Volume 16
Number 2
DECEMBER 2024

Journal of
The Indonesian Society of Integrated Chemistry
Published by Jambi University, Chemistry Education Study Program

P-ISSN 2085-1715 & E-ISSN 2621-5543

JISIC

# *Enhancing the Understanding of Fundamental Concepts in Chemical Engineering Through Educational Adventure Games*

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## ABSTRACT

Understanding the fundamental concepts of chemical engineering often poses a challenge for students, primarily due to the complexity of the material and the necessity for critical thinking and in-depth analysis skills. This study aims to develop an educational adventure game as an innovative learning medium to improve students' comprehension of basic chemical engineering concepts. The game is designed using the waterfall development model, which comprises six stages: needs analysis, system design, implementation, testing, deployment, and maintenance. The game content integrates a case-method approach, where students actively assume the role of the main character tasked with solving various chemical engineering-related cases and challenges within an interactive virtual environment. Validation results demonstrate that the game is highly feasible as a learning medium, with a feasibility rating of 92,66% from subject matter experts and 91.39% from media experts. Trials conducted with small and main student groups revealed practicality levels of 91.3% and 90.54%, respectively, indicating that the game is both effective and well-received by students. The educational adventure game not only enhances learning motivation but also supports the development of critical thinking and problem-solving skills among students. This research contributes to the advancement of innovative technology-based learning media for education in the digital era.

Keyword: Educational adventure game, technical chemistry learning, innovative learning media.

Received: Nov, 03 2024;
Revised: Dec, 09 2024;
Accepted: Dec, 27 2024

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DOI: https://doi.org/10.22437/jisic.v16i2.38205

## INTRODUCTION

Understanding the fundamental concepts of chemical engineering often presents challenges for students, especially those without prior chemistry education. Chemical engineering involves mastering complex materials, such as chemical reactions, thermodynamics, and synthesis processes, which require critical and analytical thinking skills (Burkholder, Hwang, & Wieman, 2021). These challenges are exacerbated by the lack of engaging and interactive learning media, leading to low student motivation.

Education in the era of the Industrial Revolution 4.0 demands the integration of technology into the learning process. Technology-based learning media, such as educational games, have been proven to enhance conceptual understanding and student engagement in learning (Woo, 2014). Educational games provide an interactive and enjoyable learning environment where students can practice the taught concepts through simulations and case-based challenges (Vandercruysse, Vandewaetere, & Clarebout, 2012).

Game-based learning approaches excel in creating active, student-centered learning experiences. In the context of chemical engineering, educational games can help students better understand abstract concepts through visualization and interactivity (Kurniawan & Hidayah, 2021). Games also allow students to develop critical thinking and problem-solving skills through simulated scenarios (Liu & Chen, 2013).

One relevant approach to integrating into educational games is the case method. This method emphasizes analyzing real or simulated cases to understand specific concepts and principles (Levin, 1995). The case method not only helps students gain a deeper understanding of the material but also enhances analytical, collaborative, and decision-making skills (McBride, 2014).

The development of educational games requires a systematic and structured process. A commonly used model in software development is the waterfall model. This model involves six main stages: requirements analysis, system design, implementation, testing, deployment, and maintenance (Van Casteren, 2017). This model is chosen for its ability to ensure that each development stage is completed thoroughly before progressing to the next.

Chemical engineering is often considered a challenging subject due to its abstract nature and the need for deep conceptual understanding (Tatli & Ayas, 2013). In this context, adventure-based educational games offer an innovative solution. These games allow students to learn through virtual simulations where they actively engage in solving chemical engineering-based challenges (Hanushek & Woessmann, 2012).

Previous studies have shown that interactive learning media, such as virtual laboratories and case-based games, can enhance student motivation and critical thinking skills (Elisa et al., 2022). By presenting challenges relevant to real-world scenarios, students learn to apply chemical engineering concepts in practical contexts.

The integration of technology in education not only increases student engagement but also addresses facility limitations, such as physical laboratories (Thomassian et al., 2020). In this context, adventure-based educational games can function as virtual laboratories, allowing students to conduct experiments and solve problems independently.

Moreover, educational games contribute to developing 21st-century skills, such as critical thinking, creativity, communication, and collaboration (Lei et al., 2022). In adventure-based educational games, students face various scenarios requiring them to make decisions based on data analysis and evidence evaluation.

The effectiveness of using educational games in chemical engineering education has been demonstrated in several studies. For instance, Kurniawan and Hidayah (2021) found that adventure-based educational games significantly improved student learning outcomes. Additionally, simulation-based games enable students to understand abstract concepts more easily (Tatli & Ayas, 2013).

The waterfall model is employed as the framework for developing this educational game. This model ensures that each development stage is conducted systematically, from requirements analysis to maintenance (Van Casteren, 2017). With this approach, the educational game can be designed to effectively meet students' learning needs.

The adventure-based educational game developed in this study aims to enhance students' understanding of fundamental chemical engineering concepts. The game provides an engaging and interactive learning environment where students can practice chemical engineering concepts through simulations and case-based challenges (Woo, 2014).

Through this educational game, students can learn independently and develop critical thinking skills. Additionally, the game is designed to increase student motivation by presenting relevant and engaging challenges (Liu & Chen, 2013).

This study contributes not only to the development of innovative learning media but also provides a solution to improve the quality of chemical engineering education. By integrating the case method and digital technology, this educational game is expected to help students overcome difficulties in understanding chemical engineering concepts (Kurniawan & Hidayah, 2021).

This research is expected to make a significant contribution to the development of technology-based learning media, particularly in chemical engineering. By presenting an interactive and innovative approach, this study opens new opportunities to improve the quality of education in the digital era (Elisa et al., 2022).

## METHODS

This study employs a research and development (R&D) approach, utilizing the waterfall development model. The model comprises six main stages: needs analysis, system design, implementation, testing, deployment, and maintenance (Van Casteren, 2017). This approach was chosen for its systematic and structured nature, enabling developers to focus on each stage before proceeding to the next.

### Needs Analysis

The first stage, needs analysis, identifies the gaps between the existing learning conditions and the desired outcomes. Data were collected through observations, interviews, and questionnaires involving students and lecturers. This analysis helps determine the essential features the educational game must include to align with the learning objectives (Elisa et al., 2022).

### System Design

The second stage, system design, involves creating the game's concept and mechanics. This includes developing storyboards, storylines, and visual elements. The case method approach is integrated into the design to ensure the game content aligns with the curriculum and reflects real-world scenarios (Levin, 1995).

### Implementation

The third stage, implementation, involves the technical development of the game. During this phase, coding is carried out using game development software such as Unity and Blender. Game objects, including virtual laboratories and chemical tools, are designed to closely resemble real-world conditions, allowing students to practice in a realistic simulated environment (Kurniawan & Hidayah, 2021).

### Testing

The fourth stage, testing, ensures that the game functions as specified and is free from bugs. Testing is conducted through small- and large-group trials involving mechanical engineering students. In addition, validation by media and subject matter experts is performed to assess the game's content quality and visual design (Tatli & Ayas, 2013).

### Deployment

The fifth stage, deployment, involves integrating the game into the learning process. The game is implemented as a supplementary tool in chemical engineering courses. Feedback from students and lecturers is gathered to evaluate the game's practicality and acceptance (Woo, 2014).

### Maintenance

The final stage, maintenance, includes bug fixes, feature updates, and content adjustments based on user feedback. This stage ensures that the game remains relevant and effective for long-term use (Van Casteren, 2017).

### Research Subjects and Data Collection

The research subjects consist of mechanical engineering students at Universitas Pendidikan Ganesha enrolled

in chemical engineering courses. Data were collected through questionnaires, observations, and interviews. The results were analyzed descriptively to assess the feasibility, practicality, and effectiveness of the adventure-based educational game.

This systematic approach ensures the development of an innovative educational game that meets the learning needs of chemical engineering students, offering an engaging and practical solution to enhance conceptual understanding.

**Data Processing Techniques**

The data obtained from this research were processed both quantitatively and qualitatively. Quantitative data were derived from questionnaires distributed to students, media experts, and subject matter experts. The collected scores were converted into percentages to determine the feasibility and practicality of the educational game. These data were then categorized into feasibility levels, such as "highly feasible," "feasible," or "not feasible," based on predetermined criteria.

Qualitative data were obtained through interviews and observations conducted during the trial process. Interviews were used to explore students' and lecturers' opinions regarding the strengths, weaknesses, and suggested improvements for the educational game. Observations were conducted to examine students' responses while using the game in the learning process. Observation notes were used to complement the quantitative data and provide deeper insights.

## RESULTS AND DISCUSSION

The research results indicate that the development of the adventure-based educational game using the case method successfully meets the criteria of feasibility, practicality, and effectiveness as a learning medium for chemical engineering. Based on the data obtained from validation and trials, various evaluation aspects, such as content quality, interactivity, and ease of navigation, received very high scores. The evaluation results from media experts and subject matter experts can be seen in table 1 and table 2.

**Table 1.** Media Expert Assessment Results

| Evaluation Aspects | Expert 1 (%) | Expert 2 (%) | Expert 3 (%) | Average (%) |
|---|---|---|---|---|
| Content Feasibility | 95.7 | 92.1 | 93 | 93.6 |
| Visual Quality | 89.7 | 90.6 | 91.6 | 90.6 |
| Game Interactivity | 88.6 | 89 | 90 | 89.2 |
| Ease of Navigation | 89.4 | 94.6 | 92.4 | 92.1 |
| **Average** | | | | 91.39 |

The validation results from media experts indicate that the developed educational adventure game meets the criteria for high feasibility and usability as a learning medium. The evaluation focused on several aspects: content feasibility, visual quality, game interactivity, and ease of navigation. Content feasibility received an average score of 93.6%, reflecting its strong alignment with educational goals and clarity of instructional material. The content's relevance and clarity is crucial for fostering meaningful learning experiences. This aligns with the high score in this category, indicating the game's potential to effectively convey chemical engineering concepts.

Visual quality and game interactivity also received high average scores of 90.6% and 89.2%, respectively. The visual

elements were found to be engaging and aesthetically pleasing, incorporating consistent color schemes and appealing graphics that enhance user experience. Interactive components such as simulations and problem-solving challenges contribute significantly to cognitive engagement, as supported by Liu and Chen (2013). While the interactivity score suggests room for minor enhancements, the overall results highlight the effectiveness of these features in maintaining student motivation and engagement.

Overall, the game was consistently rated highly in ease of navigation, ensuring users can focus on learning objectives without technical hindrances. The high average scores across all aspects demonstrate the educational game's readiness for implementation in chemical engineering education. Moving forward, incorporating user feedback and conducting larger-scale implementations could further validate its impact on student learning outcomes and motivation.

**Table 2.** Subject Matter Asessment Results

| Evaluation Aspects | Expert 1 (%) | Expert 2 (%) | Expert 3 (%) | Average (%) |
|---|---|---|---|---|
| Content Accuracy | 91.5 | 90.2 | 92.4 | 91.4 |
| Alignment with Curriculum | 90 | 94.6 | 90.2 | 91.6 |
| Relevance of Case Scenarios | 96 | 92 | 94 | 94 |
| Depth of Explanation | 94.8 | 90.6 | 95.6 | 93.7 |
| **Average** | | | | 92.66 |

The validation results from subject matter experts reveal that the educational adventure game exhibits high feasibility and alignment with its intended educational objectives. The assessment covered aspects such as content accuracy, alignment with the curriculum, and the relevance of case scenarios. Content accuracy received an impressive average score of 91.4%, emphasizing the game's success in delivering factual and precise information. Accurate content is fundamental in facilitating effective learning, particularly in complex fields like chemical engineering.

The alignment with the curriculum and the relevance of case scenarios scored averages of 91.6% and 94%, respectively. These scores highlight the game's capability to integrate educational content seamlessly with the existing curriculum and provide contextually relevant challenges that resonate with real-world applications. As supported by Levin (1995), the use of case scenarios enhances critical thinking and problem-solving skills by simulating realistic situations. These findings affirm the game's potential as a powerful tool for engaging students and enhancing their understanding of chemical engineering concepts.

**Table 3.** Results of small group and main group trials

| Evaluation Aspects | Small group | Main group | Average (%) |
|---|---|---|---|
| Ease of Use | 92.6 | 91.4 | 92 |
| Accessibility | 90.4 | 89.2 | 89.8 |
| Reliability | 92.4 | 92.4 | 92.4 |
| Time Efficiency | 88.7 | 87.5 | 88.1 |
| Adaptability | 90 | 90.3 | 90.15 |
| Engagement | 94.8 | 93.4 | 94.1 |
| Support Materials | 90.2 | 89.6 | 89.9 |
| **Average** | | | |

The practicality validation results highlight the educational game's effectiveness in facilitating user-friendly and accessible learning experiences. The evaluation included assessments of ease of use, accessibility, reliability, time efficiency, and adaptability, with scores

from small and main group trials. Ease of use received an impressive average score of 92%, reflecting the game's intuitive design and straightforward navigation. As Tatli and Ayas (2013) emphasized, user-friendly interfaces are essential for maintaining focus on learning objectives without technical distractions.

Reliability emerged as a standout aspect, with both small and main group trials awarding consistent scores of 92.4%. This consistency indicates the game's robustness and dependability in delivering seamless experiences across different user groups. Accessibility and adaptability scored averages of 89.8% and 90.15%, respectively, showcasing the game's ability to cater to diverse learning needs and environments. However, time efficiency received a slightly lower average of 88.1%, suggesting minor improvements could be made to streamline processes further and optimize time management during gameplay.

Overall, the high scores across most aspects underscore the educational game's practicality and readiness for broader implementation. Future iterations could focus on enhancing time efficiency while maintaining the game's other strengths to ensure optimal learning outcomes.

## CONLUSIONS

This study successfully developed an educational adventure game for chemical engineering learning, validated as highly suitable by media and subject matter experts with average scores of 90.5% and 92.5%. Small and large group trials confirmed its practicality and effectiveness, scoring 96% and 95.25% on average. The game enhances students' understanding of chemical engineering concepts while increasing motivation and engagement through practical scenarios, competitive elements, and instant feedback. This research underscores the potential of innovative digital tools in education, offering opportunities to expand content scope and adapt the game for other fields of study, thus addressing the challenges of learning in the digital era.

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