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# Deep Blended Learning Models for Chemistry Students

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**Abstract**

**Background and Aims:** The deep blended learning paradigm offers students a more adaptable, customized, and interactive learning environment by fusing the benefits of contemporary online learning with conventional classroom teaching. This study aims to explore a deep blended learning model intended to improve chemistry students' abilities for learning.

**Methodology:** A comprehensive literature review and expert panel discussions were conducted simultaneously to formulate an initial list of experts' analysis competency, A total of twenty-one experts were chosen based on their expertise in different disciplines to find out the problems faced by chemistry students in the process of deep learning. A graphical model was established using the Delphi method based on feedback from experts. The final nine experts' feedback was evaluated the blended learning model using the CIPP evaluation principles.

**Results:** According to Bloom's taxonomy of cognitive educational goals, it was found that students encounter issues such as difficulty in accurately memorizing chemical concepts, insufficient ability to summarize and generalize, a disconnect between practical application and theoretical principles, lack of practical operational skills, insufficient ability to analyze and interpret experimental data, difficulty in solving complex problems, and inadequate evaluation of experimental methods. To address these issues, this study developed a hybrid learning model that identifies effective solutions across six dimensions: knowledge, understanding, application, analysis, synthesis, and evaluation. For students, this model enhances their understanding and application of knowledge, and promotes self-directed learning, critical thinking, comprehensive innovation abilities, and active participation, thereby providing strong support for their comprehensive development and academic progress.

**Conclusion:** The hybrid learning model developed in this study effectively addresses students' difficulties in mastering chemical concepts by improving their cognitive abilities at all levels of Bloom's taxonomy. This approach promotes deeper understanding, critical thinking, and practical skills, ultimately benefiting students' academic growth and development.

**Keywords**: Chemistry students; Blended learning; Deep blended learning model; Deep learning problems and resolutions

## Introduction

In recent years, the integration of blended learning models in higher education has gained significant attention due to its potential to enhance student learning outcomes. Blended learning combines traditional face-to-face instruction with online educational materials and interactive activities, offering a more flexible and personalized learning experience. This approach is particularly relevant in the field of chemistry education, where students often face challenges in understanding complex concepts and theories. The development of a blended learning model tailored for chemistry students aims to address these challenges and improve their deep learning abilities.

Chemistry education involves a wide range of abstract concepts, intricate theories, and practical laboratory skills. Traditional lecture-based teaching methods often fall short of engaging students and fostering a deep understanding of the subject matter. According to Bodner & Domin (1995), students frequently struggle with visualizing and conceptualizing chemical phenomena, which hampers their ability to grasp fundamental principles. This issue is further compounded by traditional methods that typically emphasize rote memorization over critical thinking and problem-solving skills (Gabel, 1999). As a result, there is a pressing need for innovative teaching strategies that can enhance students' comprehension and retention of chemical knowledge.



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Blended learning has emerged as a promising solution to these educational challenges. By integrating digital tools and resources into the learning process, blended learning can provide a more interactive and engaging environment for students. Studies have shown that multimedia elements such as animations and simulations can significantly improve students' understanding of complex chemical processes (Cook & Carter, 2008). Furthermore, the flexibility of online learning allows students to learn at their own pace, revisiting difficult concepts and engaging with supplementary materials as needed (Means et al., 2009).

In addition to enhancing content delivery, blended learning models promote the development of higher-order cognitive skills. For instance, project-based learning and collaborative online activities encourage students to apply their knowledge in real-world contexts, thereby deepening their understanding and fostering critical thinking (Quillin & Thomas, 2015). Moreover, the use of data analytics in online platforms enables personalized feedback and adaptive learning paths, catering to the individual needs of each student (Makhambetova et al, 2021).

Despite its potential benefits, implementing blended learning in chemistry education is not without challenges. Technical issues, such as inadequate access to digital devices and reliable internet, can hinder the effectiveness of online components (Owston et al., 2013). Additionally, both students and instructors may require training to effectively utilize blended learning tools and methodologies (Garrison & Kanuka, 2004). Addressing these challenges is crucial for maximizing the impact of blended learning on student outcomes.

Problem Statement of Deep Learning

Fostering deep learning in chemistry students is a multifaceted challenge, involving the integration of complex concepts, practical skills, and critical thinking abilities. Traditional teaching methods often emphasize rote memorization, hindering the development of deeper understanding and application of knowledge (Gabel, 1999). This limitation is particularly evident in learning chemical principles and laws, where students struggle to move beyond surface-level learning to achieve a deeper grasp of the subject matter (Bodner & Domin, 1995). Additionally, students often struggle to connect theoretical knowledge with practical applications, leading to gaps in their understanding and retention of key concepts (Holme et al., 2015). Blended learning models offer a promising approach by combining the strengths of traditional and digital learning environments to enhance engagement, comprehension, and retention (Owston et al., 2013). However, implementing these models requires careful consideration of pedagogical strategies and technological tools to effectively address the diverse learning needs of students, ensuring that both cognitive and practical skills are developed cohesively (Garrison & Kanuka, 2004). Given the existing challenges chemistry students face in deep learning, this study aims to develop a blended learning model specifically designed to enhance their deep learning abilities.

Careful assessment of potential obstacles is necessary for Chemistry students' learning. Overcoming the obstacles to successful adoption requires guaranteeing fair access to technology and offering sufficient training for teachers and students. The results of this study would help both teachers and students using blended learning to improve students' understanding and retention of Chemistry knowledge if these problems are resolved, which will eventually result in a more interesting and successful educational experience.

## Objectives

To explore a deep blended learning model intended to improve chemistry students' abilities for learning. By leveraging the strengths of both traditional and digital pedagogies, this model seeks to provide a comprehensive and flexible learning experience that addresses the unique needs of chemistry education.

## Conceptual Framework

Educational Objectives, categorize cognitive skills into six levels: remembering, understanding, applying, analyzing, evaluating, and creating (Bloom, 1956). Blended learning utilizes this framework by offering diverse learning experiences that cater to each cognitive level. Vygotsky's Social Constructivist Theory also supports this model, emphasizing the importance of social interaction and collaborative learning in knowledge construction (Vygotsky, 1978). The Community of Inquiry (CoI) framework further



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strengthens this approach by integrating cognitive, social, and teaching presences to create a holistic learning environment (Garrison & Kanuka, 2004). In chemistry education, these theoretical perspectives inform instructional strategies that enhance deep learning, critical thinking, and practical application, addressing the inherent challenges in understanding complex chemical concepts (Gabel, 1999; Bodner & Domin, 1995).

## Methodology

This study addresses the critical question: "What blended learning model enhances deep learning abilities in chemistry students?" Based on the theoretical framework and evaluation model, this research seeks effective methods for developing a blended learning model by integrating advanced information technology and relevant research theories. The evaluation model identifies and addresses issues in chemistry students' deep learning processes and proposes measures to enhance their abilities through blended learning.

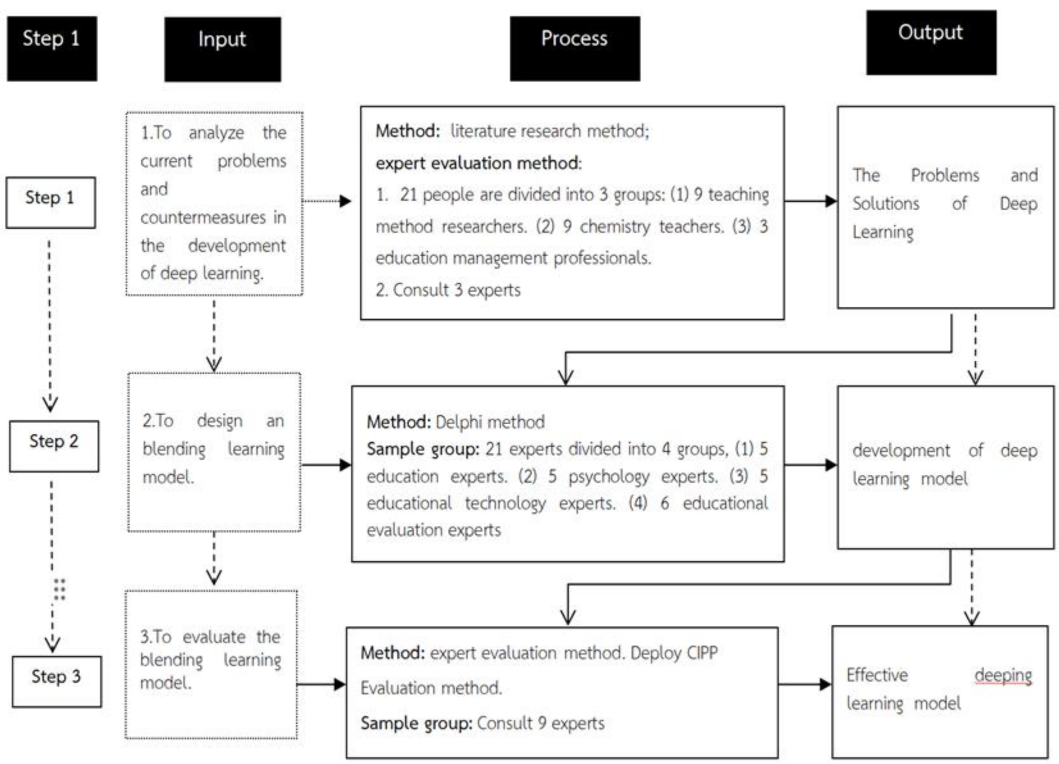


**Figure 1** Researching Mapping

To address the research question, this study employs interviews, surveys, and other research methods to gain an in-depth understanding of the needs and situations of chemistry students in deep learning. Subsequently, the Delphi method, involving multiple rounds of anonymous expert consultations, is used to design a comprehensive blended learning model for students. This model aims to provide guidance, practical references, and insights to enhance chemistry students' deep learning abilities.

**1. Participants**

The experts for the Delphi technique consisted of twenty-one members including teaching method researchers, chemistry teachers, and educational management professionals as shown in table 1. All with over 10 years of work experience, doctoral degrees, and status as academic leaders. The sample group consists of 9 teaching method researchers (42.86%), 9 chemistry teachers (42.86%), and 3 education


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management professionals (14.28%). All members of the participants were individually explained the aims and process of this study. They then gave their informed consent before proceeding further.

**Table 1** Participants

| No. | Component categories | Number of people | Percentage |
|---|---|---|---|
| 1 | teaching method researcher | 9 | 42.86% |
| 2 | chemistry teacher | 9 | 42.86% |
| 3 | education management professional | 3 | 14.28% |

**2. Research Instruments:**

2.1 For this study, we prepared and distributed 21 sets of questionnaires to experts covering the aspects of memorizing concepts of chemical knowledge, Comprehension and interpretation of charts, Application for practical operational skills, analysis and interpret experimental data, Synthesis of comprehensive experimental design, and evaluation of experimental results. The questionnaire set consisted of three parts.

Interview: Implement the designed open-ended question interview to assess the current blended learning model, allowing participants to express their opinions on various aspects. The interview is divided into three parts, with a total of 16 questions. The first part introduces the background and basic requirements. The second part collects personal information such as gender, work experience, professional title, and education. The third part contains 18 questions addressing key areas such as goal setting, major issues in deep learning, and strategies to enhance deep learning capabilities. Open-ended questions are used to allow interviewees to express their thoughts and opinions.

2.2 Procedures for Conducting the Interview:

2.2.1 Based on the research and analysis of relevant data, an interview framework related to the elements of the blended learning model was established to solicit opinions.

2.2.2 Use interview methods to gather respondents' opinions on the Development Guidelines for Blended Learning Models and submit these for review and improvement based on their suggestions.

2.2.3 Have 3 experts review the interview form for content validity and language appropriateness. Ensure clarity, completeness, and coverage of the questions, and use the feedback to refine the interview form before conducting the actual interviews.

**3. Research Procedure**

**3.1 Data Collection:** To ensure the scientific accuracy of the interview, the researcher conducted several preparatory steps. Leveraging the researcher's status as a higher education teacher, the research purpose and needs were explained to the school's teaching management department. With recognition and support from the management, the researcher obtained contact information for a randomly selected group of students, teachers, managers, and experts. Subsequently, the researcher sent the interview form, research proposal, conceptual framework, and interview documents to the sample group in advance. Contact was made to request interview appointments, and notes and audio recordings were taken. Before concluding the interview, interviewees were asked to confirm the content discussed.

**3.2 Data Analysis:** Analyzed collected data from the interviews on the opinions of the sample group, categorized the data based on content consistency, and compared the principles, concepts, and theories related to the interview questions to assess their applicability and consistency regarding the blended learning model components. After filtering the collected data, all selected data was accurately processed and analyzed in an Excel spreadsheet. For questions using the five-point Likert scale, values from 1 to 5 represent levels from strongly disagree to strongly agree. Using SPSS 24.0 statistical software, the data was averaged to reflect the overall attitudes of teachers and students toward various issues. For the remaining issues, a binary classification approach was adopted, assigning a value of 1 to selected options and 0 to unselected options. These data were then subjected to frequency analysis in SPSS 24.0 to reveal the distribution of respondents' choices on relevant questions.



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**Results**

Problems in the development of deep learning for chemistry students: Through interviews with 21 respondents, 13 issues were identified in the current development of online learning. These issues include difficulty in accurately memorizing concepts of chemical knowledge, difficulty in memorizing chemical principles or laws, insufficient ability to summarize and generalize, insufficient ability to interpret charts, disconnection between practical application and principles, insufficient problem-solving ability, lack of practical operational skills, insufficient ability to analyze and interpret experimental data, difficulty in analyzing chemical problems using tools, insufficient ability in comprehensive experimental design, insufficient ability to solve complex problems, insufficient evaluation of experimental methods, and insufficient evaluation of experimental results. These issues are shown in Table 2.

**Table 2** The survey results on the current status of deep learning.

| Item | | Strongly Agree | Agree | Not Sure | Disagree | Strongly Disagree |
|---|---|---|---|---|---|---|
| Knowledge | Difficulty in accurately memorizing concepts | 16 (76.2%) | 2 (9.5%) | 3 (14.3%) | 0 (0.0%) | 0 (0.0%) |
| | Difficulty in memorizing chemical principles or laws | 17 (81.0%) | 3 (14.3%) | 1 (4.7%) | 0 (0.0%) | 0 (0.0%) |
| Compare-tension | Insufficient ability to summarize and generalize | 18 (85.7%) | 2 (9.5%) | 1 (4.8%) | 0 (0.0%) | 0 (0.0%) |
| | Insufficient ability to interpret charts | 19 (90.5%) | 2 (9.5%) | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) |
| Application | Unable to link practical application and principle | 16 (76.2%) | 4 (19.0%) | 1 (4.8%) | 0 (0.0%) | 0 (0.0%) |
| | Insufficient problem-solving ability | 20 (95.2%) | 1 (4.8%) | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) |
| | Lack of practical operational skills | 13 (61.9%) | 5 (23.8%) | 1 (4.8%) | 2 (9.5%) | 0 (0.0%) |
| Analysis | Difficulties in analyzing chemical reaction mechanisms and principles | 18 (85.7%) | 3 (14.3%) | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) |
| | Difficulty in analyzing chemical problems using tools | 16 (76.2%) | 3 (14.3%) | 2 (9.5%) | 0 (0.0%) | 0 (0.0%) |
| Synthesis | Insufficient ability in comprehensive experimental design | 14 (66.7%) | 4 (19.0%) | 2 (9.5%) | 1 (4.8%) | 0 (0.0%) |
| | Insufficient ability to solve complex problems | 15 (71.4%) | 3 (14.3%) | 2 (9.5%) | 1 (4.8%) | 0 (0.0%) |
| Evaluation | Insufficient evaluation of experimental methods | 14 (66.7%) | 4 (19.0%) | 3 (14.3%) | 0 (0.0%) | 0 (0.0%) |
| | Insufficient evaluation of experimental results | 15 (71.4%) | 3 (14.3%) | 3 (14.3%) | 0 (0.0%) | 0 (0.0%) |

Table 2 presents the survey results on the current status of deep learning. Respondents could express their views on five levels: strongly agree, agree, unsure, disagree, and strongly disagree. Among them, 76.2% of respondents believe that it is difficult to accurately memorize chemical concepts; 81% find it difficult to remember chemical principles or laws; 85.7% believe their ability to summarize and generalize is insufficient; 90.5% believe their ability to explain charts is insufficient; 76.2% believe there is a disconnect between practical applications and principles; 95.2% believe their problem-solving ability is insufficient; 61.9% believe they lack practical operational skills; 85.7% believe their ability to analyze and interpret experimental data is insufficient; 76.2% believe there are difficulties in using tools to analyze



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chemical problems; 66.7% believe their comprehensive experimental design ability is insufficient; 71.4% believe their ability to solve complex problems is insufficient; 66.7% believe the evaluation of experimental methods is insufficient; and 71.4% believe the evaluation of experimental results is insufficient.

The survey highlights significant challenges faced by chemistry students in various areas. These challenges include difficulties in memorizing chemical concepts and principles, insufficient summarizing and generalizing skills, and struggles with interpreting charts. Students also reported gaps in connecting theoretical knowledge to practical applications, problem-solving, practical operational skills, analyzing experimental data, and using analytical tools. Additionally, there are concerns about comprehensive experimental design and the evaluation of experimental methods and results. These issues underscore critical areas that need addressing to enhance deep learning and practical competence in chemistry education.

According to Table 3, the 1st, 2nd, 3rd, 4th, 5th, 7th, 9th, 10th, 11th, 12th, 13th, 14th, 15th, 16th, 17th, 19th, 20th, 21st, 22nd, 23rd, and 24th strategies to improve deep learning ability showed high consistency with an interquartile range ($0.0 \leq IQR \leq 1.0$) or median ($4.0 \leq Md \leq 5.0$), indicating that 84.00% of respondents reached a high level of consensus. The 6th, 8th, 18th, and 25th strategies need modification.

The development of a blended learning model involved inviting 21 experts, including 9 teaching method researchers, 9 chemistry teachers, and 3 education management professionals, to evaluate the model using the Delphi method. During this period, all 21 experts provided special support with a positive attitude. The final online learning evaluation model is shown in Figure 1.

**Model Description:**

This research includes four key components: target population and sample selection, application of research tools, data collection process, and data analysis and statistical methods. The researchers aim to build a blended learning model through multiple rounds of questionnaire surveys and expert consultation.

**Table 3** Strategies for Enhancing the Deep Learning Ability of Chemistry Students

| No. | Influencing factors | Md | Mo | IQR | Result |
|---|---|---|---|---|---|
| 1 | Customize personalized learning paths. | 5.0 | 5 | 0.0 | Pass |
| 2 | Establish an online question bank. | 5.0 | 5 | 0.0 | Pass |
| 3 | Develop specific AR/VR laboratory scenarios. | 5.0 | 5 | 0.0 | Pass |
| 4 | Online virtual experiment practice. | 5.0 | 5 | 0.0 | Pass |
| 5 | Create online interactive and collaborative learning spaces. | 5.0 | 5 | 0.0 | Pass |
| 6 | Interactive chart explanation for online voting. | 4.0 | 4 | 2.0 | Modify |
| 7 | Conduct project-based teaching design. | 5.0 | 5 | 0.0 | Pass |
| 8 | Conduct data analysis training. | 4.0 | 5 | 2.0 | Modify |
| 9 | Utilize visualization and multimedia tools. | 5.0 | 5 | 0.0 | Pass |
| 10 | Create digital chemistry stories and icons. | 5.0 | 5 | 0.0 | Pass |
| 11 | Conduct metacognitive training. | 5.0 | 5 | 0.0 | Pass |
| 12 | Set up reflection and summary sessions. | 5.0 | 5 | 0.0 | Pass |
| 13 | Build a knowledge map. | 5.0 | 5 | 0.0 | Pass |
| 14 | Establish chemical practice workshops. | 5.0 | 5 | 0.0 | Pass |
| 15 | Conduct online testing. | 5.0 | 5 | 0.0 | Pass |
| 16 | Adopt online self-evaluation and peer evaluation modes. | 5.0 | 5 | 0.0 | Pass |
| 17 | Conduct offline report-sharing sessions. | 5.0 | 5 | 0.0 | Pass |
| 18 | Organize regular case discussion classes. | 4.0 | 5 | 2.0 | Modify |
| 19 | Organize social practice and enterprise projects. | 5.0 | 5 | 0.0 | Pass |



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| No. | Influencing factors | Md | Mo | IQR | Result |
|---|---|---|---|---|---|
| 20 | Hold online and offline achievement exhibitions and competitions. | 5.0 | 5 | 0.0 | Pass |
| 21 | Adopt a flipped classroom strategy. | 5.0 | 5 | 0.0 | Pass |
| 22 | Provide online video tutorials and simulations for chemical operations. | 5.0 | 5 | 0.0 | Pass |
| 23 | Establish comprehensive experimental projects and case libraries. | 5.0 | 5 | 0.0 | Pass |
| 24 | Design comparative experimental methods. | 5.0 | 5 | 0.0 | Pass |
| 25 | Introduce role-playing activities. | 3.0 | 3 | 2.0 | Modify |

1. The blended learning model is based on Bloom's taxonomy of educational objectives. This model aims to enhance students' deep learning abilities through a blended teaching approach, encompassing six levels: remembering, understanding, applying, analyzing, synthesizing, and evaluating. Each cognitive activity at a particular level builds upon the previous one, reflecting the continuity and progressive nature of cognitive development. Additionally, higher-level cognitive activities can reinforce lower-level activities, providing a comprehensive pathway for improving deep learning abilities in chemistry students.

2. The memory of knowledge concepts and the memory of principles and theorems are closely related. They have a dependent, progressive, feedback, and reinforcement relationship at the "knowledge" level. Basic concepts are a prerequisite for memorizing and understanding chemical principles and laws, and learning these principles and laws, in turn, strengthens the memory of basic concepts. These two aspects interact to form a comprehensive chemical knowledge system, promoting students' in-depth understanding and application of chemical knowledge.

3. "The ability to summarize and generalize" and "the ability to interpret charts and graphs" are important factors that influence the level of "understanding". Students' lack of these abilities can make it difficult for them to extract key points and patterns from data and experimental results, hindering their comprehensive understanding of complex chemical phenomena. This not only affects students' deep understanding and internalization of chemical knowledge but also limits their performance in experiments and real-world problem-solving.

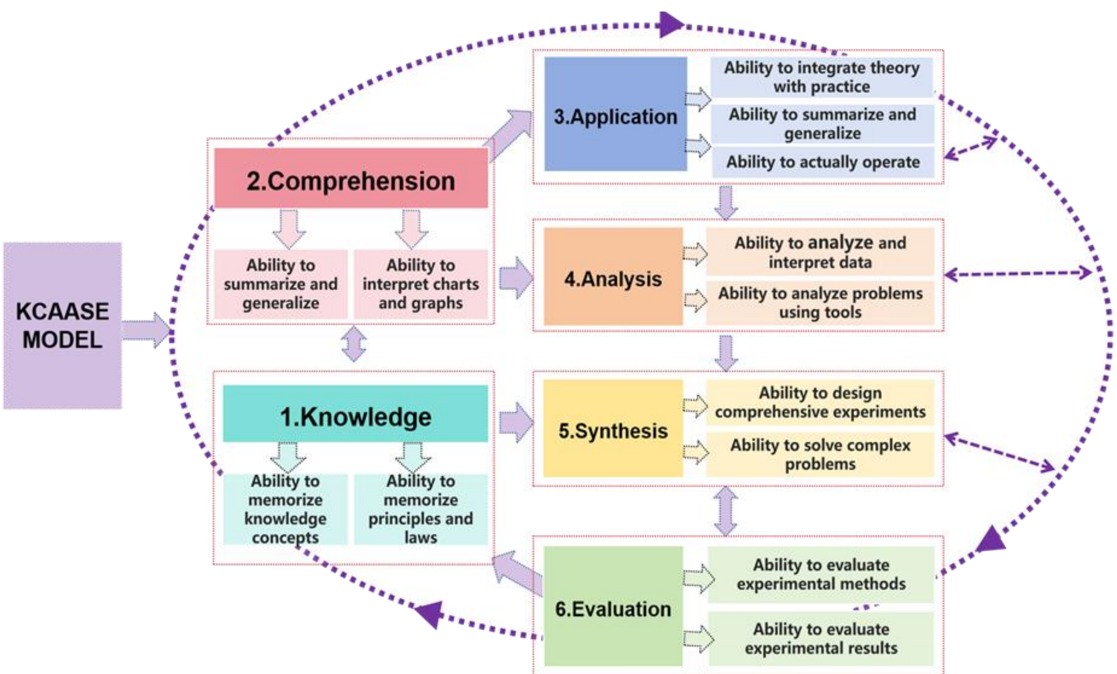




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**Figure 2** KCAASE- MODEL

4. The disconnect between theory and application makes it difficult for students to effectively apply theoretical knowledge to real-world problems, resulting in a lack of problem-solving skills. Insufficient problem-solving ability further limits students' performance in experimental design and data analysis, making it difficult for them to solve complex chemical problems. Additionally, the lack of practical operational skills directly affects students' execution and accuracy in experiments, hindering the practical application of theoretical knowledge. These factors interact and jointly constrain students' performance at the "application" level, limiting their in-depth understanding and comprehensive application of knowledge. Therefore, these abilities are crucial for students' application skills.

5. The insufficient ability to analyze and interpret experimental data makes it difficult for students to effectively understand and process experimental results. Additionally, difficulty in using tools to analyze chemical problems further limits their efficiency and accuracy in data processing and result interpretation. These two issues interact, preventing students from deeply analyzing and extracting useful information when facing complex chemical phenomena, thus hindering their understanding and application of chemical principles. This dual deficiency not only hinders critical thinking and scientific exploration but also reduces students' ability to solve real-world problems. Therefore, improving these skills is crucial for enhancing analytical proficiency.

6. Insufficient ability to design comprehensive experiments makes it difficult for students to integrate and apply various knowledge and skills, develop effective experimental procedures, and predict results. Additionally, insufficient ability to solve complex problems limits their capacity to think systematically and innovate solutions for multivariate and multi-step problems. These shortcomings are interrelated, leading to students being unable to develop comprehensive and effective plans when designing and executing complex experiments, thereby hindering the deep integration of knowledge and the development of innovative thinking. This dual deficiency limits students' autonomy and creativity in scientific research, weakening their deep learning abilities. Therefore, improving these skills is crucial for cultivating students' comprehensive abilities.

7. Insufficient evaluation of experimental methods leads to difficulties in selecting and optimizing effective experimental designs, affecting the reliability of experiments and data accuracy. Insufficient evaluation of experimental results causes biases in data analysis and interpretation, preventing students from drawing correct conclusions. These two issues are interrelated: inadequate method evaluation results in flawed experimental designs, affecting result reliability, while insufficient result evaluation hinders students from identifying and improving issues in experimental methods. Together, these deficiencies limit students' critical thinking and scientific inquiry abilities, impeding their deep understanding and innovative application of knowledge. Therefore, enhancing evaluation skills in both areas is crucial for promoting deep learning.

8. In this model, all elements interact. Knowledge and understanding are the two lowest levels, working together at the four levels of application, analysis, synthesis, and evaluation. Application, analysis, and synthesis progress layer by layer, each affecting the highest level of evaluation, which in turn promotes the deepening of knowledge and understanding. Therefore, the model emphasizes the interactions and dependencies among various elements in the online learning environment.

## Discussion

Firstly, the 13 main issues identified in this study are consistent with existing literature. For example, Bodner & Domin (1995) pointed out that students often encounter difficulties in memorizing and understanding chemical concepts. Gabel (1999) emphasized that memorizing chemical principles and laws is a major obstacle to students' learning. Holme et al. (2015) found that students lack skills in induction and summarization, leading to insufficient comprehensive understanding of knowledge. Shah and Freedman (2003) mentioned that students feel confused when processing and interpreting charts, which affects their understanding of the data. Gabel (1999) also pointed out that the lack of problem-solving skills among students in chemistry learning is a major challenge. These findings indicate that there are indeed deep-seated problems in chemistry education that urgently require effective teaching strategies and technical support. Adebusuyi et al (2023) mentioned that students often lack sufficient scientific processing skills required for practical chemistry activities.


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Secondly, based on the research findings, we propose multiple strategies to address the challenges faced by chemistry students in deep learning, supported by existing literature. For example, Means et al., (2009) pointed out that personalized education paths and online resource libraries can effectively improve learning outcomes. Cook & Carter (2008) mentioned that AR/VR technology and virtual experiments provide immersive learning experiences to help students understand complex chemical concepts. Garrison and Kanuka (2004) emphasized that interactive and collaborative spaces can promote student communication and cooperation, enhancing learning outcomes. Quillin and Thomas (2015) mentioned that project-based learning methods encourage students to apply theoretical knowledge to practical problems and enhance their practical abilities. Rebecca et al. (2020) mentioned that using online learning systems can have a positive impact on improving students' deep learning abilities by providing feedback on their mastery of concepts. The effectiveness of these strategies has been supported by multiple studies, indicating their important role in enhancing the deep learning abilities of chemistry students.

Thirdly, during the research process, we found that although most students have difficulties in handling and understanding complex chemical concepts, appropriate teaching interventions and technical support can significantly improve these abilities in a short period. The application of AR/VR technology and virtual experiments not only increases students' interest in learning but also significantly improves their understanding and memory abilities. This discovery exceeded our expectations and demonstrated the enormous potential of modern educational technology in promoting deep learning.

Fourthly, the results of this study are closely related to Bloom's cognitive theory and constructivist theory. Bloom's cognitive theory emphasizes the hierarchical nature of educational goals, from memory, comprehension, and application to analysis, synthesis, and evaluation, which is consistent with the challenges students face at different cognitive levels that we have discovered (Bloom, 1956). The constructivist theory emphasizes that learning is an active process of constructing knowledge, where students develop the ability to understand and solve problems through interaction and collaboration. This is consistent with our results achieved through strategies such as interactive and collaborative learning spaces and project-based learning (Vygotsky, 1978)

Improving students' thorough knowledge of complicated subjects like Chemistry requires addressing the difficulties they encounter in developing induction and summary abilities. Students can overcome challenges in understanding the concepts with the use of online resources and personalized learning routes. Students can rapidly advance in their skills with the correct instructional interventions and technological assistance. In the end, they can more effectively create knowledge and acquire the problem-solving abilities necessary for their academic success by creating an active learning environment that prioritizes contact and cooperation.

## Conclusion

This study summarizes the main problems faced by chemistry students in deep learning and proposes a series of effective solutions, establishing a blended learning model. We found that students have significant difficulties in memorizing chemical concepts, understanding and applying them, analyzing data, and solving complex problems. Through personalized learning paths, AR/VR technology, project-based learning, and metacognitive training strategies, students' learning outcomes and practical abilities have been significantly improved (Roschelle et al., 2016; Soderstrom & Bjork, 2015). The significance of this study lies in providing a comprehensive educational strategy to enhance the quality of chemistry education. However, a limitation of the study is the limited sample size.

## Recommendation and future research

Based on the research findings, the following recommendations are proposed to address the main problems faced by chemistry students and to enhance their learning outcomes using a deep blended learning model.

1. Develop and implement personalized learning pathways that cater to the individual needs and learning paces of students. This can be achieved through adaptive learning technologies that monitor student progress and adjust content delivery accordingly.

2. Integrate AR and VR tools into the curriculum to create immersive and interactive learning experiences. These technologies can be used to visualize complex chemical structures, simulate laboratory experiments, and explore molecular interactions in a 3D environment.


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3. Incorporate project-based learning activities that require students to apply their knowledge to real-world problems. These projects should encourage collaboration, critical thinking, and practical application of chemical principles.

Future research should expand the sample size and explore the applicability of these strategies in different educational contexts. Future research directions include further optimizing these teaching strategies, increasing teacher training, ensuring effective application in practical teaching, and exploring their impact on long-term learning outcomes.

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