Journal of Education and Learning; Vol. 13, No. 3; 2024
ISSN 1927-5250 E-ISSN 1927-5269
Published by Canadian Center of Science and Education

Computer Game Development for Balancing Chemical Equations Skill in Chemistry Education

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Received: November 26, 2023 Accepted: February 12, 2024 Online Published: April 10, 2024

doi:10.5539/jel.v13n3p99 URL: https://doi.org/10.5539/jel.v13n3p99

Abstract

This computer game was designed and developed to enhance the skills of high school students in balancing chemical equations. The game simulates a trip to the beach and consists of three missions, ranging from easy to difficult levels, enabling players to engage in a contextual learning experience. The objectives of this computer game development were to compare learning achievement before and after using the game and to evaluate the level of satisfaction in learning through the game. The study sample consisted of 27 high school students in Mathayom Suksa four, selected from a medium-sized school in Pathumthani Province, Thailand, using purposive sampling. The research employed two primary assessment tools: 1) a pretest-posttest to assess the understanding of balancing chemical equations and 2) a satisfaction evaluation form to evaluate the computer game. Data analysis was performed using the mean, standard deviation (S.D.), t-test, and normalized gain (<g>). The findings revealed that the mean learning achievement after using the computer game (13.52) was significantly higher than the mean before using the computer game (11.52) at a significance level of 0.01. The overall normalized gain for the class was at a moderate level. Furthermore, the majority of the participants expressed high satisfaction with a mean score of 4.56, indicating that the computer game was user-friendly and conducive to learning. The content, which presented chemical reactions in daily life within the computer game, was also easily comprehensible. Therefore, it could be effectively utilized to enhance classroom learning and applied to other areas of knowledge.

Keywords: balancing chemical equations, computer game, educational game

1. Introduction

A chemical equation serves as a foundation for students to comprehend chemical changes through the utilization of symbols and chemical formulas. However, achieving a perfectly balanced chemical equation is essential. The numbers derived from balancing a chemical equation, referred to as coefficients, indicate the mole ratio of reactants and products. Consequently, the skill of balancing chemical equations ranks among the highest priorities for chemistry students. This is because it constitutes a fundamental unit of the high school curriculum and a critical cornerstone for future chemistry lessons. Balancing chemical equations necessitates both comprehension and practice. Students must navigate chemical symbols, which can occasionally lead to misunderstanding due to the use of chemical symbols and intricate explanations. For example, some students can balance chemical equations but may struggle to accurately represent them through chemical symbols due to a lack of understanding of coefficients and subscripts in chemical formulas (Yarroch, 1985). This situation can pose challenges in the process of learning chemistry.

Utilizing games as educational materials is a novel pedagogical approach aimed at integrating gaming and knowledge. A fundamental concept behind this approach is to enable students to acquire knowledge while simultaneously enjoying the game (Wang & Wu, 2008). Engaging students in a way that piques their excitement and fosters a desire to learn and maintain focus is key. This enthusiasm not only facilitates effective learning but also motivates students to sustain their educational journey. Serious games and video algorithms have proven to be effective tools in enhancing the educational proficiency of nurses and midwives, as supported by research conducted with students. When used in conjunction with traditional pedagogical approaches, these technologies play a vital role in laying a robust foundation of knowledge, competencies, proficiency, and the attainment of professional qualifications (Georgieva-Tsaneva & Serbezova, 2021*)*. An educational game can be designed by combining the theories of effective learning environments and multiple intelligences to support and enhance the

learning process for students while introducing a new type of educational resource. In recent times, educational games have seen widespread development in various forms. The integration of technology, including various digital media, has significantly enhanced the convenience of modern education. As evidenced by a study on "Information Resources Usage in Project Management Digital Learning System" (Davidovitch, Belichenko, & Kravchenko, 2017), it was found that digital learning served as an effective tool in universities worldwide. This method enabled learners to access essential knowledge at any time and from any location.

In addition, there was also an emphasis on the design and creation process of learning media using technology, particularly digital media, to diversify and enhance the learning experiences for students. The finding from a study titled "Use of Digital Learning Platform in Diagnosing Seventh Grade Students' Mathematical Ability Levels" This research showed that effective learning experiences could be created for learners through a well-designed process. The design and quality assessment of a digital learning platform developed to assess the mathematical proficiency of seventh-grade students in the domains of Measurement and Geometry were also described. The empirical findings revealed that the digital learning platform demonstrated high appropriateness in terms of usefulness, suitability, and accuracy. However, its feasibility was rated at a moderately appropriate level. In summary, the digital learning platform proved valuable for obtaining substantial information in evaluating the mathematical ability levels of seventh-grade students (Chinjunthuk, Junpeng, & Tang, 2022). In addition to the various technology media mentioned earlier, there is also an innovative educational approach – computer game – that helps captivate learners' interest in lessons even more. These games have the unique ability to motivate individuals of all genders and ages to engage in both playing and learning, fostering intrinsic motivation that contributes to skill development. In a research study titled "Using Serious Games in Teaching German as a Foreign Language", it was observed that most investigations related to Digital Game-Based Language Learning (DGBLL) primarily concentrated on young language learners. The favorable feedback from participants regarding the use of digital games indicated their potential appeal to adult learners as well (Al-yaz, Spaniel-Weise, & Gursoy, 2017). Educational games provide students with the opportunity to actively participate in both learning and recreational activities. The use of educational games as pedagogical tools can inspire individuals to take a proactive role in exploring and constructing their own knowledge during the learning journey. It is evident that individuals who exhibit intrinsic motivation for learning not only gain a deeper understanding but also report enhanced overall learning experiences (Patmanthara, Yuliana, Dwiyanto, & Wibawa, 2019). Furthermore, a research paper titled "Effects of Mind Games and Games Containing Physical Activity on Attention and Visual Perception Levels of Primary School Students" demonstrated that games had an impact on the levels of interest and visual perception. In a broader context, the implementation of both mind games and physical activity cards emerged as the most successful experimental approach for enhancing visual perception. Analysis of post-test scores revealed that all experimental groups achieved significantly higher results compared to the control group. Upon closer examination of findings from the experimental groups, it was concluded that the attention post-test mean scores of students in the group exposed to both mind games and physical activity cards were higher than those of the control group, although the difference was not statistically significant (Altun, 2019). The game offers students a sense of freedom, encouraging them to observe, think critically, analyze, and develop constructive thinking while exploring alternative solutions to overcome challenges and achieve success within the game. Furthermore, the game's context fosters an environment where students can explore new concepts, experiment with different approaches, face challenges, and receive rewards for their efforts. The computer game is thoughtfully presented with captivating graphics, colorful images, sounds, and animations. Consequently, this approach to learning has the potential to alleviate the pressures and stresses often associated with traditional learning methods (Rapeepisarn, 2010). The findings from a study titled "The Effect of the Difference between Infographic Designing Types (Static vs Animated) on Developing Visual Learning Designing Skills and Recognition of its Elements and Principles" (Afify, 2018) highlight the effectiveness of utilizing both static and animated infographics in enhancing learners' abilities to identify constituent elements, thereby contributing to an improved learning process. It is evident that learners exhibit a preference for visual representations, which require less cognitive effort, over abstract textual content, thereby enhancing their overall learning experience. The game's challenging rules serve to motivate students to learn more and empower them to choose what to learn based on their individual abilities and needs. Immediate feedback in the form of learning results or achievements further reinforces this learning approach. The challenging rules of the game serve to stimulate and motivate students, encouraging them to delve deeper into their learning or empowering them to choose their learning path based on their own abilities and needs. Additionally, the immediate feedback provided, in the form of learning results, scores, or achievements, acts as another form of reinforcement. A case study conducted at a primary school in Scotland (Razak & Connolly, 2013) involving a Primary four teachers and her students, compared two methods for teaching timetables: with

and without computer games. The results indicated a slight improvement in learning outcomes when computer games were integrated. This underscores the notion that computer games do not diminish the teacher's role. To fully harness the potential of GBL, teachers require additional training and exposure to GBL practices to enhance their proficiency in this approach. When teachers provide adequate support, GBL has the potential to enhance engagement, lead to improved learning outcomes, and alleviate the tedium often associated with the learning process. Computer games are well-suited as educational media for helping students acquire knowledge, enjoy their lessons, and learn while experiencing joy simultaneously (Jakchai, 2009). Moreover, teaching through computer games offers a method for students to immerse themselves directly in the learning process as active participants. This approach also increases students' engagement in learning (Kammanee, 2004). Gamification introduces valuable attributes that act as motivational drivers, enhancing learners' performance and enabling the collection of quantifiable feedback. The gamification design process holds the potential to ensure heightened student engagement and effective utilization within the eLearning environment, thereby promoting active student participation and cultivating their enjoyment of the educational experience (Yamani, 2021). Learning through this approach can enable students to more easily achieve their learning objectives. GBL aligns with the modern education paradigm of the 21st century, which places students or learners at the center of the learning process, with teachers assuming the roles of supporters and facilitators. Computer games promote effective learning by employing a variety of multimedia elements such as animation, video, simulation, and games. Learning takes place when students encounter real-life situations and independently solve problems (Wheatly, 1991). Kolb's Experiential Learning Theory (ELT) (Kolb, 1978) underscores the crucial role of experience in the knowledge acquisition process. Students have the capacity to engage with their experiences actively or passively, thereby directly enhancing their knowledge through experiential interactions (Le Brasseur, 2023). According to a study on "Students' Acceptance of Simulation Games in Management Courses: Evidence from Saudi Arabia" (Bamufleh, Hussain, Sheikh, & Khodary, 2020), it was identified that simulation games actively and significantly contributed to the domain of educational technology. The results and data analysis suggested a positive impact on students' inclination to engage with simulation games. Higher intention among students to utilize the simulation game correlated with an increased likelihood of actual usage.

This research titled "Computer Game Development for Balancing Chemical Equations Skill in Chemistry Education" aimed to design and develop a computer game that allowed Mathayom Suksa four students to practice balancing chemical equations. The game incorporated illustrations and real-life chemical reactions to capture students' attention and motivate their learning. The study had the following objectives: 1) To design and develop a computer game for practicing the skill of balancing chemical equations among Mathayom Suksa four students; 2) To compare the students' knowledge of balancing chemical equations before and after using the computer game; and 3) To evaluate the satisfaction levels of learning when using the computer game.

2. Literature Review

2.1 Learning Material Design

Learning material refers to a tool or medium employed to impart knowledge from teachers or other knowledge sources to students, assisting them in attaining the learning objectives set by educators (Phummipak, n.d.; Brown et al., 1983; Kumut, 1976). Learning material can be categorized into three main groups based on their form or physical attributes, usage, and their roles as learning resources.

The ADDIE Model is one of the most recognized and widely utilized models in the field of learning material design (McGriff, 2000). As shown in Figure 1.

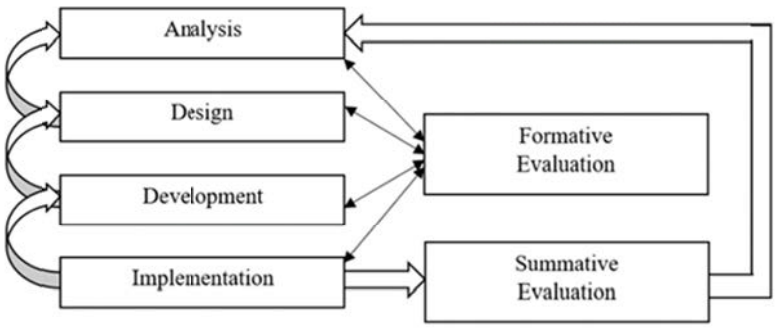


Figure 1. ADDIE Model from: McGriff, Steven J. (2000).

2.2 Computer Game for Learning

Computer games for learning refer to the utilization of computer games to facilitate and support the learning process. These games motivate students to engage in learning through play, fostering effective learning by encouraging hands-on practice and independent problem-solving. In recent times, there has been a surge in the development of educational games that incorporate content designed to enhance students' learning experiences.

Educational games are innovative tools that promote learning through play. Teachers serve as guides, instructing students on how to follow specific objectives and game rules (Kammanee, 2004). Educational games aim to capture students' attention, develop their skills, and cultivate a positive attitude toward the subject matter, thus enhancing content retention. According to research by the Office of the National Primary Education Commission (1994) and Suwannarat (1993), these games help students sharpen their observational skills, including visual, motor, memory, and sensory abilities. They also promote moral and ethical values, providing a solid foundation for future content review. By engaging in these activities, students are not just playing games but actively learning.

Various types of computer games exist, each tailored to specific learning objectives. Nevertheless, they share a common characteristic – the reinforcement of motivation. Aligned with Skinner's reinforcement *(*Skinner, 1954) principle, computer games inspire students to engage with content and acquire knowledge within well-defined rules. This concrete process encourages the active participation of all students, fostering the development of age-appropriate conceptual skills. Furthermore, teachers can assess students' learning achievements through these games (Rodpothong, 2003; Thirakoat, 2021).

Creating a computer game requires a designer's grasp of essential design principles. This includes the ability to set appropriate objectives for both content and students, and employing elements like rules and graphics to convey the meaning of the content. These principles are instrumental in improving communication, enhancing the learning process, and motivating students to reach their learning goals (Thirakoat, 2021).

Researchers have examined both the merits and drawbacks of GBL. On the positive side, students tend to relish learning through games, becoming more motivated and attentive, which in turn aids memory retention. GBL enhances decision-making and problem-solving skills and offers the benefit of instant result tracking. It can be effectively applied to teaching various subjects with careful selection of objectives and content, fostering student collaboration (Kim, 1995; Tuamklang & Tuamklang, 2012). However, certain disadvantages of GBL are worth noting. It demands a considerable amount of time, with some games entailing high costs and requiring extensive preparation. Teachers need the skills to design and create games and facilitate meaningful discussions to help students process and consolidate their learning in alignment with specified objectives.

2.3 Balancing Chemical Equation

Balancing chemical equations involves completing chemical reactions. This process yields coefficients that are essential for calculating the quantities of reactants required and the products to be obtained. The coefficients represent the mole-to-mole ratio between the reactants and the products. The Institute for the Promotion of Teaching *(*IPST, 2019; IPST, 2020*)* provides the following suggestions for balancing chemical equations: (1) Count the number of atoms for each element according to the chemical formula; (2) Balance the number of atoms for each element on both sides of the equation if the reactants and products have unequal amounts. Add coefficients (known as stoichiometric coefficients) to achieve balance. Start with the elements that appear in only one formula on each side of the chemical equation. Typically, hydrogen (H) and oxygen (O) atoms are balanced last; (3) During the balancing process, try to avoid changing the stoichiometric coefficients in front of formulas that are already balanced; and (4) If, after balancing, there are fractional coefficients, it is common practice to convert them into whole numbers by multiplying all coefficients by the smallest possible factor. This ensures that the mole ratio of reactants and products remains the same. According to Kolb, D. (1978), the process of balancing chemical equations entails the addition of the smallest possible integer coefficients to ensure that the total number of atoms of the same element on both sides of the equation is equal. The left side represents the reactants, while the right side represents the products. An arrow separates these two sides, adhering to the law of conservation of mass.

3. Method

The study employed purposive sampling, selecting a total of twenty-seven Mathayom Suksa four students from a medium-sized school in Pathumthani Province.

Two research tools were utilized in this investigation: 1) A computer game designed for learning how to balance chemical equations, and 2) A learning activities plan. Data collection involved the use of 1) An assessment form

to evaluate understanding (pretest-posttest) of balancing chemical equations, and 2) A satisfaction assessment form pertaining to the computer game.

3.1 Steps for Designing and Developing a Computer Game to Practice Balancing Chemical Equations Skill, Following the ADDIE Model: They Consisted of the Following Stages

1) Analysis stage: The researchers reviewed documents and research papers focusing on students' understanding of balancing chemical equations and the use of computers in learning. The findings revealed that most students struggled to grasp Chemistry concepts, often perceiving the subject as distant from their daily lives, challenging, and uninteresting. This perception hindered their engagement and motivation in learning. As a solution, the use of computer games was considered intriguing, offering the potential to stimulate students' interest and foster motivation for learning.

2) Design stage: The researchers developed a computer game aimed at helping students practice balancing chemical equations. The steps involved in this process are outlined below.

① Define objectives consistent with the material design – The learning objectives for students encompassed three key aspects: 1) Attaining proficiency in balancing chemical equations, 2) Gaining the ability to interpret the meaning of symbols within chemical equations, and 3) Developing an understanding of chemical reactions in their everyday lives.

② Design the computer game and gameplay, incorporated multiple elements including a storyboard, game content, characters, gameplay instructions, a flow chart for providing an overview of game stages, scenario design, rules, and reactions. The game simulated a beach trip, featuring three progressively challenging missions: Mission 1 – Preparation, Mission 2 – Long Trip, and Mission 3 – Aloha Party.

3) Computer game development to practice balancing chemical equations: The researchers employed Adobe Captivate to facilitate interactions between students and the computer game. The drag-and-drop feature proved user-friendly and convenient. Furthermore, Adobe Illustrator was used for creating characters, objects, images, and animations within the game. Subsequently, all elements underwent editing and enhancement using Adobe Photoshop. The computer game underwent a thorough quality check, involving assessment by experts in content, media, and technology. The quality was evaluated at various levels using Likert's scale. Deficiencies within the computer game were addressed, resulting in a refined version ready for testing with the students as originally planned.

4) Implementation: The computer game was installed on school computers, and comprehensive guidebooks were provided to both teachers and students for straightforward usage. The planned activities were executed seamlessly.

5) Evaluation: To evaluate students' learning achievement, pretests, posttests, and dependent t-tests were conducted. Additionally, a satisfaction form was employed to gauge students' contentment following their use of the computer game.

3.2 Design and Development of Research Tools

The researchers developed a learning activity plan on computer game which consisted of pretest and posttest to evaluate the students' understanding of balancing chemical equations. The satisfaction form was also designed to assess the students' satisfaction toward computer game.

3.3 Data Collection

The study received certification from the Research Ethics in Human Committee of Thammasat University, 2nd Edition, in the field of Social Science, allowing for human participation. Data collection was divided into two parts: the first involved gathering data from content and multimedia experts, who evaluated the computer game designed. The second part included an examination of the learning activity plan for the computer game, assessing its appropriateness. Both the pretest and posttest, designed to evaluate students' comprehension of balancing chemical equations, were scrutinized for language appropriateness and consistency with the learning objectives' index of items based on IOC. Additionally, data were collected from the student samples to assess their learning achievements before and after using the computer game for practicing balancing chemical equations, as well as to measure their satisfaction with this approach.

3.4 Data Analysis

The researchers conducted a thorough analysis of the computer game designed for practicing balancing chemical equations skills among Mathayom Suksa four students, assessing both the quality of its content and multimedia components. Simultaneously, they examined the appropriateness of the learning activity plan associated with this

game. Furthermore, the quality of the pretest and posttest, used to evaluate students' comprehension of balancing chemical equations, was scrutinized. The researchers also assessed the quality of the satisfaction evaluation form related to the computer game. In the case of learning achievement, the study compared pretest and posttest scores to determine the mean and standard deviation, analyzing the impact of learning through the computer game. Likewise, the study delved into students' satisfaction with the computer game.

3.5 Statistics for Analysis

In this study, several statistical methods were employed. The Index of Item- Objective Congruence (IOC) was utilized to evaluate the quality of the evaluation form. Additionally, data analysis involved the use of statistical tools, including t-tests, mean ($\overline{x}$), standard deviation, and normalized gain (<g>), with calculations following the formula proposed by Hake, R. R. (1998)

4. Result

4.1 Result of Computer Game Design and Development for Balancing Chemical Equation Skill.

The computer game was specifically designed and developed to allow Mathayom Suksa four students to practice the skill of balancing chemical equations. It featured real-life chemical reactions to engage students. The learning objectives encompassed the students to: 1) Acquire proficiency in balancing chemical equations, 2) Interpret the symbols used in chemical equations, and 3) Understand chemical reactions in daily life. This multimedia-based computer game followed a storyline simulating a beach trip and consisted of three progressively challenging missions. Each mission had a 30-minute duration. The first mission, 'Preparation for the beach trip,' required players to count the number of atoms in chemical structures relevant to everyday products. The second mission, 'Long trip to the beach,' involved counting atoms in balanced chemical equations commonly encountered in daily life. The third mission, 'Aloha Party,' tasked players with balancing previously unbalanced chemical equations related to common daily-life reactions. Mission 1 and 2 provided hints using images and descriptions, while Mission 3 incorporated animated videos with sound for explanation. Completing all three missions marked victory in the game. Sample screens from the computer game were illustrated in Figures 2–5.

Figure 2. The first lesson/the first mission

Figure 2 shows the game interface of the lesson on balancing chemical equations skill included three missions. The sample figure illustrated the first mission, 'Preparation for the beach trip', requiring players to count the number of atoms in chemical structures of selected products.

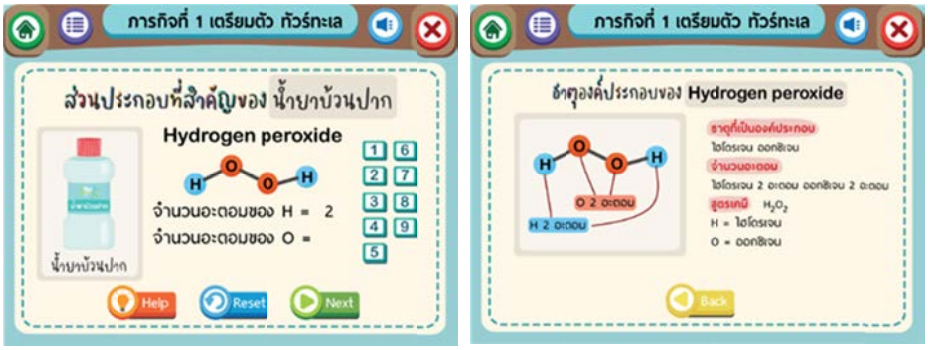


Figure 3. Test on reaction and assistance for Mission 1

Figure 3 shows the solution for Mission 1. The selected everyday product was mouthwash and the players had to count the number of atoms in chemical structures. The ‘Help’ button was available to allow the players to explore relevant concepts. The explanation of elements, number of atoms, and chemical formula was given along with images.

Figure 4. Test on reaction and assistance for Mission 2

Figure 4 shows the solution for Mission 2, focusing on counting atoms in balanced chemical equations of acid rain. These chemical equations represented the reactions commonly found in daily life. The ‘Help’ button was available to allow the players to delve into relevant concepts. The explanation of reactants, products, and calculation of the number of atoms was given along with images.

Figure 5. Test on reaction and assistance for Mission 3

Figure 5 shows the solution for Mission 3 – balancing previously unbalanced chemical equations related to daily life environment. The sample situation was barbeque grilling with charcoal, producing an incomplete combustion of wood charcoal and oxygen. The ‘Help’ button was available to allow the players to study relevant concepts. The explanation of reactants, products, and calculation of the number of atoms was given along with images.

In the evaluation of the computer game by content experts (3 experts), the mean score reached 4.56, indicating a very good level. The highest-rated area, with a mean score of 5.00, was the content's appeal in the media and its effectiveness in promoting classroom learning. The evaluation by media and technology experts (3 experts) yielded a mean score of 4.73, also at a very good level. The top three graphic elements, with average scores ranging from 4.81 to 4.78, included: the media’s capacity to make learning enjoyable, motivating students, and sustaining their attention; its usefulness as a learning tool to support students’ comprehension of balancing chemical equations outside the classroom; and its effectiveness in enhancing students’ understanding of balancing chemical equations. In terms of text elements, the language was accurately used, clear, and easily comprehensible. The text layout was well-structured and properly formatted. Sentence structure was appropriately applied, ensuring effective communication. Animation elements featured suitable size, clear and sharp visuals with high definition, meeting quality standards. Overall, the computer game was deemed to meet very high standards in both content and multimedia aspects.

4.2 Result of Learning Achievement Evaluation Before and After Using the Computer Game for Balancing Chemical Equation Skill of Mathayom Suksa Four Students

Table 1. The analysis of learning achievement evaluation before and after using the computer game

Evaluation	N	Mean	Standard Deviation	t	df	sig
Pretest	27	11.52	2.79	4.04	26	0.00**
Posttest	27	13.52	2.55			

Note. ** A statistical significance level of 0.01.

Following the assessment of learning achievement before and after utilizing the computer game, it was evident that the posttest mean score surpassed the pretest mean score. This comparison between the pretest and posttest scores distinctly indicated that the learning achievement following the utilization of the computer game exceeded the achievement before its application. This disparity in achievement held statistical significance at the 0.01 level, as illustrated in Table 1.

The evaluation form for understanding the skill of balancing chemical equations among Mathayom Suksa four students provided pretest and posttest scores, which were subject to analysis using the normalized gain (<g>) method, following the formula established by Hake R.R. (1998). This analysis was conducted with the purpose of assessing the progress in learning concerning the three defined learning objectives both before and after the implementation. The outcomes of this analysis had been detailed in Table 2.

Table 2. The learning progress evaluation before and after using the computer game based on 3 learning/evaluation objectives.

Learning Progress Based on Evaluation Objectives	Item	Progress	
		<g>	Interpretation
1. The students understand that chemical equations encompass the chemical formulas of reactants and products, directional arrows indicating the reaction's progression, and potentially symbols denoting the state of substances or other factors relevant to chemical reactions.	1–5	0.0	Low
2. The students grasped the concept that chemical reactions involve transformations resulting in new substances, while the type and quantity of atoms of each element remain unchanged.	6–10	0.7	High
3. The students are able to identify and demonstrate the coefficients acquired through the process of balancing chemical equations.	11–15	0.6	Moderate

The table above illustrated that this computer game was most effective in advancing the students' learning in alignment with the second objective, achieving a high level of normalized gain (<g>) at 0.7. This was followed by a moderate level of learning development in the third objective, with a <g> of 0.6. However, the learning development related to the first objective achieved a low level with a <g> of 0.0. This was attributed to the fact that a significant proportion of students were able to answer the questions correctly prior to playing the game. Subsequently, after engaging with the game, there was a slight increase in the number of students providing correct answers.

The assessment of learning progress was carried out to provide an overview of the entire class. This assessment involved the use of a pretest and posttest, each comprising 15 items, to evaluate learning achievements before and after the utilization of the computer game. The outcomes of this assessment were presented in Table 3.

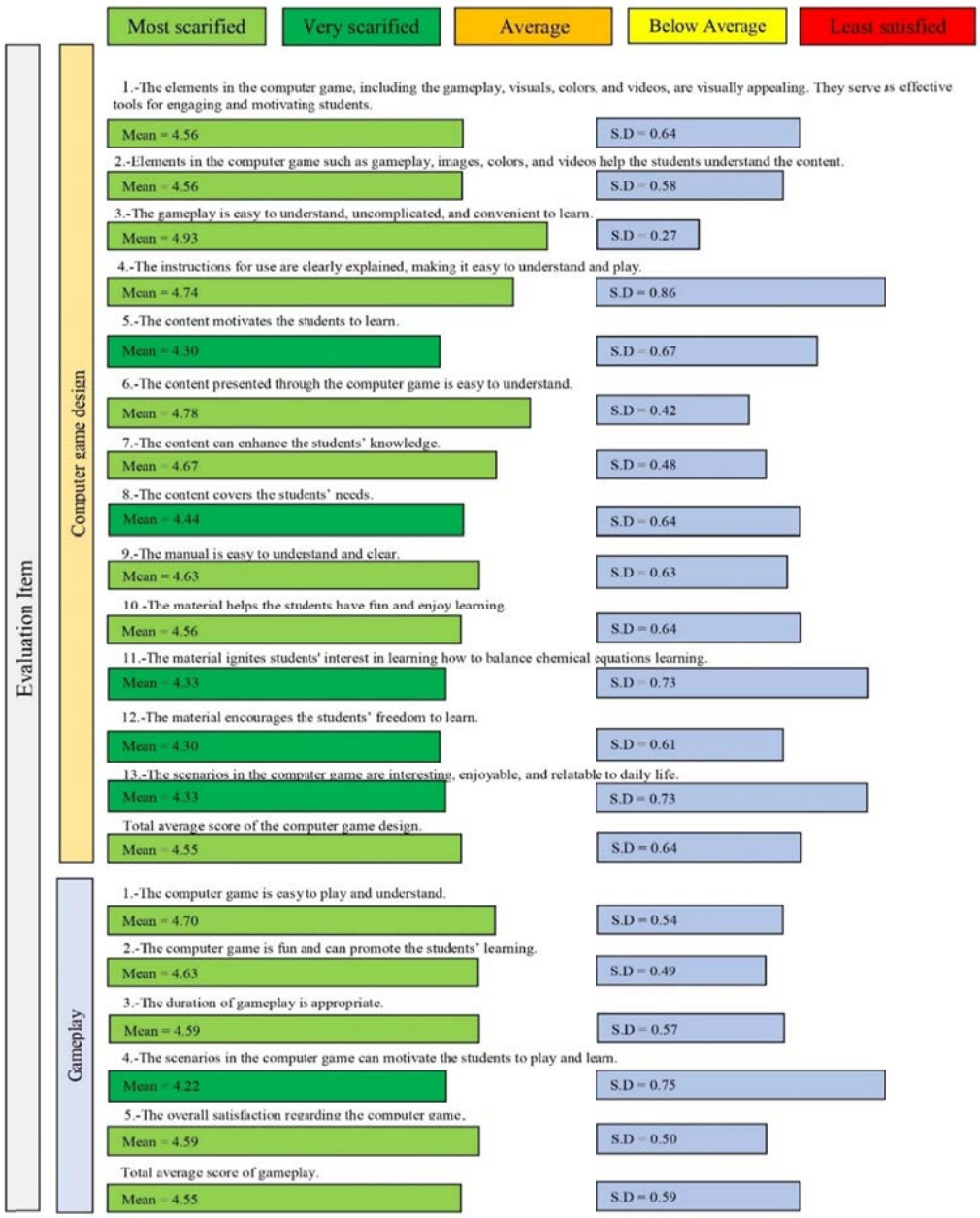
Table 3. The analysis of learning progress in the classroom using pretest and posttest evaluation of learning achievement before and after using the computer game for balancing chemical equations skill of Mathayom Suksa four

Number of All	Pretest (Full score of 15 marks)		Posttest (Full score of 15 marks)		Progress	
Students	Mean	% pretest	Mean	% posttest	<g>	Interpretation
27	11.52	76.80	13.52	90.13	0.6	Moderate

The table above illustrated that the average score (mean) before learning (% pretest) was 76.80, while the average score after learning (% posttest) was 90.13. The normalized gain (<g>) was calculated at 0.6, indicating

a moderate level of improvement. To increase the normalized gain, it was suggested that the time allocated for playing the game in each mission should have been extended beyond 30 minutes. Alternatively, more questions or items could have been added to the game to promote the students' learning.

4.3 The Result of satisfaction evaluation regarding the computer game.



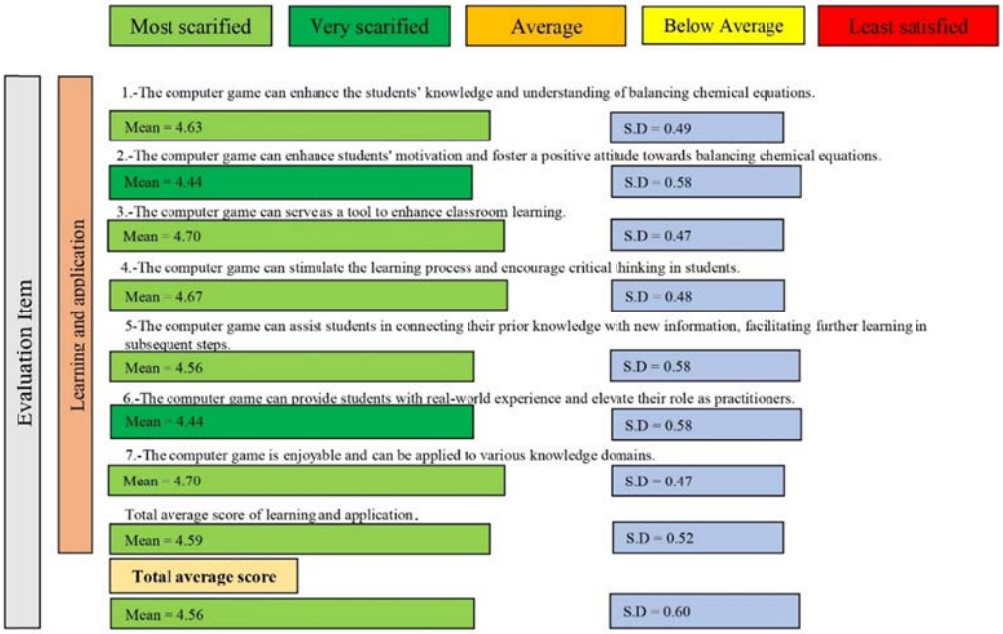


Figure 6. The result of satisfaction evaluation regarding the computer game for balancing chemical equations skill

The satisfaction evaluation of students who used the computer game indicated a high level of satisfaction, with an average score of 4.56 as illustrated in Figure 6. Students expressed the view that this game could be effectively integrated into other Chemistry lessons, enhancing the overall learning experience. Furthermore, students suggested further development of the game by increasing the number of missions and challenges to provide a greater level of complexity. They also recommended changing the hints or support features to offer more guidance rather than direct answers, with a limitation on the frequency of such assistance.

5. Discussion

Based on the evaluation by experts in terms of content, multimedia, and satisfaction, the computer game for improving the skill of balancing chemical equations among Mathayom Suksa four students met the anticipated criteria. The mean posttest score exceeded the pretest score. Students expressed a high level of satisfaction with the computer game. This was due to the step-by-step development of the game, following the ADDIE model's learning design theory. The stages were clearly defined, including an analysis, literature review, the use of a program for developing the computer game for learning, and an analysis of student and learning context.

During the design stage, the researchers delineated the development of the computer game. This included specifying learning objectives, content design, crafting problems for evaluating learning achievements, naming materials and media to align with objectives, defining gameplay mechanics, structuring the game, designing scenarios, creating screen layouts, determining content placement, configuring monitor orientation, and crafting graphic elements for buttons and lesson-linked menus, etc.

In the development stage, the researchers employed Adobe Captivate for building the computer game focused on chemical equation balancing skills. This software facilitated interactions between players/students and the game. Additionally, Adobe Illustrator was utilized for character and object illustrations, while Adobe Photoshop was employed to enhance images. Following this, the computer game underwent testing and evaluation by experts, and their feedback was incorporated to enhance the media before its intended use with students. In the implementation stage, the computer game for improving chemical equation balancing skills was installed on the school's computers. A game manual was provided to teachers and students, and planned activities were carried out. During the evaluation stage, the students' learning progress was measured through pretests and posttests, alongside an assessment of their satisfaction with the computer game for chemical equation balancing skills. Suggestions and feedback were integrated into further research. The design closely aligned with the study by Li Xicai (2018), which highlighted that the key feature of educational games, in an educational context, was their

inherent educational nature, setting them apart from typical games. Consequently, during the design and development phases, it was crucial to incorporate instructional content and aim for a balance between the educational and recreational elements of the educational game.

Additionally, this study revealed that utilizing a computer game for mastering the skill of balancing chemical equations was an effective learning method. Beyond comprehending the principles of balancing chemical equations, students found enjoyment in the game, as it offered self-paced learning opportunities outside of the classroom. This approach presented an alternative that could alleviate limitations associated with cost and human resources, making learning more accessible and effective. These findings aligned with the research conducted by Kaliappen (2019), which demonstrated that computer-based simulation games had the potential to yield positive outcomes, including enhanced learning, skill acquisition, and the cultivation of teamwork among students engaged in collaborative learning experiences. Moreover, the computer game facilitated a better understanding of language usage, consistent with the findings in the study by Turan, Avinc, Kara and Gokta (2016). In their mixed-method research, a comparison between gamification-based approaches and conventional instructional methods revealed that gamification significantly improved academic performance, reduced cognitive workload, and enhanced overall perceptions among the experimental group, resulting in higher academic achievement. This motivation-enhancing approach also resonated with the work of Halloluwa, Usoof and Hewagamage (2014), who explored methods to stimulate learner motivation in primary education in Sri Lanka. Their paper emphasized the recognition of various types of computer and video games suitable for educational purposes within the classroom environment. Furthermore, a wide array of benefits associated with these games, such as their capacity to drive continuous improvement in students, nurture the development of complex problem-solving skills, and facilitate collaborative learning, was acknowledged as factors supporting their integration into the learning process. This, in turn, contributed to the creation of a more engaging and enjoyable classroom atmosphere. However, it was essential for teachers to employ effective pedagogical strategies to ensure a successful learning experience for students. After the implementation of the computer game for enhancing chemical equation balancing skills, students' learning achievements improved compared to their performance before using the game. Additionally, students expressed a high level of satisfaction. These outcomes underscored the importance of teachers in addressing problems, analyzing the learning context, understanding students' needs, and considering their individual characteristics. Teachers adopted a student-centered approach to facilitate direct experience and exposure. The materials developed were tested and refined to suit the students' needs. Moreover, students were encouraged to practice and review lessons with prompt feedback, aligning with the ADDIE model learning design. In a study of Sameer Mosa Alnajdi's research (2018), "The Effectiveness of Designing and Using a Practical Interactive Lesson based on ADDIE Model to Enhance Students' Learning Performances in University of Tabuk" The study aimed to assess the improvement and development of students' performance through the implementation of practical interactive lessons based on the ADDIE model. The research involved pre-test and post-test evaluations for both groups, and the t-test results indicated significant improvement in students' performances in learning.

The findings demonstrated that both lessons positively affected the enhancement and development of students' performance. Furthermore, the statistical analysis affirmed that the practical interactive lesson, based on the ADDIE model, had a more substantial impact compared to traditional teaching methods. This conclusion addressed the study's central question regarding the effectiveness of using practical interactive lessons to enhance students' learning performance ("Does using practical interactive lesson based on ADDIE model enhance students' learning performance?"). The results indicated a positive and effective impact on students' performance when utilizing a well-crafted practical interactive lesson. In conclusion, learning through a computer game designed based on the ADDIE model presented an intriguing alternative that could be applied to enhance students' skills and knowledge.

Acknowledgments

The authors greatly appreciate the experts in various fields for their help, approval, advice, and time given to this research project. We would also like to thank the sample students who have contributed to this study. The authors gratefully acknowledge the funding provided by the Classroom Research Grant, Faculty of Learning and Education Sciences, Thammasat University, which was instrumental in the successful completion of this research project.

Authors' contributions

Asst. Prof. Dr. Yada Atanan was responsible for the conceptualization, methodology, formal analysis, writing of the original draft, and review and editing of the published work. Asst. Prof. Dr. Amornrat Saithongdee

contributed to the methodology, data collection, and the review and editing process. All authors have read and approved the final manuscript.

Funding

This research was financially supported by research funding provided by Classroom Research Grant, Faculty of Learning and Education Sciences, Thammasat University, Thailand.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Informed consent

Obtained.

Ethics approval

The Publication Ethics Committee of the Canadian Center of Science and Education.

The journal's policies adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

Provenance and peer review

Not commissioned; externally double-blind peer reviewed.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

References

Afify, M. K. (2018). The effect of the difference between infographic designing types (static vs animated) on developing visual learning designing skills and recognition of its elements and principles. *International Journal of Emerging Technologies in Learning*, *13*(9). https://doi.org/10.3991/ijet.v13i09.8541

Alnajdi, S. M. (2018). The Effectiveness of Designing and Using a Practical Interactive Lesson Based on ADDIE Model to Enhance Students' Learning Performances in University of Tabuk. *Journal of Education and Learning*, *7*(6), 212–221. https://doi.org/10.5539/jel.v7n6p212

Altun, M. (2019). The Effects of Mind Games and Games Containing Physical Activity on Attention and Visual Perception Levels of Primary School Students. *Journal of Education and Learning*, *8*(6), 72–82. https://doi.org/10.5539/jel.v8n6p72

Alyaz, Y., Spaniel-Weise, D., & Gursoy, E. (2017). A study on using serious games in teaching German as a foreign language. *Journal of Education and Learning*, *6*(3), 250–264. https://doi.org/10.5539/jel.v6n3p250

Bamufleh, D., Hussain, R., Sheikh, E., & Khodary, K. (2020). Students' Acceptance of Simulation Games in Management Courses: Evidence from Saudi Arabia. *Journal of Education and Learning*, *9*(4), 55–71. https://doi.org/10.5539/jel.v9n4p55

Brown, J. W., et al. (1983). *AV Instructional Technology Media and Methods*. New York : McGraw Hill Book.

Chinjunthuk, S., Junpeng, P., & Tang, K. N. (2022). Use of Digital Learning Platform in Diagnosing Seventh Grade Students' Mathematical Ability Levels. *Journal of Education and Learning*, *11*(3), 95–104. https://doi.org/10.5539/jel.v11n3p95

Davidovitch, N., Belichenko, M., & Kravchenko, Y. (2017). Information Resources Usage in Project Management Digital Learning System. *Journal of Education and Learning*, *6*(2), 146–154. https://doi.org/10.5539/jel.v6n2p146

Georgieva-Tsaneva, G., & Serbezova, I. (2021). Using Serious Games and Video Materials in Clinical Training in Nursing and Midwifery Education. *International Journal of Emerging Technologies in Learning* (iJET), *16*(16), 231–241. https://doi.org/10.3991/ijet.v16i16.23455

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, *66*(1), 64–74. https://doi.org/10.1119/1.18809

Halloluwa, T., Usoof, H., & Hewagamage, K. P. (2014). Stimulating Learners' Motivation in Primary Education in Sri Lanka-A Literature Review. *International Journal of Emerging Technologies in Learning* (Online), *9*(1), 47–52. https://doi.org/10.3991/ijet.v9i1.2964

Jakchai, P. (2009). *Color reading resistor value*. King Mongkut's University of Technology Thonburi, Department of Electrical EngineeringDepartment of Electrical Education.

Kaliappen, N. (2019). Educational benefits of using Business Strategy Game (BSG) in teaching and learning strategic management. *International Journal of Emerging Technologies in Learning* (Online), *14*(7), 209. https://doi.org/10.3991/ijet.v14i07.9792

Kammanee, T. (2004). *Pedagogical Sciences*. Bangkok: Chulalongkorn University Press.

Kim, L. S. (1995). Creative games for the language class. *English Teaching Forum*, *33*(1), 35–36.

Kolb, D. (1978). The Chemical Equation. Part I: Simple Reactions. *Journal of Chemical Education, 55*(3), 184. https://doi.org/10.1021/ed055p184

Kubrick, S. (Director). (1980). *The Shining* [Motion picture]. United States: Warner Brothers.

Kumut, P. (1976). *Research and Teaching Innovation*. Bangkok: Srinakharinwirot Prasarnmit University.

Le Brasseur, R. (2023). Virtual Site Visits: Student Perception and Preferences Towards Technology Enabled Experiential Learning. *International Journal of Emerging Technologies in Learning*, *18*(2). https://doi.org/10.3991/ijet.v18i02.32013

Li, X. (2018). Design and application of children's entertainment education software in preschool education. *International Journal of Emerging Technologies in Learning* (Online), *13*(7), 201. https://doi.org/10.3991/ijet.v13i07.8809

McGriff, S. J. (2000). Instructional System Design (ISD): Using the ADDIE Model. *Instructional Design Models*, *226*(14), 1–2.

National Commission on Primary Education. (1994). *Educational Games*. Bangkok: Kurusapa Publishing

Patmanthara, S., Yuliana, O., Dwiyanto, F., & Wibawa, A. (2019). The use of ladder snake games to improve learning outcomes in computer networking. *International Journal of Emerging Technologies in Learning* (IJET), *14*(21), 243–249. https://doi.org/10.3991/ijet.v14i21.10953

Pattharawit, S. (2015). *Development of Computer Game for Promoting Rational Antibiotics Use*. Doctoral dissertation, Silpakorn University. Pharmacy Program in Health Informatics

Phummipak, C. (n.d.). *See Region*. Pedagogical and educational technology. Bangkok: Prasarnmit.

Rapeepisarn, K. (2010). Computer games for Educational. *Journal of Communication Arts Review*.

Razak, A. A., & Connolly, T. (2013). Using games-based learning: How it influences the learning experience and outcomes of primary school children. *International Journal of Emerging Technologies in Learning* (iJET), *8*(2013). https://doi.org/10.3991/ijet.v8iS2.2782

Rodpothong, S. (2003). *Computer-Aided Teaching Papers*. Bangkok: Chulalongkorn University.

Skinner, B. F. (1954). *The Science of Learning and the Art of Teaching*. Harvard Educational Review.

Suwannarat, T. (1993). *Game Substance Development Curriculum*. Bangkok, Special Education Srinakharinwirot University

The Institute for the Promotion of Teaching Science and Technology (IPST). (2019). *Chemistry Textbook 2*. Bangkok: Chulalongkorn University Press. [in Thai]

The Institute for the Promotion of Teaching Science and Technology (IPST). (2020). *Teacher Guide of Chemistry 2*. Retrieved November 25, 2021, from https://www.scimath.org/ebook-chemistry/item/8293-4-2

Thirakoat, S. (2021). The Study of Educational Game Design Components By Factors Analysis of Player's Perception. *Journal of Graduate Studies Valaya Alongkorn Rajabhat University* (Online), *15*(3), 222–234. Retrieved from https://so02.tci-thaijo.org/index.php/JournalGradVRU/article/view/242165

Tuamklang, K., & Tuamklang, J. (2012). *Development of educational media/innovation for academic advancement*. Bangkok: Yellow Printing (1998) Co., Ltd.

Turan, Z., Avinc, Z., Kara, K., & Goktas, Y. (2016). Gamification and education: Achievements, cognitive loads, and views of students. *International Journal of Emerging Technologies in Learning* (Online), *11*(7), 64–69.

https://doi.org/10.3991/ijet.v11i07.5455

Wang, G., & Wu, H. (2008, December). Research of education game based on virtual reality. In *2008 IEEE Pacific-Asia Workshop on Computational Intelligence and Industrial Application* (Vol. 2, pp. 921–924). https://doi.org/10.1109/PACIIA.2008.243

Wheatley, G. H. (1991). Effective Environments for Promising Elementary and Middle School Students. *Developing Mathematically Promising Students*, 71–80.

Yamani, H. A. (2021). A conceptual framework for integrating gamification in e-learning systems based on instructional design model. *International Journal of Emerging Technologies in Learning* (Online), *16*(4), 14. https://doi.org/10.3991/ijet.v16i04.15693

Yarroch, W. L. (1985). Student Understanding of Chemical Equation Balancing. *Journal of Research in Science Teaching*, *22*(5), 449–459. https://doi.org/10.1002/tea.3660220507