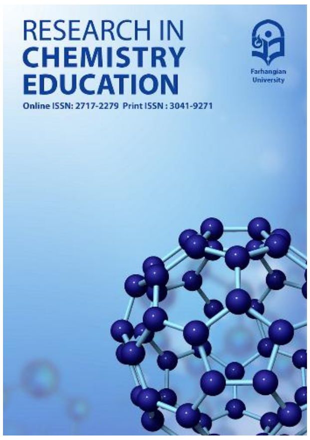
Received: 06 June 2025
Revised: 07 May 2025
Accepted: 11 November 2025
Published: 22 June 2026

Research in Chemistry Education (2026), Volume 8, Issue 2. Pages 24-48.
Print ISSN: 3041-9271
ISSN (Online): 2717-2279

Designing and validating a model of factors affecting effective chemistry education

1. Vahid Amani *: Department of Chemistry Education, Farhangian University, P.O. Box 14665-889, Tehran, Iran
2. Mohammad Azimi: Department of Educational Sciences, Farhangian University, P.O. Box 14665-889, Tehran, Iran
3. Morteza Golshani Gehraz: Department of Educational Sciences, Farhangian University, P.O. Box 14665-889, Tehran, Iran
4. Shahram Esfandiari: Department of English Language Education, Farhangian University, P.O. Box 14665-889, Tehran, Iran

*Corresponding Author's Email Address: v.amani@cfu.ac.ir



How to Cite: Amani, V.; Azimi, M.; Golshani Gehraz, M.; Esfandiari, Sh. (2026). Designing and validating a model of factors affecting effective chemistry education. *Research in Chemistry Education*, 8(2), 24-48.

DOI: 10.48310/chemedu.2025.19737.1343

Abstract:

Background and Objective: This study aimed to investigate the factors that influence effective chemistry teaching. The goal was to design and validate a proposed model of these factors. **Methods**: The study employed a mixed-methods approach (quantitative and qualitative). The qualitative part's target population included international documents similar to this study from 2010 to 2025, out of which approximately 27 studies were purposively selected. For the quantitative part, students enrolled in the chemistry department at Farhangian University in the 2021 academic year, across the country, participated in the study, with 129 respondents randomly selected to complete the questionnaire. The data for the qualitative section were collected through a systematic review of 27 relevant studies. This analysis provided the basis for the initial model design. In the quantitative phase, a researcher-developed questionnaire based on qualitative results, and theoretical literature served as the data collection instrument. Experts and chemistry education professors confirmed the content validity; SmartPLS software was used for structural equation modeling to assess convergent and discriminant validity. **Findings**: Qualitative data highlighted various factors influencing effective chemistry teaching, including skill development in learners, management and supervision, improvements in educational environments and equipment, curriculum focus, participation and interaction, technology use, and the adoption of diverse teaching methods. Quantitative data verified the content validity of the questionnaire and its convergent and discriminant validity via Smart PLS, with reliability scores of Cronbach's alpha at 0.892 and composite reliability at 0.912. Additionally, with an overall fit index (GOF = 0.461), the measurement model was deemed appropriate. **Conclusion:** The results indicate that the designed model effectively captures the key factors influencing effective chemistry teaching.

Keywords: Validation, Effective teaching, Chemistry education.

Introduction

Since the beginning of their existence, humans have strived to explore the universe. This pursuit has created a need for tools and industrial development, laying the groundwork for advances in experimental science education. Education can be viewed as one of the most powerful tools for human progress across all areas of life and has consistently influenced various fields, including experimental sciences (Satarifar et al., 2023, p. 521). Among these disciplines, chemistry stands out as a crucial branch of science, helping learners grasp the world around them (Domenici & Choicca, 2024). With the advent of more precise instruments and a deeper understanding of the microscopic world of materials, as well as the connection of various branches of science to chemistry, along with its complex calculations, the scope for progress has broadened (Saadati, 2021). Chemistry is a fascinating subject that significantly impacts daily human life—it influences everything from the air we breathe to the food we consume (Xoliyorova et al., 2024). As a key subject in secondary education (Simesso et al., 2024), chemistry is a motivating subject for many students. However, its largely subjective and intangible content presents different teaching challenges (Aboudi & Nazarpour, 2020, p. 74). In response, chemistry education continually evolves, seeking innovative methods to engage students and promote a deeper understanding of its content (Narzullayev et al., 2024, p. 119). Additionally, chemistry education is vital for helping students develop scientific skills connected to the subject (Kochkarova & Turguno, 2023). Since chemistry encompasses concepts from simple to complex, blending concrete and abstract ideas (Shiddiqi et al., 2024), it holds significant importance within the field of experimental sciences. Therefore, chemistry, as one of the most important concepts of experimental sciences, holds great value for humanity, and its teaching is highly significant due to its complex and abstract concepts. Effective chemistry teaching leads to successful learning, which in turn produces positive outcomes. Effective teaching involves a range of skills, including communication, creativity, professionalism, pedagogical knowledge, accurate assessment and measurement of students, self-development, personality, talent, or expertise in a specific content area, as well as the ability to model concepts within one's own content area (Polk, 2006). It also encompasses decision-making, creating a conducive learning environment, implementing democratic classroom discipline, considering curriculum, planning, utilizing fundamental teaching techniques, employing core methods, developing teaching strategies, and integrating educational technologies (Kindsvatter, 1998). It is worth noting that, in this study, effective chemistry teaching refers to the characteristics and indicators identified in reputable national and international research studies as factors influencing the quality of chemistry teaching. Accordingly, improving effective chemistry teaching can be achieved through existing theories and research, which highlight numerous factors that facilitate learning and are crucial for enhancing the quality of chemistry education. Various learning and leadership theories offer robust conceptual frameworks for understanding these factors and informing educational research. For example, the Universal Design for Learning (UDL) theory advocates for using diverse teaching methods to support learning and accommodate individual differences among students (Meyer et al., 2014). Moreover, the role of technology in making learning easier and creating knowledge networks is emphasized in the relationalism theory, which supports learning in electronic and technology-based environments (Goldie, 2016). From Bandura's social learning theory perspective, social interaction and participation are crucial because they consider learning as a result of observation and active engagement in social relationships (Bandura & Walters, 1977). Furthermore, ongoing curriculum revision and enhancement, in accordance with educational goals and learners' needs, are addressed by Tyler (Bhuttah et al., 2019). Improving and equipping the educational environment involves providing both physical and psychological tools to facilitate learning, as suggested by Vygotsky (Shabani et al., 2010). Finally, effective teacher management and supervision, as part of Hallinger and Murphy's educational leadership theory, improve instructional quality through classroom visits and constructive feedback (McBrayer et al., 2020). However, generally speaking, the present study considered the TPACK theoretical model as a framework for examining effective chemistry teaching because the TPACK framework, as a theoretical model for effective chemistry instruction, is based on integrating three main areas of teachers' knowledge: content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (TK) (Mishra & Koehler, 2006; Koehler et al., 2007). Content knowledge enhances teachers' ability to communicate chemistry concepts and design rigorous science lessons, while pedagogical knowledge enables the use of diverse teaching methods, classroom management, and encouraging student participation and interaction (Shulman, 1998; Mishra & Koehler, 2006). Technological knowledge provides teachers with digital tools and resources to facilitate learning, allowing the representation and presentation of chemistry concepts through various technologies (Koh et al., 2005). The combination of these knowledge domains leads to the development of pedagogical content knowledge (PCK), technological pedagogical knowledge (TPK), and technological content knowledge (TCK), which improve teachers' ability to implement effective instructional strategies, utilize technology to enhance interaction, and present academic content (Mishra et al., 2009). Ultimately, TPACK enables teachers to improve and equip the learning environment, manage and supervise effectively, increase student participation, and develop a range of skills to make chemistry learning more meaningful and effective (Malik et al., 2019). Recognizing and analyzing these factors through the theoretical frameworks can greatly help in developing and validating measurement tools for effective teaching across various subjects, including chemistry, and can guide future research. However, research shows that chemistry education often falls short of expectations and encounters many challenges. Therefore, creating and validating a model of the factors that affect effective chemistry teaching appears to be essential.

Despite the importance of effective chemistry teaching and its methods, studies have revealed a gap in the implementation of effective chemistry teaching in Iran. Ebrahimi and Eskandari (2014) found that Iranian students prefer a more supportive chemistry environment but are dissatisfied with their current classroom. Conversely, Abedi Kargiban (2013) pointed out that Iranian high school chemistry teachers have low levels of educational content knowledge, and there was no significant relationship between educational attainment and the availability of computers on the network. Zarei and Hosseininia (2023) also emphasized that Iranian high school chemistry textbooks present the nature of science with insufficient focus on scientific experimental methods and theories. Consequently, these studies reflect a deficient state of chemistry education, as traditional and other teaching methods fail to effectively engage students in the subject (Kochkarova & Turguno, 2023), leading to misunderstandings of chemistry concepts that differ from students' actual comprehension. Misconceptions are recognized as misunderstandings of concepts (Shiddiqi et al., 2024). Furthermore, many inaccurate and erroneous scientific beliefs persist among students up to university level and sometimes beyond (Sözbilir et al., 2010). As a result, many learners in secondary schools and higher education face fundamental challenges in learning chemistry. Given the importance of foundational chemistry knowledge, most students in introductory courses have a limited understanding of the subject (Waldmaul, 2014). Therefore, it is essential to note that, due to the reliance on conventional methods and the lack of effective instructional strategies, most students struggle to truly grasp chemistry concepts. Hence, there is a pressing need to adopt effective methods and establish mechanisms to address this issue. Overall, it can be concluded that achieving effective chemistry teaching requires developing a model outlining the factors influencing desirable outcomes, as a review of various studies indicates that no research has yet investigated the existence of such a model.

Given the importance of implementing effective chemistry teaching, numerous studies have examined this topic from various perspectives. Eshkoraev (2024), in a study titled '*Revolutionary Education: Using Innovative Technologies in Chemical Technology Education*,' stated that the adoption of innovative technologies produced promising results in enhancing learners' educational prospects in chemical technology. Virtual labs not only increased safety by reducing the risk of exposure to hazardous materials but also enabled repeated experiments, thereby deepening learners' understanding of chemical processes. Rashitova (2024), in a study titled '*The Use of Interactive Methods in Chemistry*,' stated that employing interactive teaching methods significantly boosts learners' interest in gaining knowledge. Shukla (2024), in a study titled '*Innovative Methods of Using Practical Experiments in Chemistry Education*,' found that practical experiments not only improve learners' conceptual understanding and engagement but also develop essential practical skills, supporting experiential learning in chemistry education to prepare learners for future scientific challenges. In a study titled 'Teacher Strategies in Managing Chemistry Learning Time to Improve Students' Learning Progress,' Mazid et al. (2023) found that hot classroom conditions during the day make it difficult for learners to understand the material taught. Therefore, the morning is considered an ideal time to engage with chemistry educational content. Learners can also review or study the lesson in the afternoon or evening to enhance their comprehension. In a study on 'Guided Inquiry-Based Learning in High School Chemistry Classes,' Orosz et al. (2023) concluded that guided inquiry learning is suitable for students new to this approach if proper scaffolding is provided. The data highlighted stages of the inquiry cycle where additional guidance is needed. The student questionnaire results also showed that students enjoyed the questioning sessions. They largely considered their work successful, though some overestimated their research skills. Widarti et al. (2023) also conducted a study on 'Social Media-Based Learning in Chemistry Learning.' They noted that using social media in chemistry education is effective and can boost learners' motivation at high school and undergraduate levels. Akrami (2024), in the research titled 'Principles of Needs Assessment in the Desirable Curriculum in Chemistry Education,' stated that needs assessment is the core foundation of activities in curriculum planning for chemistry education. If an appropriate method for needs assessment is not selected, the objectivity and validity of the results may decrease. Sattariifar et al. (2023) observed that teaching chemistry using the IBSE approach has a positive impact on learners' learning, creativity, problem-solving skills, and critical thinking. Therefore, a review of various studies indicates that no research has examined the model of factors affecting effective chemistry teaching.

Based on the above explanations, it is clear that using new and effective methods to teach chemistry concepts to students is very important. Additionally, enough research has already been conducted in this field. However, there is a lack of studies that summarize these findings, which would give an overall view of effective chemistry teaching. Therefore, because there is no existing model that identifies the factors influencing effective chemistry instruction, this study aims to develop and validate such a model. Accordingly, findings from similar international studies will be compiled through a systematic review and then validated. This study seeks to answer two research questions as follows.

1. Based on a systematic review and synthesis of international research, what components and subcomponents can be identified as factors influencing effective chemistry teaching?

2. Is the proposed model of effective chemistry teaching approved based on convergent validity, divergent validity, and structural fit indices?

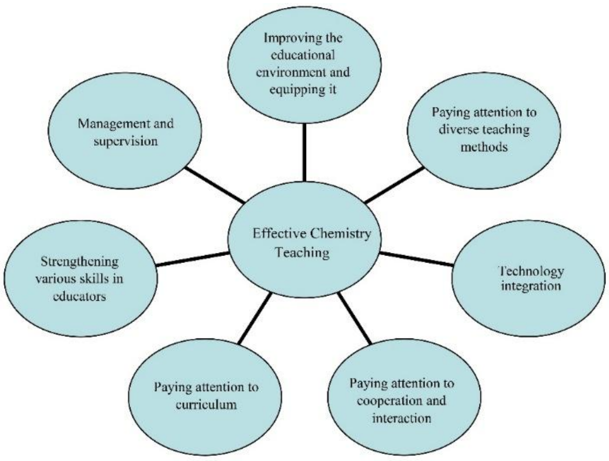


Figure 1- Theoretical Research Model

Methodology

The current research employed a mixed-methods approach. A mixed research method combines both quantitative and qualitative methods in a single study, providing a more comprehensive and nuanced view of an issue. Mixed methods are used when both comparative analysis and the development of study aspects need to be carried out thoroughly and in depth. The use of mixed methods overcomes the limitations of quantitative and qualitative methodologies, allowing researchers to obtain rich information that cannot be gathered using each method alone (Almeida, 2018). The qualitative section employed the systematic review method, one of the most valid and well-established approaches to reviewing previous research. This method is considered a type of secondary analysis of prior studies (Khodai et al., 2023). The study population comprised articles and theses related to effective chemistry teaching, published in international journals in quantitative or qualitative formats between 2010 and 2025, and presented either descriptively or through models. Notably, samples were selected using the snowball method until data saturation was reached. Each related document was briefly reviewed to gain a general impression of its relevance to the research topic, followed by thematic analysis and coding of these units. Throughout this process, any mention of themes related to factors affecting effective chemistry teaching was recorded in a table under the title 'Key Sentences', with each assigned a specific code. Researchers continued coding semantic units until saturation, meaning no new codes emerged. After completing the unit of analysis process, these codes were categorized based on their similarities or affinities, ultimately extracting the principal dimensions and subcategories from the qualitative data. It should also be noted that the reason for using the snowball sampling method to identify articles related to effective chemistry teaching is that many of the studies were published in scattered sources and could not be found through an initial search. In this method, key articles were selected as a starting point, and subsequent relevant articles were added by reviewing their references. To ensure comprehensiveness and relevance, only articles that directly focused on chemistry education with an emphasis on teaching quality and effectiveness were included in the analysis. The screening process was conducted by two independent researchers using specific inclusion and exclusion criteria, with a high agreement coefficient indicating the validity and accuracy of the article selection.

It is important to note that the search for articles was conducted in reputable scientific databases including ERIC, ScienceDirect, Springer, Scopus, using keywords such as: 'Quality Chemistry Education,' 'Effective Science Teaching,' 'Best Chemistry Instruction,' 'Chemistry Teaching Standards,' 'Optimal Science Education,' 'effective chemistry teaching,' and 'quality indicators of chemistry teaching.' The search was limited to the period between 2010 and 2024 and focused on peer-reviewed articles. Inclusion criteria for articles in the review were as follows: the article must be in English, must address chemistry education at the secondary or university level, must focus on the quality or desirability of education, and must examine at least one educational component. Articles that solely addressed science education without a focus on chemistry or lacked a clear theoretical or methodological framework were excluded. After initial screening and a more detailed review of the full texts, 27 articles were identified as suitable for qualitative analysis, which were used to develop the initial items of the instrument. The workflow is illustrated in Figure 2.

Therefore, in the first step, to compile the initial items, the systematic review method and open, axial, and selective coding techniques, as described by Strauss and Corbin (1998), were employed. In other words, this approach involved conducting text analysis at multiple levels. During the open coding stage, the researcher read the written text extracted from the documents and broke it into smaller parts. These parts were compared, conceptualized, and categorized in an ongoing process. In axial coding, the categories identified earlier were further organized and interconnected in new ways. This process aimed to identify broader categories and clarify their relationships. Finally, a selective coding, which is essentially a narrative summary of the research findings, was developed for each question. To do this, 35 scientific articles related to effective chemistry teaching (published between 2010 and 2024) were searched and screened from reputable databases. Of these, 27 articles that met the research goals in terms of methodological quality and content relevance were selected as the final sample. In analyzing these texts, key concepts related to effective chemistry teaching were identified, and conceptual codes were extracted. Then, by categorizing the codes and grouping similar ideas, the main components and dimensions of the questionnaire were designed. The questions for the questionnaire were based on the theoretical foundations of the Universal Design for Learning (UDL) (Meyer, Rose, & Gordon, 2014), the relational theory (Goldie, 2016), Bandura's social learning theory (Bandura & Walters, 1977), Thiel's curriculum development theory (Bhuttah, Xiaoduan, Ullah, & Javed, 2019), Vygotsky's sociocultural theory (Shabani, Khatib, & Ebadi, 2010), Hallinger and Murph's educational leadership theory (McBrayer et al., 2020), and self-determination theory (Deci & Ryan, 2000). Sample questions included "Is it desirable to use computational methods in teaching the principles of chemistry?" and "Is it appropriate to provide a conducive educational and learning environment for effective chemistry teaching?" Respondents answered on a Likert scale from "strongly disagree" to "strongly agree." From the initial 35 articles, 27 were selected using an appropriate methodology, and their key concepts were extracted. The items were adapted to theories such as the Technology Acceptance Model (Davis, 1989) and the TPACK framework (Mishra & Koehler, 2006), resulting in a 57-item questionnaire. To minimize bias, only peer-reviewed articles were included, and the screening process adhered to PRISMA standards (Page et al., 2021). Two researchers independently selected the sources, and the high agreement coefficient indicated reliability (Lincoln & Guba, 1985). In other words, the PRISMA guidelines were followed for transparency and reproducibility in the search and selection processes. Articles were retrieved from reputable databases, screened for quality and relevance, and irrelevant articles were excluded. The independent review by two researchers, along with a high agreement coefficient, confirmed that the article selection process complied with PRISMA guidelines and ensured comprehensive coverage of relevant studies.

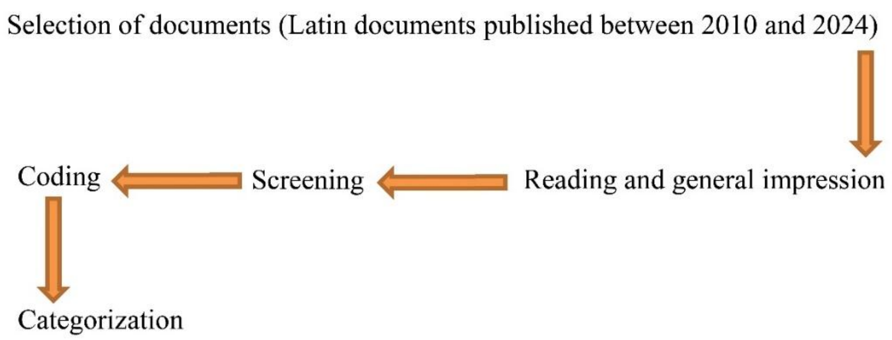


Figure 2- Research Workflow

First, the relevant international studies and documents used in the research were selected based on their publication dates, research types, and the selection criteria employed, as well as the strategies used to search for documents in databases. Next, the abstracts of these documents and their results were reviewed, and screening was conducted based on the quality and relevance of the articles. Out of approximately 35 articles, 27 were chosen as the research sample, as shown in Table 1. In the quantitative part of the study, to assess face validity, the questionnaire was distributed to 10 experts—university professors, teachers, and specialists—and necessary revisions were made based on their feedback. Additionally, to examine the content validity of the tool designed to measure students' awareness of the components affecting effective chemistry teaching, the quantitative content validity rate (CVR) index was used. For this purpose, an initial version of the tool, consisting of 54 items, was prepared and provided to 10 experts in the fields of chemistry education, educational technology, and artificial intelligence in education. Each expert rated the necessity of each item on three levels: “necessary,” “useful but unnecessary,” and “unnecessary.” The CVR value for each item was calculated using Lavish’s formula as follows.

$$CVR = \frac{ne - N}{N/2}$$

n is the number of experts who considered the item essential, and N is the total number of experts (10 people). According to the Lavish table, for 10 experts, the minimum acceptable CVR value is 0.62 (Lavish, 1975). In this study, 46 items had CVRs higher than 0.62 and were retained, while eight items with CVRs below the acceptable threshold were eliminated. To assess the reliability of the research tool, the questionnaire was distributed to 30 chemistry students at Farhangan University, confirming that its validity and reliability were acceptable, as further explained in the quantitative section. Then, to identify the factors influencing effective chemistry education, approximately 129 individuals were randomly selected from a population of 200 chemistry students at Farhangian University using simple random sampling based on the Morgan table. After collecting and analyzing the data, the overall reliability of the instrument was evaluated. Cronbach's alpha was used to assess the reliability of the research tool, and SmartPLS software was employed for data analysis. It is worth noting that the questionnaire comprised 46 questions related to optimal teaching methods in chemistry. Questions 1 to 10 addressed different teaching methods; questions 11 to 27 focused on technology use; questions 28 to 31 concerned participation and interaction; questions 32 to 35 centered on curriculum; questions 36 to 38 dealt with improving and equipping the learning environment; questions 39 to 42 involved supervision and management ;and questions 43 to 46 aimed at strengthening various skills among learners .

Table 1- Reviewed studies in the present research

No.	Research topic	Authors and publication year
1	High school chemistry teachers’ knowledge and use of teamwork as an educational strategy	Abudu, F., Ayoberd, S. A., & Marifa, H. A. (2024)
2	Inquiry-based chemistry education: A systematic review	Jegstad, K. M. (2024)
3	Meta-analysis of the effectiveness of learning cycle models and online teaching strategies in chemistry education	Vallespin, D. V., & Prudente, M. S. (2024)
4	Virtual Reality in Undergraduate Organic Chemistry Laboratory Course with an Environmental Approach: A New Approach in Chemistry Laboratory Education	Mojsoska, B., Pande, P., Moeller, M. E., Ramasamy, P., & Jepsen, P. M. (2024)
5	Using "lesson study" as a tool to address educational challenges: A case study of chemistry teachers in Nigeria.	Monday, M., & Fashakin, O. (2024)
6	The effect of context-based chemistry education on students' academic achievement: A systematic review	Tsadik Getu, G., kidan Mebrahitu, G., & Yohannes, G. (2024)
7	Effective educational approaches in high school chemistry education: A systematic review and meta-analysis.	Ahmad, Z., Ammar, M., Sellami, A., & Al-Thani, N. J. (2023)
8	Teaching performance of chemistry teachers in mainland China during the COVID-19 pandemic: A content analysis study	Chen, K., Lin, J., Wang, Z., Chen, K., & Yang, J. (2023)
9	Effective teaching and learning strategies in the chemistry classroom	Dayal, P. D., & Ali-Chand, Z. (2022)
10	Web-based conversations in teaching and learning: perceptions and potential of high school teachers and students for improving student performance in organic chemistry.	Iyamuremye, A., Mukiza, J., Nsabayezu, E., Ukobizaba, F., & Ndihokubwayo, K. (2022)

11	Performance indicators of high school students in distance learning chemistry during the COVID-19 pandemic	AlMahdawi, M., Senghore, S., Ambrin, H., & Belbase, S. (2021)
12	Factors affecting high school students' attitudes towards learning chemistry: A review of the research literature	Musengimana, J., Kampire, E., & Ntawiha, P. (2021)
13	Teaching Chemistry with Computer Simulation: Will High School Students Perform Better?	Adekunle, O., Olu, A. V., & Nwabuno, N. (2021)
14	Using Effective Questioning to Increase Student Participation in an Eleventh Grade Chemistry Class at a Government College in the Rural Area of Jacobabad	Dool, M. A., Mughal, S. H., & Rind, A. A. (2020)
15	Identifying factors affecting the quality of teaching in basic science education: physics, biological sciences, mathematics, and chemistry	Cho, J., & Baek, W. (2019)
16	A review of the use of computational methods to teach chemistry principles.	Grushow, A., & Reeves, M. S. (2019)
17	The needs for successful chemistry teaching in diverse classrooms: Teachers' beliefs and practices.	Kousa, P. M., & Aksela, M. K. (2019)
18	Low-performing students' attitudes towards learning chemistry and its teaching methods.	Kousa, P., Kavonius, R., & Aksela, M. (2018)
19	Relative Effectiveness of Guided Discovery and Demonstration Teaching Methods on Students' Performance in Chemistry in Secondary Schools in Ile-Ife, Nigeria	Folounrunso, B. E., & Sunday, A. O. (2017)
20	Factors affecting students' performance in chemistry: A case study in Zankbar high schools.	Hassan, A. A., Ali, H. I., Salum, A. A., Kassim, A. M., Elmoge, Y. N., & Amour, A. A. (2017)
21	Characteristics of Principals' Educational Leadership that Help Promote Effective Chemistry Teaching and Learning in Secondary Schools: From the Perspectives of Students and Teachers	Achimugu, L. (2016)
22	The impact of practical chemistry experiments on students' performance in chemistry in public high schools in Machakos and Nairobi counties in Kenya.	Mwangi, J. T., & Kibui, J. T. O. (2016)
23	Application of the covalent bond classification method in inorganic chemistry education	Green, M. L., & Parkin, G. (2014)
24	Developing a tool to evaluate teaching effectiveness in chemistry classes	Zheng, C., Fu, L., & He, P. (2014)
25	Quality Chemistry Education: The Role of the Teacher	Bugaje, B. M. (2013)
26	Practical Chemistry Teaching Approaches in Nigerian Secondary Schools	Avwiri, E. H. (2011)
27	Alternative methods in learning chemistry: learning with animation, simulation, video, and multimedia.	Pekdağ, B. (2010)

Results

This section aims to discuss the research findings. The results of the current study are divided into two parts: qualitative and quantitative. The qualitative findings will be discussed first.

Qualitative Section

1. Based on a systematic review and synthesis of international research, what components and subcomponents can be identified as factors influencing effective chemistry teaching?

Table 2- Factors affecting effective chemistry teaching

Open coding	Axial coding	Selective coding	Compliance with theoretical foundations
Using computational methods in teaching chemistry principles (Grushow & Reeves, 2019) Using a classification method for types of covalent bonds (Green & Parkin, 2014) Using diverse chemistry teaching strategies (Ahmad et al, 2023) Using a problem-based learning teaching method (Ahmad et al, 2023) Applying creative educational methods (Ahmad et al, 2023) Using guided discovery learning (Folounrunso & Sunday, 2017) Using supportive materials and methods (Kousa & Aksela, 2019) Using concept maps at the classroom level by the teacher (Bugaje, 2013) Integrating real-world contexts and applications into chemistry teaching (Tzadik Getu et al, 2024) Using drawing and painting during chemistry education (Dayal & Ali-Chand, 2022) Applying the learning cycle in chemistry education (Vallespin & Prudente, 2024)	Paying attention to diverse teaching methods		Universal Design Theory for Learning UDL (Meyer, Rose, & Gordon, 2014)
Using virtual reality tools (Mojsoska et al, 2024) Applying online methods in teaching chemistry (Vallespin & Prudente, 2024) Applying visual strategies in chemistry teaching (Dayal & Ali-Chand, 2022) Investigating the quality of resource and technology use (Zheng et al, 2014) Using computer simulation in education (Adekunle et al, 2021) Using computers in education (Adekunle et al, 2021) Using projectors in education (Adekunle et al, 2021)	Using technology		Relational Theory (Goldie, 2016)

Providing online facilities for education (Adekunle et al, 2021) **Using online platforms (Cho & Baek, 2019)** **Using multimedia technologies (Pekdağ, 2010)** **Using animations (Pekdağ, 2010)** **Using a variety of related films in chemistry education (Kousa et al, 2018)** **Using educational media in the classroom (Hassan et al, 2017)** **Educational program and software development (Chen et al, 2023)** **Teacher participation in technology education (Chen et al, 2023)** **Having access to the global chemistry network (Iyamuremye et al, 2022)** **Conducting web-based discussions (Iyamuremye et al, 2022)** **Integrating ICT into the Chemistry Practical Program (Mwangi & Kibui, 2016)**		Model of factors affecting effective chemistry teaching	
Using interactive teaching methods (Jegstad, 2024) **Using group work in teaching chemistry (Abudu et al, 2024)** **Dividing the classroom space into small groups (Cho & Baek, 2019)** **Strengthening students' collaborative skills (AlMahdawi et al, 2021)** **Collaboration of chemistry teachers with teachers of other disciplines to create interdisciplinary classes (Chen et al, 2023)**	Attention to participation and interaction		Bandura's social learning theory (Bandura & Walters, 1977)
Paying attention to the relevance of the curriculum to the daily lives of learners (Musengimana et al, 2021) **Adapting curriculum presentation to learners' intellectual development level (Avwiri, 2011)** **Further educational development (improvement of lesson presentation methods) (Chen et al, 2023)** **Developing diverse learning resources (producing and using different types of educational content) (Chen et al, 2023)** **Curriculum study by teachers (Monday & Fashakin, 2024)** **Prioritizing student needs when designing curricula (Monday & Fashakin, 2024)**	Paying attention to the curriculum		Tyler's Curriculum Development Theory (Bhuttah, Xiaoduan, Ullah, & Javed, 2019).

Providing a conducive teaching and learning environment (Achimugu, 2016) **Attention and control of the classroom environment (Musengimana et al, 2021)** **Equipping libraries with chemistry books (Hassan et al, 2017)** **Equipping laboratories with modern chemistry tools (Hassan et al, 2017)** **Improving school conditions (Mwangi & Kibui, 2016)**	Improving the educational environment and equipping it		Vygotsky's Social and Cultural Theory .(Shabani, Khatib, & Ebadi, 2010)
Rational use of time during chemistry education (Zheng et al, 2014) **Continuous monitoring of the teaching-learning process (Achimugu, 2016)** **Having the ability to identify students' problems (Kousa & Aksela, 2019)** **Paying attention to the adaptability of learners (Avwiri, 2011)** **Providing opportunities for learners to engage in deep learning (Mwangi & Kibui, 2016)** **Improving the quality of the chemistry teaching behavior chain (Zheng et al, 2014)**	Management and supervision		Hollinger and Murphy's Educational Leadership Theory (McBrayer et al., 2020)
Strengthening questioning skills in learners (Dool et al, 2020) **Promoting self-directed efforts (Musengimana et al, 2021)** **Strengthening learners' critical thinking (AlMahdawi et al, 2021)** **Enhancing learners' creativity and innovation (AlMahdawi et al, 2021)** **Enhancing motivation in learners (Achimugu, 2016)**	Strengthening a variety of skills in learners		Self-determination theory (Deci & Ryan, 2000)
Paying attention to learners' interests (Musengimana et al, 2021) **Controlling teacher behavior (Musengimana et al, 2021)** **Having more support and resources (Kousa & Aksela, 2019)** **Having theoretical connections (Kousa & Aksela, 2019)** **Practicing with inspiring and meaningful activities (Kousa & Aksela, 2019)** **Visiting chemical institutes (Kousa Et al, 2018)**	Other cases		

Visiting museums related to chemistry (Kousa et al, 2018) Visiting chemistry exhibitions (Kousa et al, 2018) Visiting chemical companies (Kousa et al, 2018) Using various magazines in teaching chemistry (Kousa et al, 2018) Providing learners with lots of chemistry exercises (Mwangi & Kibui, 2016) Using improvised materials in the absence of standard equipment (Bugaje, 2013)		

Table 2 presents the components related to effective chemistry teaching, which align with international research standards. An attempt was made to reference these through systematic analysis and Strauss and Corbin coding, as shown in Table 2. Data collected from research related to this study indicate that factors influencing desirable chemistry education include enhancing various skills in learners, management and supervision, improving and equipping the educational environment, paying attention to the curriculum, encouraging participation and interaction, using technology, and applying diverse teaching methods. After gathering data from relevant research, the necessary classification was performed, and the identified categories were listed.

Quantitative Section

2. Is the proposed model of effective chemistry teaching approved based on convergent validity, divergent validity, and structural fit indices?

In the quantitative part of the research, the raw data were analyzed. To examine and validate the obtained model, the fit of the research model was assessed in three stages: 1. fitting the measurement models, 2. fitting the structural models, and 3. fitting the overall model. First, the correctness of the relationships in the measurement models was confirmed using reliability and validity criteria. Then, the relationships within the structural section were analyzed and interpreted. Finally, the overall fit of the research model was evaluated.

Measuring factor loadings: Factor loadings were determined by calculating the correlation between each item and its respective variable. A value of 0.4 or higher was considered acceptable. Accordingly, the factor loadings of the measurement model questions and their relevant significance coefficients can be seen in Table 3.

Table 3- Factor loadings and t-value coefficients of questionnaire items

Question	Factor Load	T-values	Question	Factor Load	T-values
Q1	0.456	3.518	Q24	0.705	13.455
Q2	0.473	4.898	Q25	0.678	9.246
Q3	0.530	4.530	Q26	0.697	10.485
Q4	0.548	4.740	Q27	0.726	12.662
Q5	0.559	5.747	Q28	0.741	14.882
Q6	0.494	4.748	Q29	0.829	19.019
Q7	0.508	4.247	Q30	0.767	11.320
Q8	0.568	6.657	Q31	0.818	12.488
Q9	0.663	9.203	Q32	0.803	14.465

Q10	0.656	8.672	Q33	0.617	5.210
Q11	0.660	10.770	Q34	0.760	10840
Q12	0.440	4.284	Q35	0.784	11.992
Q13	0.557	7.960	Q36	0.878	15.647
Q14	0.612	9.253	Q37	0.827	13.891
Q15	0.696	12.366	Q38	0.618	8.076
Q16	0.681	11.521	Q39	0.737	9.772
Q17	0.641	8.908	Q40	0.864	19.906
Q18	0.697	11.926	Q41	0.796	16.110
Q19	0.692	9.762	Q42	0.770	10.326
Q20	0.663	9.553	Q43	0.787	19.421
Q21	0.669	10.008	Q44	0.826	24.367
Q22	0.739	13.604	Q45	0.825	21.473
Q23	0.765	16.164	Q46	0.741	13.571

In Table 3, an effort was made to validate the factor loadings at the PLS software level, allowing the factor loadings to be visible in Table 3. As shown, all factor loadings exceed 0.4, and their significant t-coefficients are all above 1.96, indicating that the factor loadings of all questions are significant at the 95% confidence level. There is no need to remove questions (Davari & Rezazadeh, 2016).

Table 4- Indicators related to the internal consistency of the research instrument

Variable	Cronbach's alpha coefficient	AVE	Composite reliability (CR)
Attention to diverse teaching methods	0.751	0.584	0.807
Use of technology	0.911	0.505	0.924
Attention to participation and interaction	0.800	0.620	0.867
Attention to the curriculum	0.728	0.548	0.828
Improving the learning environment and equipping it	0.744	0.796	0.887
Management and supervision	0.869	0.620	0.804
Strengthening a variety of skills in learners	0.806	0.632	0.873
Factors affecting effective chemistry teaching	0.892	0.511	0.912

Additionally, indicators related to the internal consistency of researcher-made tools include coefficients such as Cronbach's alpha, convergent validity, and the composite reliability coefficient. These indicators were also assessed using PLS software, and their values are presented in Table 4. As shown in Table 4, the values for the reliability of the research model variables exceed 0.7, indicating good reliability for this study.

Convergent validity: Convergent validity is a measure used to assess measurement models, with the critical value for the mean variance extracted criterion being 0.5; values above 0.5 indicate acceptable convergent validity (Barclay et al., 1995). Therefore, since the coefficient of the average variance in Table 4 is all above 0.5, they demonstrate convergent validity.

Divergent validity: Divergent validity is the third indicator for assessing the fit of measurement models in the partial least squares method. It is also acceptable when the average amount of variance extracted for each variable exceeds the shared variance between that variable and the other variables in the model (Funnel & Locker, 1981). Accordingly, based on Table 5, the research model demonstrates divergent validity.

Table 5- Divergent validity matrix of the measurement model

Variables	Paying attention to diverse teaching methods	Using technology	Paying attention to participation and interaction	Paying attention to the curriculum	Improving the educational environment and equipping it	management and supervision	Strengthening a variety of skills in learners	Factors affecting effective chemistry teaching
Paying attention to diverse teaching methods	0.764							
Using technology	0.616	0.710						
Paying attention to participation and interaction	0.429	0.601	0.787					
Paying attention to the curriculum	0.567	0.393	0.588	0.740				
Improving the educational environment and equipping it	0.518	0.218	0.472	0.676	0.892			
Management and supervision	0.489	0.474	0.627	0.723	0.794	0.932		
Strengthening a variety of skills in learners	0.755	0.527	0.726	0.601	0.601	0.826	0.794	
Factors affecting effective chemistry teaching	0.704	0.707	0.491	0.246	0.246	0.491	0.557	0.944

Another indicator of internal consistency in researcher-made instruments is divergent validity, which is mentioned in Table 5 and was also analyzed using PLS software. As shown in Table 5, the value of the square root of the average variance extracted (AVE) for each construct, displayed along the main diagonal, exceeds the correlation values between constructs, shown in the off-diagonal cells. Therefore, the research model demonstrates divergent validity.

Structural model fit evaluation indicators: For structural model fit, the following evaluation indicators were considered in order: 1. Significant t numbers and 2. R^2 index.

T-Value: The fundamental indicator for assessing the relationship between variables in the model's structural component is the t-value. If these values exceed 1.96 at the 95% confidence level, it signifies the validity of the relationships between the variables. Table 3 and Figure 1 display the T-value figures used to evaluate the structural aspect of the research model. As shown, all significant coefficients surpass 1.96, and therefore, all the paths are confirmed at a 95% confidence level, supporting the fit of the structural model (Davari & Rezazadeh, 2014).

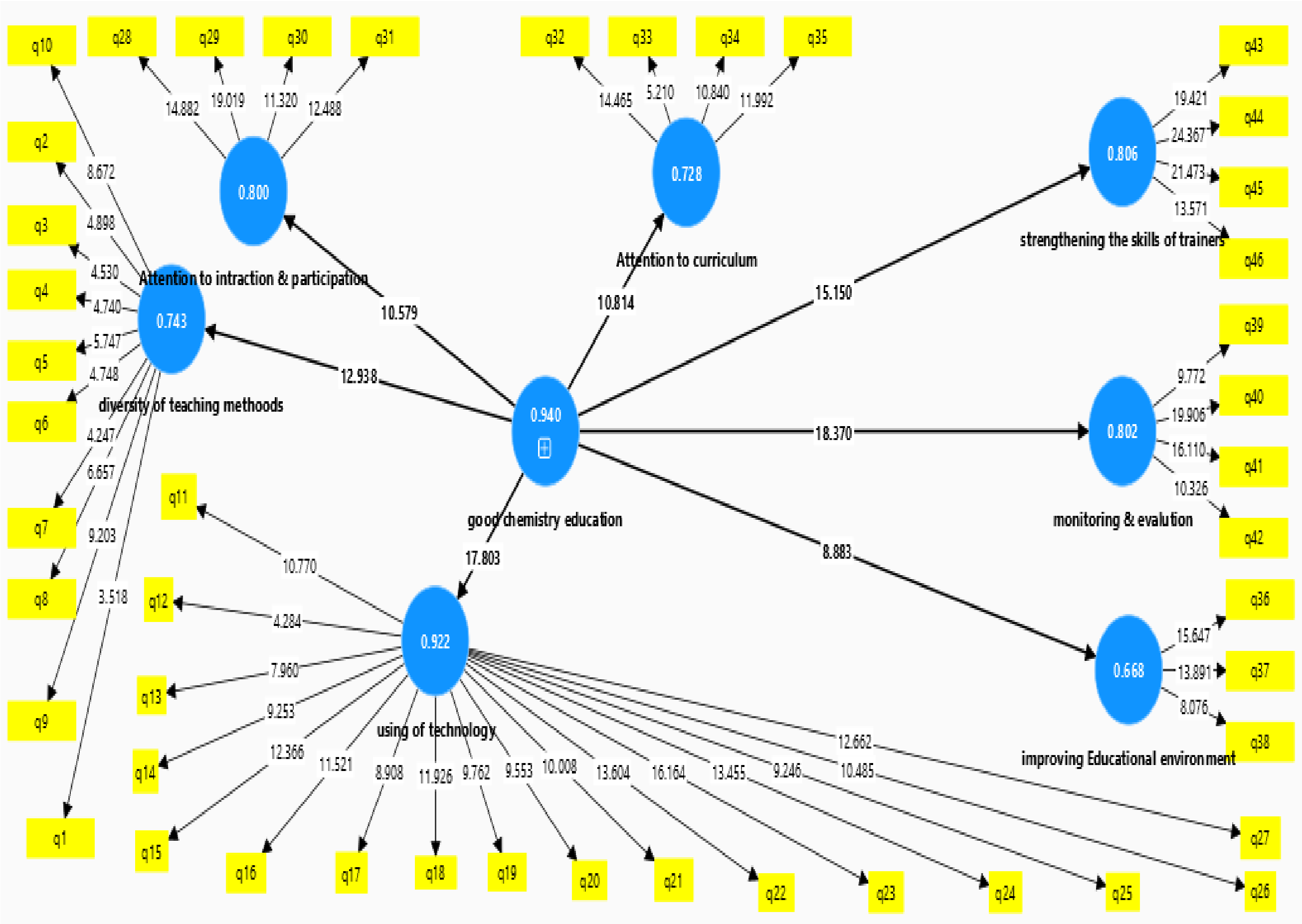


Figure 1- T-values for assessing the structural effectiveness of the model

Coefficient of Determination Index (R2): The coefficient of determination is used to connect the measurement part and the structural part and indicates the effect that an exogenous variable has on an endogenous variable. From this perspective, the three values of 0.19, 0.33, and 0.67 represent criteria for weak, medium, and strong effects (Melazehi et al., 2021). Accordingly, the structural fit of the model is acceptable based on the coefficient of determination, as shown in Table 6.

Table 6- Values related to structural model fit assessment indices

Variables	R^2
Paying attention to diverse teaching methods	0.560
Using technology	0.662
Paying attention to participation and interaction	0.327
Paying attention to the curriculum	0.361
Improving the educational environment and equipping it	0.490
Management and supervision	0.356
Strengthening a variety of skills in learners	0.490
Factors affecting effective chemistry teaching	0.390

Therefore, it is important to recognize that one of the key indicators for evaluating the fit of the structural model is the R-squared value, which was assessed using PLS software. Its values indicate how well the researcher-made tool's structural model fits the data.

Overall model fit evaluation index: The overall model includes both measurement models and structural equations. By confirming its fit, the assessment is completed within a single model. To evaluate the overall model, only one index called the goodness of fit index (GOF) is used, which assesses the validity or quality of the research model in general. Welts et al. (2009) introduced three cutoff values of 0.01, 0.25, and 0.36 as indicators of weak, moderate, and strong GOF. The GOF value for the research model is calculated as follows.

GOF= $\sqrt{(Communality)}(Rsqure) = 0.461$

Since the GOF value for the current research model was obtained, the model of factors influencing effective chemistry teaching shows an overall perfect fit.

SRMR is also an index that measures the average standardized differences between the observed and modeled correlation matrices. A lower SRMR value indicates a better model fit. Typically, a value ≤ 0.08 is considered a good fit, between 0.08 and 0.10 is considered acceptable, and above 0.10 is considered poor (Heer et al., 2010). Based on this, it is worth noting that the PLS software yielded an SRMR value of 0.096 after analyzing the data, indicating an acceptable fit.

Investigating the impact of factors affecting effective chemistry teaching: After fitting the measurement models, the structural model, and the general model, it becomes possible to examine the factors influencing desirable chemistry education. Considering the T-values, the relationships between the model variables, and the standardized coefficients of the research model, along with the associated standard errors, are detailed in Table 7.

Table 7- The impact of factors affecting effective chemistry teaching

Row	Path	Path coefficient	T-statistic	Test result
1	Paying attention to diverse teaching methods ⟹ effective chemistry teaching	0.735	12.938	Confirmation
2	Using technology ⟹ effective chemistry teaching	0.823	17.803	Confirmation
3	Paying attention to participation and interaction ⟹ effective chemistry teaching	0.672	10.579	Confirmation
4	Paying attention to the curriculum ⟹ effective chemistry teaching	0.699	10.814	Confirmation
5	Improving the educational environment and equipping it ⟹ effective chemistry teaching	0.665	8.883	Confirmation
6	management and supervision ⟹ effective chemistry teaching	0.784	18.370	Confirmation
7	Strengthening a variety of skills in learners ⟹ effective chemistry teaching	0.767	15.150	Confirmation

As shown in Table 7, the T-statistic values of these six components are greater than 1.96. Therefore, it can be confidently stated that the seven components described can predict the variables affecting desirable chemistry education at a 95% confidence level.

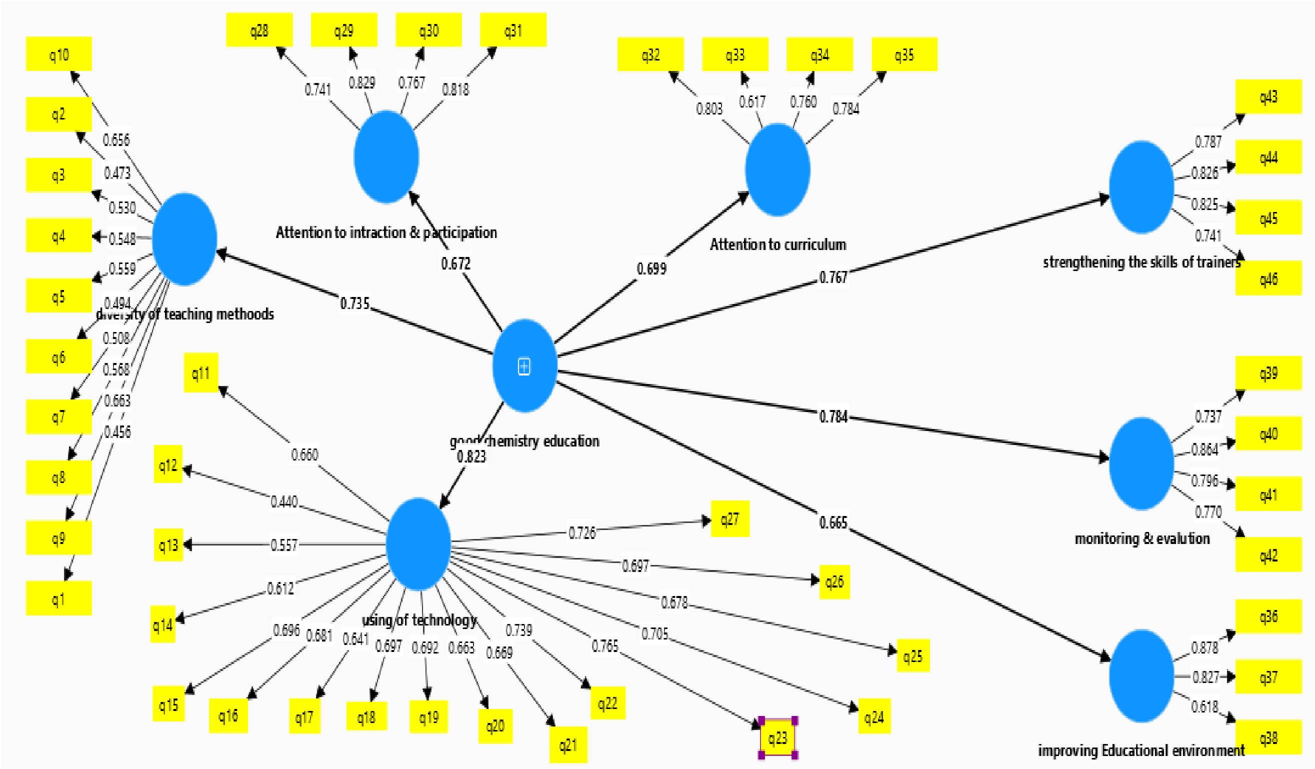


Figure 2- Standardized coefficients of the research model

Discussion and Conclusion

In subjects like experimental science, it is crucial to consider various methods and mechanisms to teach these subjects as effectively as possible. Among experimental subjects, chemistry is also essential, and the use of diverse methods is equally important in this regard. Chemistry stands out from other subjects due to its unique blend of theoretical and practical aspects, making it crucial to prioritize optimal education in this field. Therefore, the purpose of this study is to develop and validate a model of factors influencing effective chemistry teaching. To achieve this, related and similar documents were first examined in a systematic review. While extracting data from these documents, the model was designed and validated.

Instructors should recognize students' abilities and skills and work to develop them to deepen their understanding of chemistry concepts. By fostering curiosity and encouraging questions, teaching can lead to productive results. Motivating students to participate in creative activities during chemistry classes allows them to explore independently. Teaching chemistry is not just about memorizing formulas or definitions; it aims to empower students to think critically, analyze problems, draw conclusions, and apply knowledge in various situations. Therefore, skills such as careful observation, data analysis, logical reasoning, proper experimental conduct, teamwork, and time management should be cultivated. These skills will benefit students in their future studies, careers, and daily lives. This aligns with constructivist theory, which emphasizes that learning is most effective when students actively participate in constructing knowledge through curiosity, questioning, and creativity (Subedi, 2021). Carlisle et al. (2015) noted that guided activities to improve learners' spatial skills in general chemistry enhance their understanding of spatial relationships among and within molecules. This research also supports findings from Orsuz et al. (2023). Besides strengthening students' abilities, effective classroom management and supervision are essential, requiring instructors to adopt best practices for managing time and facilitating teaching and assessment. Teachers need to adapt to classroom conditions using various strategies and provide sufficient support for learners; thus, management and supervision are vital for delivering quality education. Educators and administrators should create supportive environments that enable teachers to teach with confidence and enthusiasm. Supporting teachers, fostering innovation, providing development opportunities, and offering constructive feedback help improve education. Continuous monitoring enables the identification of strengths and weaknesses, facilitating targeted performance improvements. Hartanto et al. (2022) noted that effective school leadership enhances the quality of chemistry education, resulting in improved exam scores, accreditation, public trust, and student success. Moreover, Sembiring and Tijow (2025) found that strong supervision in secondary schools across Kota Jayapura significantly enhances learning quality, student achievement, and emotional well-being. Equipping educational facilities with the proper tools is also crucial, as chemistry involves both practical and theoretical components. Laboratories must be well-equipped to provide effective learning through accurate experiments. Classrooms should be welcoming, calm, and conducive to learning, with resources such as laboratory equipment, teaching aids, display devices, and basic amenities like proper lighting and ventilation to enhance educational quality. Insufficient staffing can hinder effective teaching and disengage students. Kerekes (2024) emphasizes that upgrading facilities, investing in laboratory infrastructure, training teachers, and developing interactive programs can help ensure students receive a fair and comprehensive science education. The curriculum also plays a vital role. It should be relevant and sufficiently connected to chemistry concepts to prepare students for higher levels, while also aligning with their developmental stages. If the curriculum is not suitable, it can lead to misunderstandings and negative attitudes toward the subject. Since chemistry heavily relies on interaction and hands-on participation, promoting collaboration through group work and interactive methods is beneficial. Lessons should be purposeful and practical. If the goal is solely to pass exams and earn grades, student interest will decline. Instead, linking topics to real-world applications—such as medicine, agriculture, the environment, or industry—can boost motivation. The curriculum needs to be well-structured, precise, suited to students' levels, and aligned with current scientific advancements. Shin et al. (2019) assert that a coherent curriculum has a positive impact on student learning, especially in high- and medium-performing schools. Zhong (2011) also highlights that reforming curriculum systems, content, teaching methods, and assessment practices in coordination chemistry enhances graduates' innovative skills. These findings support the work of Shuhrat Qizi (2024). To stay competitive globally and prevent setbacks, integrating technology into education is crucial. Using the Internet, educational videos, and online resources transforms traditional learning into a more engaging and interactive experience. For example, students understand better when they watch videos of chemical reactions or see molecular models. Technology can also simulate experiments that are not feasible in school due to safety or logistical concerns, allowing students to observe and analyze without risks. This aligns with the SAMR model, which identifies four levels of technology integration to improve engagement and deepen learning (Bicalho et al, 2023). Scheweiker and Levonis (2023) found that advanced tools like lightboard videos and virtual labs enhance student engagement and learning outcomes in chemistry. Song et al. (2025) further emphasize that virtual technologies benefit chemistry learning, especially for high school students compared to college students. This study agrees with Vidarti et al. (2023), who highlight the importance of recognizing the diversity among learners. Since each student processes concepts differently, using varied teaching strategies is essential. Some learners learn visually, others through hands-on activities, and some through listening. Relying on a single teaching method can hinder understanding. Employing different techniques—such as oral explanations, group work, demonstrations, Q&A, and experiments—can increase engagement and interest. This approach aligns with Gardner's theory of multiple intelligences, which suggests students have different learning styles and intelligences, so teaching should be flexible and diverse (Kahovec, 2002). Zhu et al. (2024) support this, stating that diverse strategies, including problem-based, analogy, and transfer methods, improve self-learning and creativity in organic chemistry. Sugano et al. (2019) also emphasize that innovative teaching methods promote positive development among secondary chemistry students, boosting performance, attitude, and motivation.

In the quantitative section, the research findings show that all examined dimensions—whether related to teaching methods, educational planning, technology use, or management, supervision, and improvement of the learning environment—significantly contribute to promoting effective chemistry education. This highlights that improving chemistry education requires a multidimensional approach rather than relying on a single factor. Such an approach includes innovation in teaching methods, alignment with the curriculum, opportunities for participation and interaction, effective technology use, proper infrastructure and equipment, along with strong management and supervision. The existence of a meaningful relationship between these components and desirable chemistry education confirms that enhancing science learning involves integrating human, technological, organizational, and environmental factors, each of which is vital for the sustainability and effectiveness of the teaching-learning process. The model analysis results indicate that the assessment tool accurately captures the conceptual structure of desirable chemistry education. Statistical analyses show that the questionnaire items align well with the theoretical constructs and effectively distinguish different dimensions of desirable education. This suggests that participants clearly understood each component, as reflected in responses consistent with the theoretical framework. Additionally, the internal consistency within each construct indicates that both theoretical reasoning and empirical responses support the identified dimensions. In this regard, the present study aligns with the research of Ahmadi et al. (2024), as that study also reported satisfactory reliability of the instrument examined. Furthermore, it is consistent with Mojtaba-Zadeh (2023), since that research demonstrated acceptable factor loadings for the instrument's scales. The structural analysis of the model reveals that the variables sufficiently explain variations in desirable education, implying that the proposed model provides a solid understanding of the relationships among the influencing factors. Overall, the model's goodness-of-fit suggests that combining measurement and structural indicators offers a meaningful, coherent, and reliable framework for understanding the studied phenomenon. Therefore, the findings are both statistically and conceptually valid. However, it is important to note that the lack of qualitative methods, like in-depth interviews or content analysis, limits deeper insights into the dimensions of desirable education. Additionally, since the tool was only administered at one point in time without retesting, it does not provide information about the stability of the results over time, which is a limitation. Moreover, the designed tool is not context-specific and may not be equally effective across different provinces or cultural regions.

Therefore, it is worth noting that the model developed in this research is in a favorable state. One limitation of this study is that the sample only included students of chemistry education at Farhangian University. As a result, the findings cannot be generalized to other chemistry students at different universities or other educational groups. Based on the results, the following suggestions are proposed:

1. Chemistry educators are encouraged to incorporate active methods such as collaborative learning, problem solving, project-based learning, and experiment-based learning into chemistry classes. 2. It is recommended to use laboratory simulation software, multimedia content, augmented reality, and virtual education platforms when teaching chemistry. 3. It is suggested to develop a system for monitoring and evaluating professors' teaching that considers both the effectiveness of the teaching methods and student participation. 4. It is proposed to include skills like critical thinking, time management, teamwork, and problem solving in educational programs. 5. Since the statistical population of the study included only chemistry education students at Farhangian University, it is recommended that future research be conducted with more diverse samples, such as students from other universities and teachers working in schools, to improve the generalizability of the findings. 6. Given that the research instrument was measured at a single point in time and a test-retest was not conducted, it is suggested that future studies use longitudinal or test-retest methods to examine the stability and sustainability of the results over time. 7. Since the tool designed in the present study is not context-based and may not be equally effective in different cultural and geographical

regions, it is suggested that future research be conducted in various contexts and provinces to facilitate comparison and localization of the model.

Conflict of Interest

The authors have declared no conflicts of interest.

Acknowledgments

The authors are grateful to the Farhangian University for financial support.

References

Abboudi, J. & Nazarpour, H. (2021). Study and investigation of factors affecting interest and motivation in second-year secondary school students in chemistry. *Research in Chemistry Education*, *2*(4), 73-96. [In Persian]. https://chemedu.cfu.ac.ir/article_1645.html?lang=en

Abedi Kargiban, Z. (2013). Investigation of chemistry teachers' pedagogical content knowledge in Iranian high schools. *World Applied Sciences Journal, 24*(9), 1199–1205. https://doi.org/10.5829/idosi.wasj.2013.24.09.13104

Abudu, F., Ayoberd, S. A., & Marifa, H. A. (2024). Senior high school chemistry teachers' knowledge and use of group work as a teaching strategy. *Journal of Mathematics and Science Teacher*, *4*(2). em062. https://doi.org/10.29333/mathsciteacher/14410

Achimugu, L. (2016). Principals' instructional leadership qualities that enhance effective teaching and learning of chemistry in secondary schools from the perspectives of students and teachers. *International Journal of Science and Research (IJSR), 5*(7), 661–667. https://doi.org/10.21275/v5i7.ART2016240

Adekunle, O., Olu, A. V., & Nwabuno, N. (2021). Teaching chemistry with computer simulation: Would senior school students perform better? *Crawford Journal of Multidisciplinary Research, 2*(2), 16-32. [Link]

Ahmad, Z., Ammar, M., Sellami, A., & Al-Thani, N. J. (2023). Effective pedagogical approaches used in high school chemistry education: a systematic review and meta-analysis. *Journal of Chemical Education, 100*(5), 1796-1810. https://doi.org/10.1021/acs.jchemed.2c00739

Ahmadi, N., Taqvaee Yazdi, M., & Safarian Hamadani, S. (2024). Design and validation of the lesson study assessment tool. *Journal of Educational Strategies in Medical Science, 17*(5), 123–133. [In Persian]. http://edcbmj.ir/article-1-3177-en.html

Akrami, Z. (2024). The Principles of Needs Assessment in the Optimal Curriculum in Chemistry Education. *Research in Chemistry Education*, *6*(3), 64-84. [In Persian]. DOI: 10.48310/chemedu.2024.16579.1243

AlMahdawi, M., Senghore, S., Ambrin, H., & Belbase, S. (2021). High school students' performance indicators in distance learning in chemistry during the COVID-19 pandemic. *Education Sciences, 11*(11), 672. https://doi.org/10.3390/educsci11110672

Almeida, F. (2018). Strategies to perform a mixed methods study. *European Journal of Education Studies,* 5(1): 137–151. https://doi.org/10.5281/zenodo.1406214

Avwiri, E. H. (2011). Approaches for effective teaching of chemistry in Nigerian secondary schools. *Journal of Research in Education and Society*, *2*(1), 236–240. https://icidr.org.ng/index.php/Jres/article/view/1165

Bandura, A., & Walters, R. H. (1977). Social learning theory (Vol. 1, pp. 141–154). Englewood Cliffs, NJ: Prentice Hall. https://www.scirp.org/reference/referencespapers?referenceid=2730439

Barclay, D., Higgins, C., & Thompson, R. (1995). The Partial Least Squares (PLS) approach to causal modeling: Personal computer adoption and use as an Illustration. *Technology Studies, 2,* 285–309. https://www.scirp.org/reference/referencespapers?referenceid=2800017

Bhuttah, T. M., Xiaoduan, C., Ullah, H., & Javed, S. (2019). Analysis of curriculum development stages from the perspective of Tyler, Taba, and Wheeler. *European Journal of Social Sciences, 58*(1), 14–22. https://www.scirp.org/reference/referencespapers?referenceid=3288762

Bicalho, R. N. D. M., Coll, C., Engel, A., & Lopes de Oliveira, M. C. S. (2023). Integration of ICTs in teaching practices: propositions to the SAMR model. Educational technology research and development, *71*(2), 563–578. https://doi.org/10.1007/s11423-022-10169-x

Bugaje, B. M. (2013). Qualitative chemistry education: The role of the teacher. *IOSR Journal of Applied Chemistry*, *4*(5), 10-14. https://www.iosrjournals.org/iosr-jac/papers/Vol4-issue5/D0451014.pdf

Carlisle, D., Tyson, J., & Nieswandt, M. (2015). Fostering spatial skill acquisition by general chemistry students. *Chemistry Education Research and Practice*, *16*(3), 478-517. https://doi.org/10.1039/C4RP00228H

Chen, K., Lin, J., Wang, Z., Chen, K., & Yang, J. (2023). Teaching performance of chemistry teachers in the Chinese mainland during the COVID-19 pandemic: a content analysis study. *Journal of chemical education*, *100*(4), 1466-1475. https://doi.org/10.1021/acs.jchemed.2c00873

Cho, J., & Baek, W. (2019). Identifying factors affecting the quality of teaching in basic science education: Physics, biological sciences, mathematics, and chemistry. *Sustainability, 11*(14), 1–18. https://doi.org/10.3390/su11143958

Davari, A. & Rezazadeh, A. (2014). Structural Equation Modeling with PLS Software. Tehran: Jihad Daneshgahi Publishing Organization.

Dayal, P. D., & Ali-Chand, Z. (2022). Effective teaching and learning strategies in a chemistry classroom. *New Zealand Journal of Educational Studies*, *57*(2), 425–443. https://doi.org/10.1007/s40841-022-00242-7

Deci, E. L., & Ryan, R. M. (2000). The" what" and" why" of goal pursuits: Human needs and the self-determination of behavior. *Psychological Inquiry*, *11*(4), 227–268. https://doi.org/10.1207/S15327965PLI1104_01

Domenici, V., & Chiocca, G. (2024). Perception of chemistry and chemistry education: A case study and some reflections. *Substantia, 8*(2), 119-134. https://doi.org/10.36253/Substantia-2612

Dool, M. A., Mughal, S. H., & Rind, A. A. (2020). Usage of effective questioning to enhance students ‘level of participation in a grade XI chemistry classroom of a government degree college in the rural district of Jacobabad. *License, 3*(3), 222–231. DOI: https://doi.org/10.36902/sjesr-vol3-iss3-2020(222-231)

- Ebrahimi, N. A., & Eskandari, Z. (2014). Development and application of the democratic chemistry classroom environment inventory (DCEI) in Iranian universities. *International Journal of Physics and Chemistry Education*, 6(1), 34-57. https://doi.org/10.51724/ijpce.v6i1.54

Eshkoraev, S. (2024). Revolutionizing education: Harnessing innovative technologies in teaching chemical technology. *Multidisciplinary Journal of Science and Technology, 4*(3), 69–81. https://mjstjournal.com/index.php/mjst/article/view/976

Folounrunso, B. E., & Sunday, A. O. (2017). Relative effectiveness of guided discovery and demonstration teaching techniques on performance in chemistry in senior secondary schools in ILE-IFE, Nigeria. *European Journal of Education Studies, 3*(9), 663–678. https://doi.org/10.5281/zenodo.999983

Fornell, C., & Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *Journal of Marketing Research*, 18(1), 39–50. https://doi.org/10.2307/3151312

Goldie, J. G. S. (2016). Connectivism: A knowledge learning theory for the digital age? *Medical Teacher, 38*(10), 1064–1069. https://doi.org/10.3109/0142159X.2016.1173661

Green, M. L., & Parkin, G. (2014). Application of the covalent bond classification method for the teaching of inorganic chemistry. *Journal of Chemical Education, 91*(6), 807–816. DOI:10.1021/ed400504f

Grushow, A., & Reeves, M. S. (2019). Using computational methods to teach chemical principles: overview. *ACS Symposium Series*, 1–10. DOI:10.1021/bk-2019-1312.ch001

Hartanto, H., Suherman, D., Warta, W., & Barlian, U. C. (2022). Learning system management to improve the quality of learning chemistry for students of State 8 SMA Negeri 8 Bekasi and Taman Students High School of Bekasi. *International Journal of Educational Research & Social Sciences*, 3(5), 1927–1934. DOI:10.51601/ijersc.v3i5.428

Hassan, A. A., Ali, H. I., Salum, A. A., Kassim, A. M., Elmoge, Y. N., & Amour, A. A. (2015). Factors affecting students' performance in chemistry: A case study in Zanzibar secondary schools. *International Journal of Educational and Pedagogical Sciences*, *9*(11), 4086–4093. file:///C:/Users/arash/Downloads/10006159.pdf

Iyamuremye, A., Mukiza, J., Nsabayezu, E., Ukobizaba, F., & Ndihokubwayo, K. (2021). Web-based discussions in teaching and learning: Secondary school teachers' and students' perceptions and potential to enhance students' performance in organic chemistry. *Education and Information Technologies*, *27*(2), 2695–2715. https://doi.org/10.1007/s10639-021-10725-7

Jegstad, K. M. (2024). Inquiry-based chemistry education: A systematic review. *Studies in Science Education*, *60*(2), 251-313. https://doi.org/10.1080/03057267.2023.2248436

Kahovec, J. (2002). Scattering Methods for the Investigation of Polymers. In Macromolecular Symposia (Vol. 190). file:///C:/Users/arash/Downloads/10.1515_ci.2003.25.3.21a.pdf

Kerekes, J. (2024). The Impact of the Lack of Chemistry and Physics Laboratories in Schools. *Educatia 21 Journal*, *28*, 333-341. https://doi.org/10.24193/ed21.2024.28.36

Khodaei, M., Askarian, F., Dehghan Ghahfarokhi, A., & Tayebi, B. (2023). A systematic review of the economic benefits of sport development. *Applied Research of Sport Management*, *12*(1), 51–66. [In Persian]. DOI: 10.30473/arsm.2023.65848.3716

Kochkarova, R. R., & Turgunov, E. (2023). Improving the methodology of teaching chemistry lessons at school with the help of different games. *American Journal of Applied Science and Technology*, *3*(10), 15–19. https://doi.org/10.37547/ajast/Volume03Issue10-04

Koehler, M. J., Mishra, P., & Yahya, K. (2007). Tracing the development of teacher knowledge in a design seminar: Integrating content, pedagogy and technology. *Computers & Education*, *49*(3), 740-762. https://doi.org/10.1016/j.compedu.2005.11.012

Koh, J. H. L., Chai, C. S., & Lee, M. H. (2015). Technological pedagogical content knowledge (TPACK) for pedagogical improvement: Editorial for special issue on TPACK. *The Asia-Pacific Education Researcher*, 24, 459-462. https://doi.org/10.1007/s40299-015-0241-6

Kousa, P. M., & Aksela, M. K. (2019). The needs for successful chemistry teaching in diverse classes: teachers' beliefs and practices. *LUMAT: International Journal on Math, Science and Technology Education*, *7*(1), 79-100. DOI: https://doi.org/10.31129/LUMAT.7.1.390

Kousa, P., Kavonius, R., & Aksela, M. (2018). Low-achieving students' attitudes towards learning chemistry and chemistry teaching methods. *Chemistry Education Research and Practice, 19*(2), 431-441. https://doi.org/10.1039/C7RP00226B

Malik, S., Rohendi, D., & Widiaty, I. (2019, February). Technological pedagogical content knowledge (TPACK) with information and communication technology (ICT) integration: A literature review. In 5th UPI International Conference on Technical and Vocational Education and Training (ICTVET 2018) (pp. 498-503). https://doi.org/10.2991/ictvet-18.2019.114

Mazid, H., Rachmalia, L., Suyanta, S., & Widjajanti, E. (2023). Teacher strategies in managing chemistry learning time to improve student learning achievement. *Journal Penelitian Pendidikan IPA,* 9(11), 1129-1136. https://doi.org/10.29303/jppipa.v9i11.5192

McBrayer, J. S., Akins, C., Gutierrez de Blume, A., Cleveland, R., & Pannell, S. (2020). Instructional Leadership Practices and School Leaders' Self-efficacy. *School Leadership Review,* 15(1), 1-34. https://scholarworks.sfasu.edu/slr

Meyer, A., Rose, D. H., & Gordon, D. T. (2014). Universal design for learning: Theory and practice. CAST Publishing.

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, *108*(6), 1017-1054. https://doi.org/10.1111/j.1467-9620.2006.00684.x

Mojsoska, B., Pande, P., Moeller, M. E., Ramasamy, P., & Jepsen, P. M. (2024). Virtual reality in an eco-niche undergraduate organic chemistry laboratory course: New practice in chemistry lab teaching. *Journal of Chemical Education*, 101(11), 4686–4693. DOI: 10.1021/acs.jchemed.4c00099

Mojtanazadeh, M. (2023). Designing and validating a tool to assess the curriculum quality of universities in Iran. *Journal of Educational Strategies in Medical Science, 16*(4), 323-334. [In Persian]. http://edcbmj.ir/article-1-2094-en.html

Monday, M., & Fashakin, O. (2024). Using lesson study as a tool to cope with instructional challenges: A case study of chemistry teachers in Nigeria. *African Journal of Teacher Education, 13*(2), 53–73. https://doi.org/10.21083/ajote.v13i2.8024

Musengimana, J., Kampire, E., & Ntawiha, P. (2021). Factors affecting secondary school students' attitudes toward learning chemistry: A Review of the literature. *Eurasia Journal of Mathematics, Science and Technology Education, 17*(1). em1931. https://doi.org/10.29333/ejmste/9379

Mwangi, J. T., & Kibui, J. T. O. (2016). Effect of chemistry practicals on students' performance in Chemistry in public secondary schools of Machakos and Nairobi Counties in Kenya. *International Journal of Science and Research, 6*(8), 586-588. https://doi.org/10.21275/ART20175884

Narzullayev, M., Xoliyorova, S., Pardayev, U., & Tilyabov, M. (2024). The method of organizing chemistry lessons using the case study method. *Modern Science and Research, 3*(5), 119-123. https://doi.org/10.5281/zenodo.11120435

Orosz, G., Németh, V., Kovács, L., Somogyi, Z., & Korom, E. (2023). Guided inquiry-based learning in secondary-school chemistry classes: A case study. *Chemistry Education Research and Practice, 24*(1), 50-70. DOI: 10.1039/D2RP00110A

Pekdağ, B. (2010). Alternative methods in learning chemistry: Learning with animation, simulation, video, and multimedia. *Journal of Turkish Science Education*, 7(2), 79-110. https://www.tused.org/index.php/tused/article/view/513?articlesBySimilarityPage=29

Polk, J. A. (2006). Traits of effective teachers. *Arts Education Policy Review*, 107(4), 23-29. https://www.tandfonline.com/doi/pdf/10.3200/AEPR.107.4.23-29

Saadati, Masoud (2021). The need for rethinking in experimental science education again. *Research in Chemistry Education*, *2*(4), 1-4. [In Persian]. file:///C:/Users/arash/Downloads/10009513990401.pdf

Shukla, Y. (2024). Innovative methods of using practical experiments in teaching chemistry. *International Journal of Multidisciplinary Research in Arts, Science and Technology*, *2*(2), 9-16. https://doi.org/10.61778/ijmrast.v2i2.38

Sattarifar, A., Ghahremani, J. & Tahmasbzadeh Sheikhlar, D. (2023). Design and validation of the optimal model of chemistry curriculum with IBSE approach. *Journal of Educational Strategies in Medical Sciences*, *16*(6), 519-530. [In Persian]. http://edcbmj.ir/article-1-2992-en.html

Schweiker, S., & Levonis, S. (2023). Enhancing chemistry education through technology-enhanced learning: impact on student outcomes. *ASCILITE Publications*. https://doi.org/10.14742/apubs.2023.463.

Sembiring, D. A. K., & Tijow, M. A. (2025). The relevance and impact of academic supervision on educational excellence in secondary schools. *Journal Manajemen, Kepemimpinan, dan Supervisi Pendidikan*, *10*(1), 260-274. DOI: 10.31851/jmksp.v10i1.16860

Shabani, K., Khatib, M., & Ebadi, S. (2010). Vygotsky's zone of proximal development: Instructional implications and teachers' professional development. English language teaching, *3*(4), 237–248. https://doi.org/10.5539/elt.v3n4p237

Shiddiqi, M. H. A., Arthamena, V. D., Ayyubi, M., Manarisip, A. J., & Aznam, N. (2024). Systematic literature review: Analysis of misconception problems and diagnostic instruments for learning chemistry. *Journal Penelitian Pendidikan IPA*, *10*(4), 168-179. https://doi.org/10.29303/jppipa.v10i4.5189

Shin, N., Choi, S. Y., Stevens, S. Y., & Krajcik, J. S. (2019). The impact of using a coherent curriculum on students' understanding of core ideas in chemistry. *International Journal of Science and Mathematics Education*, *17*, 295-315. https://doi.org/10.1007/s10763-017-9861-z

Shuhrat qizi, R. S. (2024). Use of interactive methods in chemistry. *International Bulletin of Medical Sciences and Clinical Research*, *2*(8), 115-119. https://doi.org/10.5281/zenodo.10032381

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *American Educational Research Association*, 15(2), 4-14. http://www.jstor.org/stable/1175860

Simesso, M. D., Gutu, T. S., & Tarekegn, W. M. (2024). The contribution of using cooperative learning methods to students' achievement and retention in secondary schools during chemistry lessons. *Education Research International*, *2024*(1), 1830124. https://doi.org/10.1155/2024/1830124

Song, Q., Li, M., Zhang, Z., & Zhou, Q. (2025). Learning effectiveness of virtual technologies in chemistry using a three-level meta-analysis. *Education and Information Technologies*, 30, 14737–14759. https://doi.org/10.1007/s10639-025-13321-1

Sözbilir, M., Pınarbaşı, T., & Canpolat, N. (2010). Prospective chemistry teachers' conceptions of chemical thermodynamics and kinetics. *Eurasia Journal of Mathematics, Science and Technology Education*, 6(2), 111–120. https://doi.org/10.12973/ejmste/75232

Subedi, R. R. (2021). Constructivist Approach in Learning Chemistry: A Case of High School in Nepal. *Interdisciplinary Research in Education*, *6*(2), 35-42. https://doi.org/10.3126/ire.v6i2.43535

Sugano, S. G., Nabua, E., Barquilla, M., Buan, A., & Inutan, E. D. (2019). Meta-analytic review of studies on the effectiveness of chemistry teaching methods on student transformation. *Journal of Physics: Conference Series*, 1340, 012082. https://doi.org/10.1088/1742-6596/1340/1/012082

Tsadik Getu, G., Kidan Mebrahitu, G., & Yohannes, G. (2024). Effects of context-based teaching chemistry on students' achievement: A systematic review. *Journal Pijar Mipa*, *19*(2), 190-197. https://doi.org/10.29303/jpm.v19i2.6458

Vallespin, M. R. D., & Prudente, M. S. (2024). Meta-analysis on the effectiveness of learning cycle models and online teaching strategies in chemistry education. *International Journal of Instruction*, *17*(2), 335–350. https://doi.org/10.29333/iji.2024.17219a

Wetzels, M., Odekerken, S. G., & Vanoppen, C. (2009). Using PLS path modeling for assessing hierarchical construct models: an empirical illustration. *MIS Quarterly*, *33*(1), 177-195. https://doi.org/10.2307/20650284

Widarti, H. R., Sriwahyuni, T., Rokhim, D. A., & Syafruddin, A. B. (2023). Social media-based learning in Chemistry learning: A review. *Eclética Química*, *48*(2), 17-21. https://doi.org/10.26850/1678-4618eqj.v48.2.2023.p17-21

Woldeamanuel, M., Atagana, H., & Engida, T. (2014). What makes chemistry difficult? *African Journal of Chemical Education*, *4*(2), 31–43. https://www.ajol.info/index.php/ajce/article/view/104070

Xoliyorova, S., Tilyabov, M., & Pardayev, U. (2024). Explaning the basic concepts of chemistry to 7th-grade students in general schools based on STEAM. *Modern Science and Research*, *3*(2), 362-365. https://doi.org/10.5281/zenodo.10966929

Zarei, E., & Hossein Nia, R. (2023). Analysis of high school chemistry textbooks used in Iran for representations of the nature of science. *Interchange*, 54(2), 253–270. DOI: 10.1007/s10780-023-09490-y

Zheng, C., Fu, L., & He, P. (2014). Development of an instrument for assessing the effectiveness of chemistry classroom teaching. *Journal of Science Education and Technology*, 23, 267-279. https://doi.org/10.1007/s10956-013-9459-3

Zhong, G. (2011). Reformation and practice on the curriculum system and teaching model of coordination chemistry for postgraduates. *Advances in Computer Science, Environment, Ecoinformatics, and Education*, August 21-22, 2011. Proceedings, Part V (pp. 26–31). https://doi.org/10.1007/978-3-642-23357-9_6

Zhu, Y., Zhao, Y., Yao, R., Song, W., & He, Z. (2024). Practice and exploration of diversified teaching modes in organic chemistry. *Curriculum Learning and Exploration*, *2*(2), 46–48. https://doi.org/10.18686/cle.v2i2.3818