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Enhancing higher-order thinking skills in chemical equilibrium through a game-based learning module

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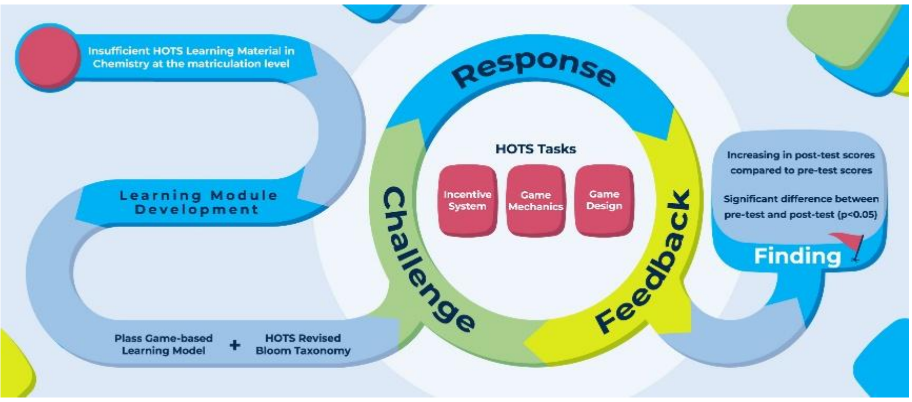
Abstract

In 21st-century learning, higher-order thinking skills (HOTS) are essential for matriculation students. However, lacking HOTS materials gives students less opportunity to practice HOTS in chemistry. This research paper developed a game-based learning module based on the Revised Bloom's taxonomy and a game-based learning model. Pre-experimental design with a one-group pre-test and post-test was employed to measure the effects of the module on students' HOTS namely analyzing, evaluating, and creating thinking skills, involving 30 students at matriculation college. The result shows an increase in mean scores in post-test compared to pre-test scores and paired sample T-test shows a significant difference between pre-test and post-test scores with $p<0.05$. The findings contributed to the potential of game-based learning for promoting HOTS at the matriculation level and providing learners with a quality education.



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Highlights

- Lacking HOTS materials limits students' opportunities to practice HOTS in chemistry.
- Game-based learning has potential for promoting HOTS at the matriculation level.
- Game-based learning module applying HOTS for quality 21st-century learning.
- Matriculation needs more HOTS materials that are aligned with the syllabus.
- A Game-based model with Revised Bloom's Taxonomy offers HOTS module for learning.

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1. Introduction

Along with the effort to make effective 21st-century learning, the Sustainable Development Goal (SDG) is primarily focused on assuring wellness, economic prosperity, environmental laws, and academic advancement to promote sustainable growth. The education system has played a role in the fourth goal of SDG, which is to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all. Since 2013, the Malaysian government, through the Ministry of Education (MOE) has introduced a strategic plan called Malaysian Education Blueprint (MEB) that has a specialized focus on improving lifelong learning in 21st-century learning within the years 2013-2025. One of the focuses is to strengthen the skills of higher-order thinking, and Malaysia aims to be among the top one-third of countries in the Programme for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMSS). The efforts to strengthen higher-order thinking skills (HOTS) are gaining continuous attention among teachers and educators (Saban, 2021). Much research also proved that HOTS helps students articulate their ideas clearly and effectively (Ichsan *et al.*, 2019) and is essential for global sustainable growth and future industry.

Previous research has reported that one of the challenges in implementing HOTS in chemistry subjects is that students' mastery of HOTS in chemistry is very weak (Azid and Md-Ali, 2020; Misrom *et al.*, 2020). Generally, HOTS involves the skills of analyzing, evaluating, and creating according to the Revised Bloom Taxonomy by Anderson and Krathwohl (2001). In chemistry, analyzing needs skills of separating chemical concepts into their parts and relating to one another; Evaluating acquired students to make a judgment about the value of information in chemistry-related phenomena; and creating allows students to generate new ideas by applying chemistry concepts in problem solutions. Mastery in analyzing, evaluating, and creating in the chemistry subject will make chemistry learning more meaningful and lifelong benefited students.

However, students are weak mastering these skills due to insufficient opportunities to develop HOTS at the matriculation level (Jamal *et al.*, 2020; Khamhaengpol *et al.*, 2021; Sasson *et al.*, 2022; Wan *et al.*, 2022). Therefore, educators should create more opportunities for students to practice HOTS skills throughout their education. This could include activities such as group projects, problem-solving, and critical-thinking exercises. Additionally, educators should provide students with feedback on their work to help them refine their skills and improve their understanding of chemistry. These types of activities help students to better understand the concepts they are learning and to develop the skills they need to apply their knowledge in real-world scenarios. Additionally, providing feedback helps to ensure that students are engaging with the material in a meaningful way and that they are making progress toward mastering the content.

In learning Chemical Equilibrium, students need HOTS to construct the concept by making the relation between one topic and another (Aini *et al.*, 2019). HOTS is needed to learn various factors and effects on chemical equilibrium (Rokhim and Septiani, 2021). For example, analyzing skills are needed to distinguish information using appropriate formulas. Evaluating skills helps students to examine the provided conditions to relate to the dynamic equilibrium. Creating thinking skills enables students to innovate and optimize conditions or products of chemical reactions. Additionally, learning activities can help students build ideas and gain a more in-depth understanding of the material. Game-based learning strategies can be used to engage students and help to develop problem-solving and critical thinking skills, as well as allow them to practice and apply what they are learning.

Game-based learning can provide an interactive learning environment to upskill their 21st-century skills with HOTS (Noh and Karim, 2021; Patiño *et al.*, 2023). An effective engagement can provide a comprehensive understanding beyond chemistry by using the game setting (Chen *et al.*, 2021). Game-based learning requires active learning so that students learn chemistry directly, and not put chemistry as an isolated subject (Tangkui and Keong, 2020; Tong *et al.*, 2022). Through game-based learning, students can apply the knowledge they have acquired in the game setting, which allows them to gain a more holistic and in-depth understanding of the subject. Based on Plass *et al.* (2020), game-based learning promotes active learning, as students are encouraged to think critically and interact with the game environment. This helps them to view chemistry as an interconnected subject, rather than an isolated one. By engaging in game-based learning, students develop higher-order thinking skills such as problem-solving, critical thinking, and creative thinking. Bello *et al.* (2016) also reported that there was a significant difference in students' achievement after the game-based learning was applied as the learning approach, as students had improved their critical and evaluative thinking. Previous research studies have proven that game-based learning module helps to create an enjoyable learning experience that connects the learning content with the real world (Farihah *et al.*, 2021), and this research focused on the effects of HOTS after the implementation of the game-based learning module among the matriculation students in chemical equilibrium concepts.

This study aimed:

1. To develop a game-based learning module on the Chemical Equilibrium topic at the matriculation level.
2. To evaluate the effects of the game-based learning module on students' higher-order thinking skills, namely analyzing, evaluating, and creating.

The research questions are:

1. What are the key features of an effective game-based learning module for chemical equilibrium that can promote higher-order thinking skills?
2. What are the changes in the higher-order thinking skills of students after using the Equi-Brilliant Module?

2. Research method

2.1. Research design

This study uses an experimental research design with a one-group pre-test and post-test. The one-group pre-test and post-test were chosen to obtain a carefully controlled situation (Johnson and Christensen, 2019) while performing the intervention using the module that had been developed. It is also widely accepted that the one-group pre-test and post-test were measured while testing the effectiveness of new teaching and learning approaches or curricular innovations (Cohen *et al.*, 2017). In this research, the game-based learning module is a new approach to be implemented to improve a conventional method at the matriculation institution.

2.2. Research sample

Two types of samples were used in this study. A random sample was used to answer RQ1, which involved thirty-seven chemistry lecturers from a population of 371 chemistry lecturers at matriculation colleges in Malaysia. Purposive sampling was used to answer RQ2, which involved thirty students of a one-year science program from a matriculation college located in south Malaysia.

2.3. Research instrument

The instruments involved are achievement tests in the form of pre-test and post-test questions, the game-based learning module during the intervention, and survey forms for the need analysis on key features of the game-based learning module, as well as module reflection to see the effect of the game-based learning module on students' HOTS. The achievement tests were built by the researcher and the questions prepared were ten HOTS items, involving analyzing (C4), evaluating (C5), and creating (C6) thinking skills in the form of multiple-choice questions for C4 and C5 questions and open-ended questions for C6 questions. For the survey purpose, twenty-one 5-Likert scale questions were constructed, to obtain the key features of the game-based learning module. For the module reflection, open-ended questions were prepared to get feedback from the users regarding this module. The instruments were validated by the chemistry content experts and were tested for reliability.

2.4. Module development

This study used the ADDIE model for module development, which involves the analysis, design, development, implementation, and evaluation of the module.

2.4.1. Need analysis phase

This phase is to find the key features of a game-based learning module to enhance students' HOTS in the Chemical Equilibrium topic. The analysis involves 37 chemistry lecturers, who were selected randomly from 370 chemistry lecturers from matriculation colleges in Malaysia. Survey forms on key features of the game-based learning module on the Chemical Equilibrium topic were distributed through Google Forms to reach the chemistry lecturers from all matriculation colleges in Malaysia.

2.4.2. Design and development phase

The game-based learning module was designed based on the combination of the Revised Bloom Taxonomy (Anderson and Krathwohl, 2001) and the game-based learning model (Plass *et al.*, 2015). The analyzing, evaluating, and creating items are implemented in a game setting adapted from Plass *et al.* (2015) model that includes the elements of Challenge, Response, and Feedback. The combination of both HOTS and Plass *et al.* (2015) model integrates a learning process with learning objectives that prepare students with HOTS tasks, game design, an incentive system, and game mechanics in a continuous game loop as an interactive learning environment. The game-based learning design used a game board as a platform for the learning process to occur. During the development phase, this module was validated by chemistry experts to ensure that it is relevant and valid for implementation among matriculation students.

2.4.3. Implementation and evaluation phase

The implementation of this game-based learning module is run for 30 science students at Matriculation College. The one-group pre-test and post-test were used during the implementation. Students sit for the pre-test before the intervention and sit for the post-test after the intervention to see the effect of this module on students' HOTS in the chemical equilibrium topic. The reflection form is assigned for each sample to see the evaluation from the students after using the game-based learning module.

3. Results

To answer RQ1, the descriptive analysis using percentage and mode determines the suitable key features of the game-based learning module to be developed in the topic. **Table 1** shows the survey results.

The key features chosen by the chemistry lecturers at the Matriculation College include the 11 items listed in **Table 1**. Items 1, 4, 5, 8, and 11 got 100% scores, showing that all agreed to include these features in the game-based learning module. Items 2,3,6,7,9, and 10 obtained the highest per cent of "totally agree" and "agree," showing that the items were also preferred as the key features for the module.

To answer RQ2, the pre-test and post-test results were compared. The significant difference in the scores toward HOTS among students in their pre-test and post-test performances was determined using a paired-sample t-test. The hypothesis was formulated as:

H_o: There is no significant difference between the pre-test and the post-test

H1: There is a substantial difference between the pre-test and the post-test

Table 1. Findings of key features of the game-based learning module survey based on 5-Likert scale form.

No	Key Features	Mode	Percentage (%)	Description
1	Clear teaching objectives	5	100	Totally agree
2	Questions like a real exam	5	51.4	Totally agree
3	Integrate with technology	4	54.1	Agree
4	Cater to students' response	5	100	Totally agree
5	Quick Feedback	5	100	Totally agree
6	Incentive system (points, scores, drawbacks)	5	56.8	Totally agree
7	HOTS elements are integrated into each activity	5	40.5	Totally agree
8	Real-life problems on the Chemical Equilibrium topic	5	100	Totally agree
9	A clear guide to running the activities	5	51.4	Totally agree
10	Align with the matriculation syllabus	4	54.1	Agree
11	Consider the timeline of the matriculation system	5	100	Totally agree

Source: Elaborated by the authors.

The analysis's result is shown in Table 2;. The pre-test mean score was 49.61, while the post-test mean score was 73.06. From the average point of view, the value between the pre-test and post-test increased after the intervention using the GBL model.

Table 2. Pre-test and post-test statistics.

Test	Mean	N	Std. Deviation	Std. Error Mean
Pre-test	49.61	30	8.273	1.486
post-test	73.06	30	9.740	1.749

Source: Elaborated by the authors.

Based on Table 3, the result of the paired sample T-Test was significantly different in that the significance level (P) was 0.000 < 0.05. The result of the statistical analysis rejects the null hypothesis (H_o) and confirms the alternative hypothesis (H_1). Therefore, there was a significant difference between HOTS Test (pre) scores and HOTS Test (Post) scores.

Table 3. Paired samples test.

Test	Mean	*df*	Sig. (2-tailed)
Pre-test - post-test	-23.452	30	0.000

Source: Elaborated by the authors.

4. Conclusions

In conclusion, the game-based learning module has proven to be an effective strategy to enhance students' higher-order thinking skills. The new generation needs new ways of learning while enhancing their 21st-century skills like analyzing, evaluating, and creating thinking skills to be applied in solving real-world problems. For this study that focuses on the matriculation level, this module helps to develop students' thinking and prepares students for a higher level of education after completing the pre-university level.

Suggestions for the next researchers to conduct the game-based learning module in a wide range of samples and can study deeper effects of game-based learning for each HOTS category like analyzing, evaluating, and creating so that more significant findings according to each HOTS category can be measured. The empowerment of HOTS among matriculation students can produce quality graduates for 21st–century labor demands and contribute to the sustainable development growth goals by 2030.

Authors' contribution

Conceptualization: Nurul Hanani Rusli; Nor Hasniza Ibrahim; **Data curation**: Norliyana Md Aris; **Formal Analysis**: Nurul Hanani Rusli; **Funding acquisition**: Not applicable; **Investigation**: Nurul Hanani Rusli; Nor Hasniza Ibrahim; **Methodology**: Nurul Hanani Rusli; **Project administration**: Nurul Hanani Rusli; **Resources**: Norliyana Md Aris; **Software**: Not applicable; **Supervision**: Nor Hasniza Ibrahim; **Validation**: Nurul Hanani Rusli; Norliyana Md Aris; **Visualization**: Nurul Hanani Rusli; **Writing – original draft**: Nurul Hanani Rusli; **Writing – review & editing**: Nor Hasniza Ibrahim.

Data availability statement

All data sets were generated or analyzed in the current study.

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Conflict of interest

The authors declare that there is no conflict of interest.

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