced chemical waste (Wood, 1990). Standard experiments typically require 5–100 g of reagents and 100–500 cm^3 of solutions, whereas microscale experiments use only 0.05–1.0 g and $< 25 \text{ cm}^3$.

Microscale experiments may use custom apparatus or adapted tools, and even common materials. Wood (1990) noted that microscale is particularly effective in secondary education because it fosters motivation better than teacher demonstrations or videos, by enabling direct student participation. Reported benefits include:

1. lower costs and reduced hazardous waste;
2. shorter duration, allowing multiple experiments in one class;
3. reduced need for specialized safety equipment such as fume hoods; and
4. improved safety for otherwise high-risk experiments, such as hydrogen-oxygen reactions.

Overall, microscale chemistry offers efficiency, safety, and inclusivity, ensuring that every student can participate actively in laboratory work. It not only improves conceptual understanding but also develops problem-solving, analytical thinking, and teamwork skills.

The reviewed literature consistently demonstrates that both gamification and microscale chemistry experiments independently contribute to improved student motivation, engagement, and learning outcomes in science education. Prior studies on gamification have emphasized the role of game mechanics (e.g., points, levels, rewards, and competition) and motivational drivers (e.g., achievement, recognition, and social interaction) in sustaining learners' engagement and reinforcing desired learning behaviors (Chiewa nan & Chiarawattanasuk, 2018; Laisakul, 2019). Empirical studies further confirm that integrating gamification into classroom instruction enhances student motivation, participation, and learning achievement across various instructional contexts, including science and chemistry education (Meesuk, 2015; Chaiyasiri, 2019; Promharaj, 2021; Lutfi et al., 2023).

Similarly, research on microscale chemistry experiments highlights their pedagogical value in promoting hands-on learning, safety, cost efficiency, and inclusive participation, while simultaneously supporting students' conceptual understanding, analytical thinking, and problem-solving skills (Szafran et al., 1989; Wood, 1990). Microscale approaches are particularly effective at the secondary level, as they allow students to actively engage in experimental processes rather than passively observing demonstrations, thereby fostering deeper scientific reasoning and collaborative learning.

Despite these well-documented benefits, the existing literature reveals two notable gaps. First, most previous studies have examined gamification and microscale chemistry as separate instructional strategies, with limited research exploring their systematic integration within a single instructional design. Second, while prior studies frequently report improvements in motivation and achievement, fewer investigations have explicitly examined how such integrated approaches contribute to the development of scientific competency, particularly within internationally recognized frameworks such as PISA 2018.

In response to these gaps, the present study integrates gamification with microscale chemistry experiments within a structured instructional framework designed explicitly to enhance scientific competency and learning achievement in chemistry. By operationalizing gamification through clearly defined game mechanics (e.g., points, levels, missions, and team-based challenges) and embedding them within microscale, curriculum-aligned laboratory activities, this study extends previous research by

demonstrating how these two approaches can function synergistically to support both cognitive and competency-based learning outcomes. Consequently, this research contributes to the existing body of knowledge by providing empirical evidence and a practical instructional model that aligns motivational theory, hands-on experimentation, and scientific competency development in secondary chemistry education.

VII. Research Framework

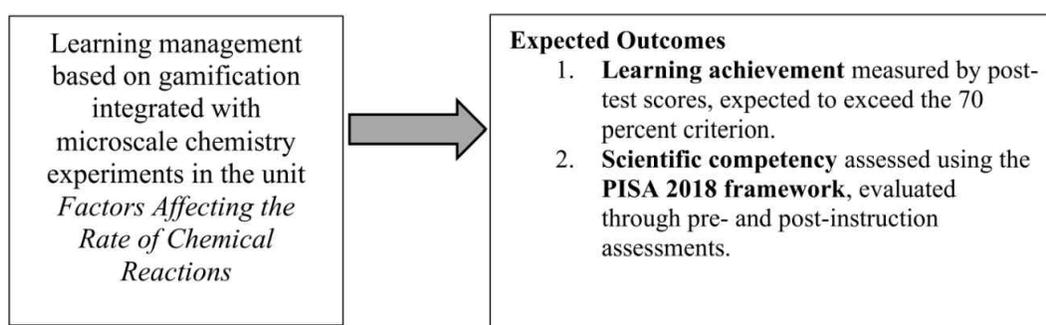


Figure 1

VIII. Research Procedure

Research Design

This study employed a one-group pretest-posttest repeated-measures design, expressed as O1 X O2, where O1 represents the pre-intervention assessment of students' scientific competency, X represents the gamification-integrated microscale chemistry instructional intervention, and O2 represents the post-intervention scientific competency assessment.

IX. Participants and Grouping Procedures

The population comprised Grade 11 students enrolled in the special academic enrichment program at Montfort College, Chiang Mai, Thailand (three classrooms; 150

students in total). The sample consisted of 50 Grade 11 students from an intact classroom assigned to the researcher for chemistry instruction, selected through purposive sampling. Data collection was conducted during the second semester of the 2024 academic year.

For instructional implementation, students were organized into 10 heterogeneous groups of five. Each group included a balanced mix of higher-, middle-, and lower-achieving students to promote collaborative learning, peer support, and equitable participation.

X. Instructional Intervention: Gamification-Integrated Microscale Chemistry Lessons

The instructional intervention consisted of four gamification-integrated lesson plans, implemented over a four-week period (12 class periods in total) in the chemistry unit *Factors Affecting the Rate of Chemical Reactions*. Each lesson plan was designed to address a specific factor affecting reaction rate and incorporated microscale chemistry experiments alongside structured gamification missions to promote active engagement, collaboration, and scientific competency development.

Across all lesson plans, instruction followed a consistent gamified learning structure comprising two core phases: (1) Point-Hunting (question-and-answer activities) to reinforce conceptual understanding, and (2) Mission Completion (hands-on microscale experiments) to support inquiry, experimentation, and teamwork. Group points were accumulated weekly and contributed to a level-based progression system (Bronze, Silver, Gold, Platinum, Diamond), reinforced through leaderboards and rewards.

A summary of the four lesson plans, including instructional focus, experimental missions, and time allocation, is presented in Table 1.

Table 1 Summary of Gamification–Integrated Lesson Plans and Experimental Missions

Lesson Plan	Instructional Focus (Factor Affecting Reaction Rate)	Microscale Experimental Mission	Key Gamification Elements	Duration (Class Periods)
Plan 1	Introduction to Reaction Rate & Concentration	Investigating the effect of butterfly pea solution concentration reacting with household bleach	Points, missions, levels, leaderboard	3
Plan 2	Temperature	Studying the effect of temperature on the rate of color fading in butterfly pea solution	Points, time constraints, competition	3
Plan 3	Surface Area	Exploring the effect of reactant surface area on reaction rate using modified microscale setups	Missions, role assignment, rewards	3
Plan 4	Catalyst	Investigating the catalytic effect of CuSO_4 on reaction rate	Cumulative scoring, badges, group ranking	3
Total	—	—	—	12 periods

Each lesson explicitly integrated gamification mechanics with scientific inquiry. For example, experimental missions required students to design procedures, collect and interpret RGB-based color data using the Color Picker application, and present findings within a specified time limit. Team roles (e.g., leader, recorder, operator) were rotated weekly to promote equitable participation and collaborative responsibility.

Detailed instructional procedures, mission descriptions, scoring systems, and classroom activity flows for each lesson plan are provided in the Sample Lesson Plan (Appendix) to further illustrate how gamification was operationalized in classroom practice.

X I. Research Instruments and Quality Assurance

1. Gamification–integrated lesson plans and learning activity packages

Four lesson plans and their associated gamification learning activity packages were reviewed by three experts. Content congruence was examined using the Index of Item–Objective Congruence (IOC), yielding an overall IOC mean of 0.98. Two items received lower IOC values (0.67) and were revised according to expert feedback prior to

implementation.

To clarify the perspectives/criteria used in expert evaluation (as requested by reviewers), the expert review was conducted across the following domains:

- Alignment between learning objectives and learning activities
- Appropriateness of gamification mechanics (e.g., goals, rules, points, levels, competition, leaderboards, rewards) for intended outcomes
- Instructional feasibility (time allocation, classroom management, materials)
- Clarity of instructions and learning procedures
- Appropriateness and alignment of assessment methods with lesson objectives and activities

2. Microscale chemistry experiment kits

The microscale kit included standardized procedures for preparing butterfly pea solutions across concentrations and monitoring color/optical responses. The kit supported reaction-rate investigations under varying conditions and enabled systematic measurement through RGB- based tracking.

3. Performance assessment rubric (Learning Achievement)

Learning achievement was evaluated using a group product/performance assessment rubric consisting of six criteria rated on five performance levels. Expert validation indicated maximum IOC values (IOC = 1.00 for all rubric criteria). Scores were summed, converted to percentages, and interpreted against the 70% criterion.

4. Scientific competency assessment (Single consistent instrument used throughout the manuscript)

Scientific competency was assessed using a 25-item Likert-type student self-assessment grounded in the PISA 2018 scientific literacy framework. Items were rated on a

five-point scale and organized into six sub-indicators that operationalize the three PISA domains:

- (1) Scientific understanding
- (2) Scientific problem-solving
- (3) Scientific reading and writing
- (4) Scientific responsiveness
- (5) Research skills
- (6) Scientific communication

Content validity was confirmed through expert review (IOC = 0.94), and internal consistency reliability was high (Cronbach's alpha = 0.85).

Table 2. Summary of Research Instruments and Measurement Structure

Instrument	Purpose / Outcome	Structure (Domains / Criteria)	Items / Levels	Validation / Reliability
Gamification-integrated lesson plans & activity packages	Ensure instructional quality and alignment	Expert review domains: (1) objective-activity alignment, (2) appropriateness of gamification mechanics, (3) feasibility, (4) clarity, (5) assessment alignment	Expert-rated checklist / IOC	IOC overall mean = 0.98 (2 items = 0.67 revised)
Microscale chemistry experiment kit	Support hands-on reaction-rate investigations	Standardized procedures for preparation, setup, measurement with RGB tracking	4 activities (reaction rate factors)	Expert review (content/safety/procedure) as reported in manuscript
Performance assessment rubric (Learning Achievement)	Evaluate group laboratory report/product quality	6 criteria: (1) introduction completeness, (2) background/planning accuracy, (3) procedure correctness, (4) results/conclusion clarity, (5) presentation quality, (6) timeliness	5 levels per criterion	IOC = 1.00 for all criteria
Scientific competency assessment (PISA 2018-based)	Measure scientific competency pre/post	6 sub-indicators operationalizing PISA 2018 domains	25 items: 5-point Likert scale	IOC = 0.94; Cronbach's alpha = 0.85

XII. Data Collection Procedures

Data collection was conducted over four weeks during the second semester of the 2024 academic year. Prior to implementation, the researcher developed and refined the research instruments (lesson plans, activity packages, microscale kits, performance rubric, and scientific competency assessment). The researcher personally implemented the intervention and collected all data.

Before the intervention, an orientation session was conducted to explain the objectives, procedures, gamification rules, and the roles of students and the teacher. Students were then organized into 10 heterogeneous groups of five.

The procedures were as follows:

- Week 1: Students completed the scientific competency self-assessment (pre-test; O1). The researcher collected the data and implemented Learning Activity Package 1.
- Week 2: Learning Activity Package 2 was implemented.
- Week 3: Learning Activity Package 3 was implemented.
- Week 4: Learning Activity Package 4 was implemented. After the final activity, students completed the scientific competency self-assessment again (post-test; O2).

After completion of the intervention, each group's work/product was evaluated using the performance assessment rubric to determine learning achievement. All data were prepared for statistical analysis.

XIII. Data Analysis

Descriptive statistics (mean and standard deviation) were used to summarize scientific competency outcomes (pre- and post-intervention). Performance rubric scores were summed and converted to percentages for comparison against the 70% criterion.

To test hypotheses at $\alpha = .05$, non-parametric procedures were applied:

1. Scientific competency (pre vs. post): the Wilcoxon Signed-Rank Test was used to

compare paired pre- and post-test scores for the same students.

2. Learning achievement vs. 70% criterion: a one-sample Wilcoxon signed-rank test was conducted on the differences between each group's achievement percentage and the 70% benchmark (i.e., testing whether the median difference was greater than zero), using the 10 groups as the unit of analysis.

XIV. Ethical Considerations

Permission to conduct the study was obtained from the school administration. Students were informed about the study purpose, procedures, voluntary participation, and confidentiality. No personal identifiers were reported, and data were analyzed and presented in aggregate form. Participation or non-participation did not affect students' course grades, and students could withdraw at any time without penalty.

XV. Results

Part 1: Development Outcomes of the Gamification-Integrated Lesson Plans with Microscale Chemistry Experiments for the Unit *Factors Affecting the Rate of Chemical Reactions*

1.1 Outcomes of Lesson-Plan Development (Gamification)

The development of the gamification-integrated lesson plans followed a systematic, multi-step design process to ensure curricular alignment, pedagogical coherence, and appropriate integration of gamification and microscale chemistry principles. The development process comprised the following steps.

Step 1: Curriculum and Theoretical Analysis The researcher first analyzed the Chemistry strand of the Basic Education Core Curriculum and the learning standards related to *Factors Affecting the Rate of Chemical Reactions*. In parallel, key theoretical foundations were reviewed, including gamification principles (game mechanics and motivational drivers), active learning, constructivist learning theory, and microscale chemistry pedagogy. This step ensured that the lesson plans addressed both content standards and competency-based learning goals, particularly scientific competency as

defined in the PISA 2018 framework.

Step 2: Initial Design of Lesson Plans and Microscale Activities Based on the curriculum analysis, four lesson plans were drafted, each focusing on a specific factor affecting reaction rate (concentration, temperature, surface area, and catalyst). For each lesson, microscale chemistry experiments were designed using butterfly pea (*Clitoria ternatea*) solution and household chemicals to ensure safety, feasibility, and environmental friendliness. Simultaneously, gamification elements—including goals, rules, points, levels, time constraints, competition, leaderboards, and rewards—were embedded into the instructional flow through structured missions, team roles, and cumulative scoring systems.

Step 3: Integration of Gamification Mechanics into Instructional Activities Gamification was operationalized through a consistent instructional structure across all lesson plans, consisting of (1) a point-hunting question-and-answer phase to reinforce conceptual understanding and (2) a mission completion phase involving hands-on microscale experimentation. Group-level progression (Bronze to Diamond levels) and weekly leaderboards were incorporated to sustain motivation, accountability, and collaboration throughout the four-week intervention.

Step 4: Expert Review and Revision The draft lesson plans and learning activity packages were submitted to three experts for content validation. The expert evaluation employed the Index of Item-Objective Congruence (IOC) and focused on alignment between objectives and activities, appropriateness of gamification mechanics, instructional feasibility, clarity of procedures, and assessment alignment. The overall IOC mean was 0.98, indicating very high congruence. However, two items under Domain 1 (activity-objective alignment) received moderate IOC values (0.67), as some activities were not sufficiently aligned with the stated learning objectives. These components were revised in accordance with expert feedback to strengthen alignment and instructional coherence.

Step 5: Finalization for Classroom Implementation After revision, the lesson plans were finalized and prepared for classroom implementation. The completed plans demonstrated comprehensive integration of curriculum content, microscale experimentation, and gamification mechanisms, making them suitable for fostering students' scientific competency and learning achievement. Detailed instructional procedures and examples of lesson implementation are provided in the Sample Lesson Plan section.

Overall, the results indicate that the gamification-integrated lesson plans were developed through a rigorous and transparent process, resulting in instructional materials that were pedagogically sound, practically feasible, and appropriate for use in

secondary chemistry education.

1.2 Outcomes of Microscale Chemistry Kit Development

Guided by the goal of reducing chemical consumption for environmental conservation, the researcher designed a set of microscale experiments for the unit *Factors Affecting the Rate of Chemical Reactions*. To minimize background-color interference during light-intensity measurement, a white tray was used; wells had identical dimensions to control reflection effects, and RGB light intensity was measured consistently at the center of each well (see Figure 1A).

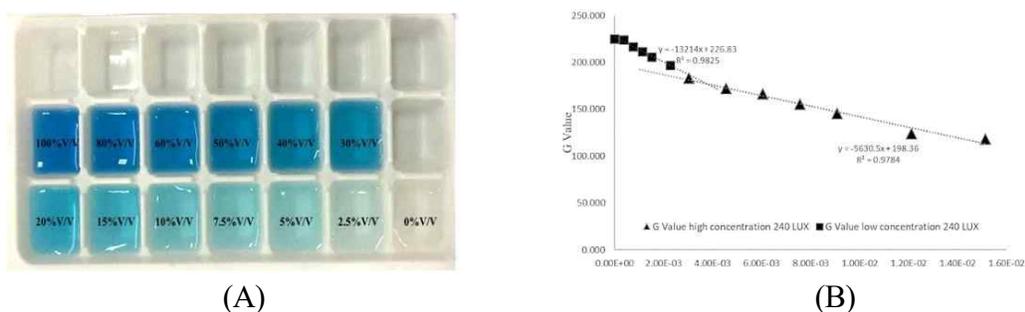


Figure 1. (A) Color images of butterfly pea solution obtained with the microscale kit; (B) standard curve showing the relationship between G value and the concentration of butterfly pea solution measured with the microscale apparatus in a school laboratory.

Measurements of RGB light intensity for butterfly pea solutions at different concentrations were taken at the center table of the classroom (ambient illuminance \approx 240 lux). The linear relationships in Figure 1B indicate that G value reliably tracks solution color across two ranges:

- For 0–15% v/v: $y = -13214x + 226.83$, coefficient of determination $R^2 = 0.9825$.
- For 20–100% v/v: $y = -5630.5x + 198.36$, coefficient of determination $R^2 = 0.9784$.

Across the four laboratory activities in this unit, experimental outcomes were clearly observable and accurate, appropriate for the learners' level, and readily implementable in regular classes (see examples in Figure 2).



Figure 2. Examples of experiments using the microscale kit for Factors *Affecting the Rate of Chemical Reactions* in conjunction with the Color Picker application.

The analysis further showed that employing butterfly pea color fading with household bleach helped students grasp factors affecting reaction rate. The smartphone Color Picker enabled continuous color tracking and convenient conversion to concentration. Some students suggested extending activity time in Activities 3–5 by 20–30 minutes to ensure adequate data collection from all three experimental sets per session.

Part 2: Learning Achievement of Grade 11 Students Taught with Gamification - Integrated Microscale Chemistry in the Unit *Factors Affecting the Rate of Chemical Reactions*

The sample consisted of 50 students, grouped into 10 teams (N = 10 groups). Learning achievement was assessed with a six-item performance rubric specific to the unit. Results showed that all groups exceeded the 70% criterion. The mean score across groups was 26.30/30, equivalent to 87.67%, meeting the criterion (see Table 3).

Table 3. Group mean scores for learning achievement (criterion = 70%)

Group	Score (max 30)	Percentage	Criterion Outcome
1	25	83.33	Pass
2	26	86.67	Pass
3	27	90.00	Pass
4	28	93.33	Pass
5	27	90.00	Pass
6	25	83.33	Pass
7	27	90.00	Pass
8	23	76.67	Pass
9	29	96.67	Pass
10	26	86.67	Pass
Mean (10 groups)	26.30	87.67	Pass

A one-sample Wilcoxon signed-rank test showed that the mean achievement ($87.67 \pm 2.92\%$) was significantly higher than the 70% criterion ($W = 55.00, p = .001 < .05$), supporting the study hypothesis.

Table 4. Learning achievement (N = 10 groups)

Variable	N	Mean (%)	SD	W	p-value
Learning achievement	10	87.67	2.92	55.00	.001

Wilcoxon Signed-Rank testing showed that the mean achievement ($87.67 \pm 2.92\%$) was significantly higher than the 70% criterion ($W = 55.00, p = .001 < .05$), supporting the study hypothesis.

Part 3: Development of Scientific Competency in the Unit *Factors Affecting the Rate of Chemical Reactions* (Grade 11)

A 25-item self-assessment instrument measured scientific competency. Pre-test scores fell in the moderate range (means 2.50–2.84), while post-test scores rose to the good range (means 3.56–4.11), as shown in Table 5.

Table 5. Mean scientific competency scores (N = 50)

Subscale	Pre-test Mean	SD	Post-test Mean	SD
1. Scientific understanding	2.79	0.88	4.02	0.80
2. Scientific problem-solving	2.60	0.69	4.11	0.73
3. Scientific reading & writing	2.84	0.84	3.71	0.88
4. Scientific responsiveness	2.71	0.83	3.56	0.84
5. Research skills	2.50	0.71	3.82	0.77
6. Scientific communication	2.77	0.90	3.96	0.65

A Wilcoxon Signed-Rank Test comparing pre- and post-test scores yielded $W = 0.00$, $p = .016$ ($p < .05$), indicating significant improvement in students' scientific competencies across all domains.

Part 4: Reflections on Scientific Competency

Following implementation, several student groups maintained strong interest in microscale experimentation, independently extending ideas into self-designed investigations and developing a national-level science project for the Dow-CST Award (2024) organized by Dow Thailand and the Chemical Society of Thailand. The project, "A Smartphone-Based COD Test Kit for Wastewater," received an Honorable Award. The kit enabled smartphone readout integrated with a LINE-based chatbot, achieved accuracy comparable to standard methods, used small quantities of chemicals, and followed green-chemistry principles. These outcomes illustrate students' capacity to apply knowledge and scientific competencies at an advanced level, including design and science communication in authentic contexts.

XVI. Discussion and Recommendations

Effectiveness of the Gamification-Integrated Lesson Plans

The findings demonstrate that the four gamification-integrated lesson plans were highly effective and appropriate for classroom implementation. Expert evaluations rated the lesson plans at a very good level across all assessed domains, confirming that the instructional design was coherent, feasible, and aligned with the intended learning objectives. This result directly addresses Objective 1 of the study.

From a theoretical perspective, the effectiveness of the lesson plans can be attributed to the deliberate integration of eight core gamification mechanisms (goals, rules, scoring, levels, time constraints, competition, leaderboards, and rewards) within an active learning framework emphasizing participation, hands-on practice, and peer knowledge sharing. The structured team-based gamification cycle—weekly point accumulation, mission completion, and level progression—appears to have sustained engagement and accountability across student groups. As a result, students remained consistently involved throughout the four-week intervention rather than showing declining interest over time.

These findings are consistent with prior research indicating that well-designed gamification enhances learner motivation and engagement (Chanaat Poondet & Thanita Lertpornkulrat, 2016; Laisakul, 2019). Moreover, the results align with studies by Wachira Udomrat (2017) and Thakorn Boonsan (2017), which reported that cooperative, game-based instructional designs not only improve academic outcomes but also strengthen collaborative behaviors. The present study extends this body of research by demonstrating how gamification can be systematically operationalized within chemistry lesson planning, rather than being used as an add-on activity.

XVII. Learning Achievement

Students who participated in the gamification-integrated microscale chemistry instruction achieved learning outcomes significantly higher than the established 70% criterion ($\bar{x} = 87.67$, $p = .001$), thereby supporting Hypothesis 1. This finding is consistent with the minimum achievement benchmark recommended by the Office of

the Basic Education Commission and Bloom's (1976) mastery learning perspective, which emphasizes that effective instruction should enable the majority of learners to achieve clearly defined performance standards.

The observed gains in learning achievement may be explained through intrinsic motivation theory (Malone & Lepper, 1987). The instructional activities were designed to be enjoyable, appropriately challenging, and socially interactive, while incorporating rewards and measured competition. These features likely enhanced students' intrinsic motivation, leading to sustained effort and deeper engagement with chemical concepts. Furthermore, the integration of microscale experiments allowed students to repeatedly test ideas and observe outcomes directly, reinforcing conceptual understanding through experiential learning.

This result is consistent with Adisak Mek-Samut (2016), who found that gamification-based instructional strategies significantly improved students' achievement and interest in chemistry. The present study contributes additional evidence by showing that when gamification is combined with microscale experimentation, learning achievement can be improved even in conceptually challenging topics such as reaction rates.

XVIII. Development of Scientific Competency

The results strongly support Hypothesis 2, indicating significant improvements in students' scientific competency across knowledge, scientific process skills, and scientific dispositions. After the intervention, students demonstrated improved abilities to design appropriate experiments, use scientific instruments safely, collect and analyze data systematically, and explain relationships among factors affecting reaction rates. Particularly notable gains were observed in data interpretation and scientific communication, which are central components of the PISA 2018 scientific literacy framework.

Three interrelated mechanisms help explain these outcomes. First, hands-on learning through microscale experiments aligns with constructivist learning theory, which emphasizes knowledge construction through direct experience. The microscale RGB-based monitoring enabled repeated measurements and immediate feedback, supporting data-driven reasoning and iterative refinement of understanding during reaction-rate investigations. Second, collaborative group work created opportunities for argumentation, questioning, and reflective dialogue, processes known to support both cognitive development and positive attitudes toward science. Third, the gamification

mechanisms embedded in the learning activities enhanced students' self-efficacy (Bandura, 1997) by providing clear goals, incremental success experiences, and visible progress through levels and rewards. These elements encouraged students to take intellectual risks, ask questions, and assume greater responsibility for their learning.

These findings are consistent with Prasert Polsan (2018), who reported that microscale chemistry experiments positively influence students' scientific skills and analytical thinking. The present study extends this work by demonstrating that integrating microscale experimentation with gamification can further strengthen scientific competency development, particularly in secondary chemistry education.

This study has several limitations. First, the one-group pretest–posttest design lacked a comparison/control group; therefore, causal interpretations should be made cautiously. Second, scientific competency was measured through student self-assessment, which may be influenced by response bias. Third, variation in environmental conditions (e.g., classroom or home lighting) may have affected RGB-based color measurements despite standardized procedures. Future studies should incorporate a control group or quasi-experimental comparison, include additional performance-based or external assessments of scientific competency, and more tightly control measurement conditions to strengthen internal validity.

XIX. Recommendations for Practice and Future Research

1. The findings suggest that integrating gamification with microscale chemistry experiments is a promising instructional approach for teaching reaction-rate concepts. Teachers are encouraged to adapt this model to their specific contexts, taking into account available resources, instructional time, and student grade levels. Attention should also be given to environmental conditions, such as classroom lighting, to improve the accuracy of color-based measurements. Additionally, incorporating structured opportunities for student reflection and feedback during instruction may further enhance learning effectiveness.

2. Future studies should explore the application of this instructional model in online or blended learning environments, such as Moodle-based courses or flipped classrooms, to compare its effectiveness across different instructional contexts. Further research should also examine the model's impact on broader 21st-century skills, including creativity, communication, teamwork, and digital literacy. Finally, employing more diverse assessment methods—such as performance-based tasks, in-depth interviews, and

digital learning analytics—would provide a more comprehensive understanding of students' learning processes and competency development.

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Appendix
Sample Lesson Plan

Learning Management Plan

Learning Area: Science and Technology (Learning Strand) **Term:** Semester 2
Academic Year: 2024 **Title of Subject:** Chemistry
Subject Code: W 32222 : Grade 11

Unit No.: Unit 1 **Title of Unit:** Rate of Reaction
Time Allocated: 12 periods

1. Strand and Indicators (Core Thai Basic Education Curriculum)

Chemistry Strand

Understand chemical equations and balancing chemical equations; stoichiometric relationships in chemical reactions; rates of chemical reactions; equilibrium in chemical reactions; properties and reactions of acids–bases; redox reactions and electrochemical cells; and the application of knowledge for practical benefits.

Learning Outcomes

1. Calculate the rate of a chemical reaction and draw graphs showing the decrease or increase of substances that are not directly measured in the reaction.
2. Conduct experiments and explain the effects of concentration, surface area of reactants, temperature, and catalysts on the rate of chemical reactions.
3. Compare reaction rates when changes occur in concentration, surface area of reactants, temperature, and catalysts.
4. Provide examples and explain factors affecting the rate of chemical reactions in daily life or industrial contexts.

2. Topic and Sub-topics from the Core Thai Basic Education Curriculum

1. Rate of Reaction

- 1.1 Definition of the rate of a chemical reaction
- 1.2 Measurement and calculation of the rate of a chemical reaction
- 1.3 Concepts related to chemical reactions
- 1.4 Energy and the progress of chemical reactions
- 1.5 Factors affecting the rate of chemical reactions
- 1.6 Concentration and the rate of chemical reactions
- 1.7 Surface area and the rate of chemical reactions
- 1.8 Temperature and the rate of chemical reactions
- 1.9 Catalysts and inhibitors in chemical reactions
- 1.10 Rate law and reaction mechanisms

21st Century Learner Skills (3Rs × 8Cs × 2Ls)

- R1 – Reading
- R2 – (W)riting
- R3 – (A)Rithmetics

- C1 – Critical Thinking and Problem Solving
- C4 – Collaboration, Teamwork, and Leadership
- L1 – Learning

3. Learners' Key Competencies and Desirable Characteristics

3.1 Learners' Key Competencies

- 1. Communication Capacity
- 2. Thinking Capacity
- 3. Problem-Solving Capacity
- 4. Capacity for Applying Life Skills
- 5. Capacity for Technological Application

3.2 Desirable Characteristics

- 1. Love of nation, religion, and king
- 2. Honesty and integrity
- 3. Self-discipline
- 4. Avidity for learning
- 5. Observance of the principles of the Sufficiency Economy Philosophy in one's way of life
- 6. Dedication and commitment to work
- 7. Cherishing Thai-ness
- 8. Public-mindedness
- 9. Being healthy and well-balanced (health and aesthetics)

4. Learning Objectives (Specify K–P–A Completely)

4.1 Students can correctly conduct an experiment measuring the increase or decrease of measurable substances in a reaction. (K, P)

4.2 Students can correctly calculate the rate of a chemical reaction. (K, P)

4.3 Students can correctly explain and experiment on the effect of concentration on the rate of a chemical reaction. (K, P)

4.4 Students can correctly explain and experiment on the effect of reactant surface area on the rate of a chemical reaction. (K, P)

4.5 Students can correctly explain and experiment on the effect of temperature on the rate of a chemical reaction. (K, P)

4.6 Students can correctly explain and experiment on the effect of catalysts on the rate of a chemical reaction. (K, P)

4.7 Students can correctly explain and provide examples of factors affecting the rate of chemical reactions in daily life. (K, P)

4.8 Students demonstrate self-discipline, avidity for learning, and commitment to work. (A)

5. Learning Activities (Session Plan): Instructional Design

5.1 Period No.: Periods 1–3

Objectives Addressed

4.1 Students can correctly conduct an experiment measuring the increase or decrease of measurable substances in a reaction. (K, P)

4.2 Students can correctly calculate the rate of a chemical reaction. (K, P)

4.8 Students demonstrate self-discipline, avidity for learning, and commitment to work. (A)

Primary instructional design process used: Grouping Process (group-based process)

1) Goal-Setting Step

1.1 The teacher introduces the lesson by presenting chemical equations and asking students to collaboratively balance the equations to review prior knowledge before entering the topic of reaction rate.

1.2 The teacher informs students of the objectives of the learning unit on the rate of chemical reactions.

2) Planning Step

2.1 The researcher conducts an orientation and explains the objectives of using learning activity packages based on the gamification concept integrated with microscale chemistry experiment kits to develop students' scientific competency in Chemistry, within the learning unit "Rate of Reaction," so that learners understand their roles and the teacher's role in teaching and learning. The instruction using the learning activity packages is implemented over a period of four weeks.

2.2 The teacher divides learners into 10 groups, with 5 students per group, using heterogeneous grouping (high-, medium-, and low-achieving students in the same group).

2.3 The teacher administers the scientific competency assessment to all students before instruction.

3) Answer-Seeking Step

3.1 The teacher explains the rules and learning process for the unit "Rate of Reaction" and the presentation format, which will resemble gameplay integrated with microscale chemistry experiment kits. This approach aims to develop students' scientific competency and improve the quality of students' worksheets. Each week, group scores will be collected from gameplay, question answering, and completing missions. Scores will accumulate continuously for four weeks and will be aggregated in the final week. The scoring levels are as follows:

Score	Level
1–10 points	Bronze
11–20 points	Silver
21–30 points	Gold
31–40 points	Platinum
41 points and above	Diamond

3.2 Each class period is divided into two phases: (1) “Point-Hunting Q&A” and (2) “Mission Conquest.” Details of the learning process are as follows.

3.3 Phase 1: Point-Hunting Q&A. Each group learns the weekly content, reviews lessons collaboratively within the group, and then plays a Q&A game for that week to earn points. In the first week of gameplay, each group receives four cards. The cards have the following properties:

Special Card	Function
Resource-Stealing Card	Steal 5 points from any group and add them to the group’s own score.
Defense Card	Prevent being robbed of points or prevent a counterattack.
Counterattack Card	Use to counter a group that uses the Resource-Stealing Card; the group that used the Resource-Stealing Card will instead lose 5 points.
Score $\times 2$ Card	Earn double points when answering correctly.

Note: Each group may use each card only once. After use, the card must be returned to the teacher. Therefore, each group must plan the use of cards appropriately.

3.4 Phase 2: Mission Conquest. Each group must complete assigned missions integrated with microscale chemistry laboratory work within a specified time. Each member must have a clear role and responsibilities as follows:

Role	Responsibilities
Captain (Group Leader)	Directs, manages, and checks the assigned work for that week.
Scout (Information Search)	Searches for information from reliable sources.
Priest (Thinking Role)	Thinks and writes the chemistry laboratory worksheet.
Support (Support Role)	Supports and assists in writing the chemistry laboratory worksheet.
Operator (Operations Role)	Types documents / performs operational tasks.

Within each group, the Captain must rotate weekly, and the Captain assigns roles to members based on appropriateness for the mission. The group that completes the mission the fastest within the time limit, with the highest correctness and completeness, receives the “Super Team” badge for that week, which will be included in the cumulative score summary in Week 4.

3.5 The teacher presents instructional media on reaction rates and provides examples of chemical reactions and calculations of reaction rates.

3.6 The teacher explains the principles of microscale laboratory work using the microscale experiment kit on reaction rates and instructs all students to download the Color Picker application.

3.7 The teacher demonstrates the microscale experiment using the microscale kit on reaction rates.

3.8 The teacher begins Phase 1 (Point-Hunting Q&A) using a game titled “The Tycoon Game.” The rules are as follows:

Each group must answer questions on the Tycoon game board. The teacher asks one representative from each group to take turns—one person per round—to roll dice and move the game piece according to the number rolled. If the piece lands on a question, each group must submit an answer simultaneously using Jamboard/Padlet, with a time limit of 1 minute. A correct answer earns 2 points per item. If a group lands on a “Skip 1 Turn” space, that group must refrain from answering that question, and another group has the right to roll the dice to locate the next question. If, in any round, a group lands on a “Score $\times 2$ ” space, that group receives double points when answering correctly. After the teacher finishes explaining the rules, the class plays the game until completion.

4) Evaluation Step

4.1 The teacher summarizes the scores from the game and provides an opportunity for each group to use their special cards within 3 minutes,

then summarizes the scores again after the card-use period ends.

4.2 The teacher begins Phase 2 (Mission Conquest), which involves a microscale chemistry experiment: Experiment 1: Studying the bleaching rate of butterfly pea flower solution using laundry bleach. The group that submits first and meets the specified criteria correctly will receive the “Super Team” badge.

4.3 The teacher asks each group to select a Captain (group leader), and the Captain assigns roles to group members according to their abilities and aptitudes. Then, students collaboratively summarize and reflect on the microscale chemistry experiment on reaction rates using the microscale experiment kit. Students are given time to complete the mission while the teacher provides guidance.

5) Application Step

5.1 The teacher summarizes the scores and announces the group with the best mission score and the “Super Team” badge, provides examples of each group’s work, and facilitates discussion on the strengths and weaknesses of each group’s output.

5.2 The teacher summarizes all groups’ scores and ranks groups for the week.

5.3 The teacher and students summarize the lesson together and respond to students’ questions.

5.4 The teacher provides solutions and explanations for university entrance examination-style questions on reaction rates.

6. Teaching Strategies / Teaching Methods (Specify the methods used)

- Lecture
- Experiment
- Small Group Discussion
- Game

7. Material Aids / Learning Resources (Instructional Media and Sources)

7.1 Supplementary documents on the rate of chemical reactions

7.2 PowerPoint on the rate of chemical reactions

7.3 iPad, notebook, smartphone

7.4 Microscale chemistry experiment kit on the rate of chemical reactions

8. Assessment / Evaluation (Scientific competency self-assessment (pre/post); performance/achievement assessment rubric)

Learning Objectives (Specify all objectives)	Assessment Methods	Assessment Instruments	Criteria for Passing Each Objective
4.1 Students can correctly conduct an experiment measuring the increase or decrease of measurable substances in a reaction. (K, P)	Worksheet evaluation; participation in activities	Scientific competency assessment; achievement assessment	70%
4.2 Students can correctly calculate the rate of a chemical reaction. (K, P)	Worksheet evaluation; participation in activities	Scientific competency assessment; achievement assessment	70%
4.8 Students demonstrate self- discipline, avidity for learning, and commitment to work. (A)	Evaluation based on neat, timely submission of work	Scientific competency assessment; achievement assessment	70%

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