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# Development of a Web-Based Adventure Game for Teaching Chemical Bonding to Senior High School Students

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## **Keywords**

Adventure Game; Chemistry Learning; Covalent Bonding; Game-Based Learning; Learning Media

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## **Abstract**

The abstract nature of chemical bonding concepts poses a significant challenge in senior high school chemistry education. To address this, we developed a web-based adventure game as an innovative instructional medium for teaching covalent bonding, moving beyond conventional drill-based approaches by integrating learning within a narrative-rich, interactive environment. Following a structured methodology, the study began with a requirement analysis, leading to a system design articulated through use case diagrams and flowcharts. The game was subsequently implemented using Unity, PHP, and MySQL, resulting in a functional prototype featuring explorable worlds where players complete missions by answering questions on covalent bonding. Testing confirmed that the game met all specified functional requirements. The results demonstrate that this game successfully transforms abstract chemical principles into a tangible and engaging learning experience through its contextual challenges and score-based evaluation system. It is concluded that the implementation of a story-driven adventure game holds significant potential for bridging the representational gap in chemistry education, effectively enhancing student engagement and conceptual understanding. This research provides a strategic alternative for educators, offering a game-based learning tool that is both accessible via web browsers and aligned with the proficiencies of digital-native learners.

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## **1. Introduction**

Chemistry serves as a fundamental pillar of science, concerned with the composition, structure, properties, and transformations of matter. At the Senior High School level, a solid grasp of chemical bonding such as ionic, covalent, and metallic bonds constitutes a crucial foundation for understanding more complex topics, from stoichiometry to organic reactions (Baltieri et al., 2021). These principles underpin explanations for why elements combine and how the properties of compounds are determined. A significant challenge in chemistry education, however, lies in the inherently abstract nature of the subject, which operates at a submicroscopic level not directly observable. Students are required to visualize the interactions between atoms, ions, and electrons, a task that demands considerable abstract thinking. In the current digital era, students who are digital natives exhibit a strong affinity and literacy for interactive media, including games (Feltrero et al., 2023).

This presents a strategic opportunity to leverage students' intrinsic engagement as a basis for developing innovative and relevant learning media.

Within the pedagogical context, Game-Based Learning (GBL) is widely recognized for its potential to foster immersive learning environments. Previous research, such as that by (Prasetya et al., 2025), affirms that educational games can significantly enhance intrinsic motivation and student engagement. Core game design principles including balanced challenges, immediate feedback, and compelling narratives can facilitate a deeper conceptual understanding by reducing cognitive load and making abstract concepts more tangible (Hooshyar et al., 2021; Huynh et al., 2021). The exploration of technology integration in chemistry education, encompassing the use of interactive animations and simulations, has emerged as a growing trend, indicating a shift towards more dynamic and visual learning modalities (Teplá et al., 2022).

Despite its foundational nature, chemical bonding is frequently a topic where students encounter significant conceptual difficulties. The root of this problem lies in the poorly bridged gap between macroscopic, submicroscopic, and symbolic representations (Mujibaturrahmi et al., 2022). Conventional teaching methods, predominantly reliant on lectures and worksheet exercises, have proven ineffective in bridging this representational gap. These traditional approaches often induce a high cognitive load by compelling students to visualize invisible processes based solely on textual descriptions. Consequently, a perception of chemistry as a difficult and tedious subject is formed, leading many students to achieve only a level of rote memorization without the ability to apply bonding concepts to explain phenomena in everyday life (Utha et al., 2023).

Consequently, an alternative instructional strategy is required to transform the abstract concepts of chemical bonding into a more tangible, engaging, and contextual learning experience. The proposed solution involves the design of a game-based learning environment specifically engineered to address the specific challenges of visualizing submicroscopic processes. Such an environment is anticipated to function as a catalyst for constructing accurate mental models among students, while simultaneously fostering their motivation and interest in chemistry.

A review of the scientific literature indicates that technology-based solutions for this issue have been extensively explored. Several studies propose the use of interactive animations and simulations to visualize bond formation and electron movement, which have demonstrated efficacy in enhancing student comprehension (Tasker & Dalton, 2008). Furthermore, the GBL approach has been implemented through serious games or educational games designed for specific learning objectives (Wicaksono & Prasetya, 2025). The literature suggests that games utilizing puzzle, role-playing game (RPG), and simulation genres can improve student engagement and cognitive learning outcomes (Qian & Clark, 2016). Advancements in web technology have also been leveraged, with several studies reporting the development of web-based media that offer broad accessibility without the need for additional software installation (Nahak & Edwin Ariesto Umbu Malahina, 2025).

More specifically, the exploration of games in chemistry education has yielded promising results. Prior research has established a robust foundation regarding the efficacy of GBL in enhancing learning achievement and motivation. However, upon closer examination, the majority of existing chemistry learning games tend to focus on drill mechanisms and practice problems in the format of isolated quizzes or challenges (Byusa et al., 2022). While effective for practice, this approach often lacks the immersive narratives necessary to connect chemical concepts to a context or story that sparks curiosity. The adventure game genre, whose strength lies in its rich narrative and story-driven progression, remains significantly underexplored for teaching chemical bonding (Mardiana et al., 2019).

Based on the identified gap, this study aims to: (1) Design and develop a web-based adventure game that integrates learning content on covalent chemical bonding for senior high school students; and (2) Measure the effectiveness of this web adventure game in enhancing students' conceptual understanding compared to conventional instructional methods. The novelty of this research lies in the synthesis of the narrative-rich adventure game genre with game mechanics that analogically model the process of chemical bond formation.

Within this game, missions, challenges, and character interactions are designed to directly correlate with the application of bonding concepts, creating a unique context-based learning experience. The research scope is delimited to covalent bonding material as stipulated in the senior high school curriculum. The game will be developed using standard web technologies (HTML5, CSS, JavaScript), and testing will involve tenth-grade students, with the assessment focused on conceptual understanding.

## **1.1 Literature Review**

### **1. Game**

According to (Lee et al., 2022), a game is a structured activity designed to provide entertainment through specific challenges, rules, and objectives. As an interactive medium, games enable players to participate actively in achieving the game's goals via a systematic framework and clearly defined mechanics. In a digital context, games function not only as an entertainment medium but also as an effective learning tool, as they are capable of stimulating user interest and engagement through elements of competition, exploration, and achievement.

### **2. Game-Based Learning**

(Prasetya & Syidada, 2025) define Game-Based Learning (GBL) as a pedagogical approach that integrates game elements into the educational process to enhance learner motivation and engagement. Through interactive designs that incorporate challenges, rewards, and immediate feedback, GBL can transform passive learning into an active and meaningful experience. This approach not only fosters learning interest but also assists learners in comprehending concepts in a contextual and enjoyable manner.

### **3. Chemical Science**

(Hidayanti, 2021) posits chemistry as a branch of science concerned with the structure, composition, properties, and transformations of matter, along with the accompanying energy changes. This field of study involves understanding the relationship between observable macroscopic phenomena and their explanations at the microscopic level of atoms and molecules. In an educational context, chemistry plays a vital role in cultivating students' analytical and conceptual thinking skills regarding natural phenomena in their environment.

## **2. Research Methods**

### Research Methodology

The execution of this research will follow a structured sequence of stages to ensure the study is conducted systematically and achieves its predefined objectives.

### Requirement Analysis

The requirement analysis stage constitutes the initial step undertaken by the researcher to comprehend the specific problem to be addressed through the game development. In this phase, the research focuses on identifying the root causes of the difficulties associated with the predetermined topic. The needs analysis is conducted using two primary methods: observation and a comprehensive literature review.

#### **1. Observation**

The observation method was conducted by the researcher through direct monitoring of processes and phenomena related to the learning environment. This observation aimed to ascertain how high school students interact during lessons on chemical bonding and to identify the obstacles they encounter in this process. Through observation, the researcher can gain a clear understanding of the students' need for more interactive and engaging learning media.

#### **2. Literature Review**

The literature review method was conducted by examining several written sources, such as scientific journals, books, research articles, and other publications relevant to the research topic. This review aims to identify findings from previous studies to serve as a reference in constructing the game to be developed and to provide alternative perspectives on the problems within the predetermined topic. Furthermore, the literature review also seeks to establish a theoretical foundation for the concepts to be utilized.

The findings from the observation and literature review indicate several user requirements. These requirements were subsequently categorized into two primary groups, namely:

### 1. Functional Requirements

Functional requirements refer to the core features that a system must possess to operate according to its intended purpose.

- The system must be capable of storing player data.
- The system shall be capable of displaying a leaderboard.
- The system shall be capable of presenting questions pertaining to chemical bonding concepts.
- The system shall perform point calculations based on the player's time to complete challenges.

### 2. Non-Functional Requirements

Non-functional requirements describe how a system operates, focusing on qualities such as performance, usability, reliability, and user experience, rather than specifying what the system does.

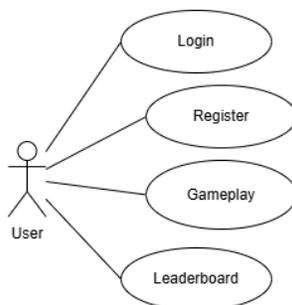
- Web-Based Game.
- Ease of Navigation

### Design Phase

The design phase constitutes a subsequent step following the completion of the needs analysis. In this stage, the researcher designs the game system to be developed, based on the findings from the preceding needs analysis. The primary objective of this phase is to produce a conceptual design that serves as the foundation for developing the web-based adventure game as an interactive learning medium. To architect the system, the researcher employs several modeling diagrams, namely use case diagrams and flowcharts.

#### Use Case

A use case diagram is employed to illustrate the interactions between users and the system. This diagram enables the researcher to identify the specific functionalities that the system must provide to fulfill the user requirements identified during the needs analysis stage.



*Fig. 1 Use Case*

The use case diagram in this research delineates the interactions between the user and the developed web-based adventure game system for learning chemical bonding. This diagram elucidates the core functionalities accessible to the user and illustrates how the user engages with the system to concurrently achieve learning and entertainment objectives.

The primary actor in this system is the User, specifically a student who utilizes the application for combined learning and gameplay. Based on the diagram, four main use cases describe the user's activities within the system: Login, Register, Gameplay, and Leaderboard.

#### 1. Register

The registration process is executed by a new user to create an account for system access. During this stage, the user inputs personal data, such as a username, email address, and password. This feature ensures that each user possesses a unique identity, which is used to save game progress and learning data.

## 2. Login

Upon account creation, the user performs a login process to access the system. This function plays a critical role in authenticating user data, ensuring that only registered accounts are granted access to the full suite of game features.

## 3. Gameplay

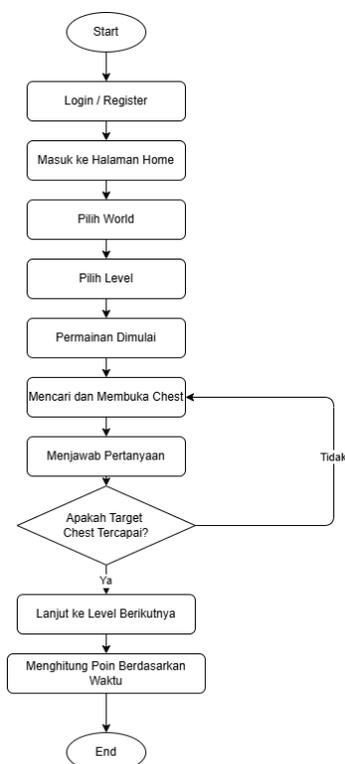
Gameplay constitutes the core of the system, representing the primary activities within the game. In this phase, the user can explore the game world, complete challenges, and answer questions related to chemical bonding concepts. This process not only hones the user's cognitive abilities in understanding chemical principles but also enhances learning motivation through competitive elements and interactive visuals.

## 4. Leaderboard

The leaderboard feature functions to display player rankings based on the scores or points accumulated during gameplay. This element fosters a competitive atmosphere that motivates users to continuously improve their performance in both comprehending the learning material and completing game missions with optimal results.

### Gameplay Flowchart

The gameplay flowchart illustrates the procedural sequence of the game, commencing from user authentication through to the final score calculation. This diagram serves to delineate the game's logical progression systematically, thereby enabling both developers and users to comprehend the sequence of interactions that occur during gameplay.



*Fig. 2 Gameplay Flowchart*

Collectively, the game flow of the web-based adventure game for learning chemical bonding can be described through the following sequential stages:

### 1. Login/Register

The initial stage involves user authentication. If a user does not possess an account, the system will direct them to register by providing the required data. Users with existing accounts can proceed directly to log in to access the system.

### 2. Home

Following successful authentication, the user is directed to the main homepage. From this interface, the user can access several menus, including 'Select World', 'Leaderboard', and 'Profile'.

### 3. Select World

From the main homepage, the user selects the 'Select World' menu to choose the game world they wish to explore. Each world represents a distinct theme or difficulty level, corresponding to specific chemical concepts to be learned.

### 4. World Selection

At this stage, the user selects one of the available worlds. This world selection determines the missions and learning context that the user will encounter throughout the gameplay.

### 5. Select Level

Upon selecting a world, the user is directed to the 'Select Level' page, which displays the list of levels available within that chosen world.

### 6. Level Selection

The user selects the level they wish to play. Each level features distinct challenges and questions, designed with varying degrees of difficulty.

### 7. Gameplay Commences

Upon level selection, the gameplay commences. The player can control a character to explore the game environment according to the pre-designed scenario.

### 8. Level Completion

At this stage, the player undertakes missions to complete the current level, involving the following sub-processes:

#### a. Locating and Unlocking Chests

The player explores the game area to locate chests dispersed throughout the game world.

#### b. Answering Questions

To unlock a chest, the player must correctly answer a question pertaining to chemical bonding concepts.

#### c. Achieving the Chest Target

The player must successfully unlock a specified number of chests to progress to the subsequent level.

### 9. Point Calculation

Upon level completion, the system calculates a point total based on the completion time and the number of correct answers. This aggregate score is subsequently stored as the final result and displayed on the leaderboard, serving as both an evaluation metric and a motivational incentive for the player.

## Implementation

The implementation phase is conducted following the completion of the system design. During this stage, the previously developed system architecture is realized into a functional, executable system. The objective of the implementation phase is to materialize the system design so that it can be tested and utilized by end-users, aligning with the requirements identified during the needs analysis phase. For this implementation process, the technologies employed include the Unity game engine for client-side development, PHP for server-side backend logic, and MySQL for database management.

## Testing

The testing phase is conducted after the system has been successfully implemented in the preceding stage. In this phase, the developed system is evaluated to assess whether the features integrated into the game align with the specified user requirements. While various testing methodologies are available, this research employs the Blackbox Testing approach.

## 3. Result and Discussion

### 3.1. Prototype

The result of the implementation, based on the system design formulated in the design phase, is a game prototype with a display resolution of  $1920 \times 1080$  pixels. This implementation encompasses the development of several key interface components, namely the home screen, the world selection screen, the level screen, and the in-game screen.

#### 1. Home Screen

The home screen serves as the initial interface presented upon launching the game. This page features several primary navigation elements in the form of buttons, which function to direct the user to the world selection screen, display the leaderboard, and access the settings menu.



Fig. 3 Home Screen

#### 2. Select World Screen

The world selection screen is the interface displayed after the user navigates from the home screen. This page presents a list of available worlds that can be played. Each world represents a specific difficulty level or learning topic. To unlock a subsequent world, the player must first complete all levels within the preceding world. The challenges encountered by the player are tailored to the selected world, both in terms of mission complexity and the difficulty level of the questions.

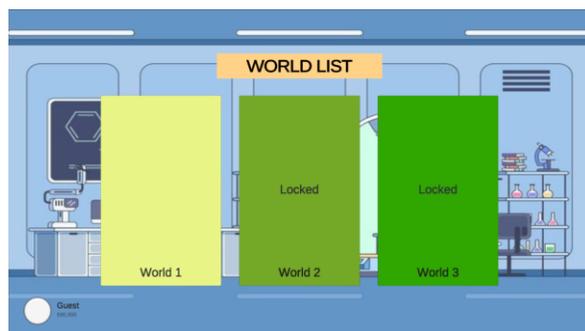


Fig. 4 Select World Screen

#### 3. Select Level Screen

Upon selecting a world, the system displays the level selection screen. From this interface, the player can choose the specific level they wish to undertake. Each level features a distinct difficulty, calibrated according to the material complexity and challenges designed for its respective world.

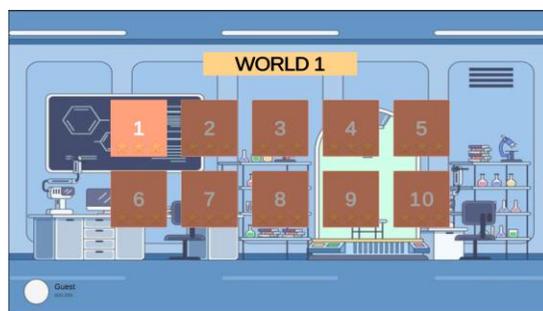


Fig. 5 Select Level Screen

#### 4. In-Game Screen

The in-game screen serves as the primary interface where the player controls a character to explore the game world and complete challenges within the active level. This screen enables the player to maneuver the character, access the workspace, and interact with various interactive objects embedded throughout the game environment.

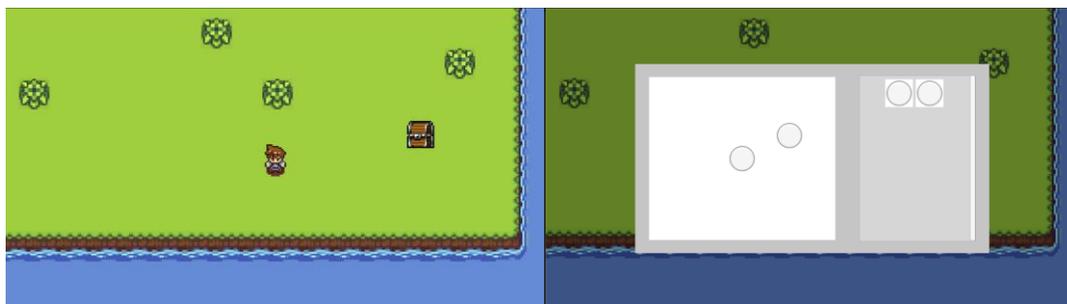


Fig. 6 In-Game Screen

#### 4. Conclusions

This research has resulted in the development of a web-based adventure game learning medium, specifically designed to assist Senior High School students in comprehending the concepts of chemical bonding, with a particular focus on covalent bonds. Based on the stages of needs analysis, design, implementation, and testing, it has been established that the constructed system successfully fulfills the predefined functional and non-functional requirements.

The implementation results demonstrate that the developed game successfully integrates interactive and narrative elements into chemistry education. Features such as the home screen, world selection screen, level selection screen, and in-game interface provide a more contextual and engaging learning experience through challenge visualization and a score-based evaluation system. This approach has proven effective in enhancing student engagement and learning motivation compared to conventional methods, which tend to be passive and rely heavily on rote memorization.

Conceptually, this research demonstrates that the implementation of an adventure game-based learning approach holds significant potential for bridging the gap between abstract understanding and visual representation in chemistry education. Consequently, the development of this learning medium can serve as a strategic alternative for enhancing instructional effectiveness while simultaneously fostering interest in chemistry among the digital generation.

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