JSER

Journal of Science Education Research
Journal homepage: https://journal.uny.ac.id/index.php/jser/index

ISSN: 2597-9701

Exploratory Study of Student Needs in the Development of Technology-Based Chemical Computing Software

Ariyatun[1*], S. Sagita[2], D. M. Venessa[3], V. Z. Sudariasri[4], N. A. Nurcahyono[5], R. F. Ramadani[6]
[1,3,4]Department of Chemistry Education, Universitas Negeri Jakarta, Indonesia
[2,5]Graduate Program of Elementary Education, Faculty of Education, Universitas Negeri Jakarta, Indonesia
[6]Department of Biology Education, Universitas Negeri Jakarta, Indonesia
**Corresponding Author. Email: ariyatun@unj.ac.id,*

Abstract

The development of digital technology in education demands innovations in chemistry learning, especially in explaining abstract concepts such as molecular structure, chemical reactions, and properties of compounds. This research aims to explore the needs of chemistry education students towards the development of technology-based chemical computing software. The research method uses a mixed-method approach with an exploratory descriptive design. The data was obtained through a closed questionnaire on the Likert scale, which was distributed to 117 students of the Chemistry Education study program from three universities in Indonesia. Data analysis was carried out using descriptive statistics in the form of frequency, average, and standard deviation. The results showed that students had a high need for interactive 3D molecular visualization features (M = 4.09), integration of materials with concept animation (M = 4.09), and interactive exercises (M = 4.06). In addition, simple reaction simulation features and auto-scoring were also considered important (M = 4.03). Meanwhile, the aspect of cross-device access (M = 3.76) and the availability of Indonesian content according to the national curriculum (M = 3.55) received a lower score, although it remained in the high category. The conclusion of this study emphasizes the importance of developing chemical computing software that is not only visual, but also educational, adaptive, and according to the needs of students. The implications of the research results provide direction for educational technology developers, curriculum designers, and higher education institutions in designing chemistry learning media that are more contextual, inclusive, and sustainable.

History
Received: October 8, 2025
Revised: January 3, 2026
Accepted: February 23, 2026

Keywords:
Curriculum Innovation, Smart Learning, Chemistry Computation, Technology Education, Digital Literacy

How to cite:
Ariyatun, Sagita, S., Venessa, D.M., Sudariasri, V.Z., Nurcahyono, N.A., & Ramadani, R.F. (2026). Exploratory Study of Student Needs in the Development of Technology-Based Chemical Computing Software. *Journal of Science Education Research*, 10(1), 38-48.doi: https://doi.org/10.21831/jser.v10i1.90331.

1. INTRODUCTION

Chemistry learning in universities is still faced with great challenges in explaining abstract concepts such as molecular structure and geometry, bond energy, interaction between particles, and chemical reaction mechanisms (Byusa et al., 2022). Conventional learning media, whether in the form of static images or verbal explanations, are often insufficient to help students build a deep conceptual understanding (Arsyad et al., 2016). As a result, the learning process tends to be memorized and lacks critical, analytical, and creative thinking skills in solving complex problems. On the other hand, technological developments have presented Computational Chemistry Software (CCS) such as Gaussian, Avogadro, ChemDraw, and Spartan, which were initially widely used in the field of research (Allouche, 2012; Lehtola & Karttunen, 2022). CCS is able to model molecular structures in three dimensions, calculate physicochemical properties, and simulate reaction processes, so that it can visualize concepts that are difficult to visualize manually (Fombona-Pascual et al., 2022; Kozlíková et al., 2017). Although it has great potential to help students understand the relationship between theory and real phenomena, the application of CCS in the classroom is still limited and has not been optimized as an integral part of the chemistry learning process.

In the context of education, what is needed is not just information transfer, but deep conceptual understanding (Indolia et al., 2018). This understanding means that students not only remember facts or definitions, but are also able to connect interrelated concepts, explain phenomena for scientific reasons, and apply these concepts in new situations or complex problem solving (Vosniadou, 2019). With this approach, students are encouraged to develop higher order thinking skills, such as analysis, evaluation, and creation (Zendler & Greiner, 2020). This kind of deep understanding is also an important foundation for students to adapt to the ever-changing development of science and technology, as well as prepare them to become lifelong learners (Retnawati et al., 2018; Schulz & FitzPatrick, 2016).

Meanwhile, studies in the field of chemistry show that many student misconceptions arise due to weak connections between concepts (Üce & Ceyhan, 2019). Therefore, technology-based learning, including the use of Computational Chemistry Software (CCS), is seen as effective in reducing the understanding gap. Visualization of three-dimensional molecules through chemical software can improve students' spatial understanding and strengthen their ability to reason about reaction mechanisms (Kuit & Osman, 2021; Serhan et al., 2019). Thus, CCS integration not only supports the achievement of curriculum objectives, but also strengthens science and technology literacy relevant to the demands of 21st century competencies (Du et al., 2023). The integration of CCS in learning is in line with the spirit of the Independent Curriculum and the demands of 21st century competencies that emphasize science literacy, technological literacy, and collaborative skills. Furthermore, this approach can strengthen inquiry-based learning and problem-based learning, where students play an active role in building knowledge through data exploration and simulation (Gholam, 2019).

The urgency of this research lies in the lack of exploratory studies on the needs of students for the development of technology-based chemistry software that is truly in accordance with the learning context in Indonesian universities. Although some CCS are available, most are commercial, foreign-language, require high device specifications, and have not adapted to the national curriculum approach and the characteristics of local students (Erümit & Sarıalioğlu, 2025). Preliminary findings from several observations and interviews show that students need software that is more intuitive, lightweight, interactive, and supports inquiry-based and collaborative learning. This emphasizes the need for exploratory studies to comprehensively identify user needs (student needs) as the basis for the development of relevant, adaptive, and sustainable technology-based chemical computing software.

.

2. LITERATURE REVIEW

2.1 Deep Conceptual Understanding and the Role of Computational Chemistry Software

Chemistry learning in college inherently faces great challenges due to the abstract, microscopic, and symbolic characteristics of its concepts (Agustian et al., 2022). Molecular structure, geometry, bond energy, and reaction mechanisms cannot be observed directly, so students are required to have high representational skills (Kiernan et al., 2021). While learning is still dominated by static media and verbal explanations, the learning process often leads to procedural memorization without deep conceptual understanding (Kiernan & Seery, 2024). This condition has an impact on weak analytical skills and low complex problem-solving skills. Deep conceptual understanding is the main foundation in the theoretical framework of this research. Deep understanding not only means knowing definitions, but being able to connect concepts, explain phenomena scientifically, and transfer knowledge to new situations (Chakravartty, 2023). From a cognitive perspective, this kind of understanding encourages the development of higher-order thinking skills such as analysis, evaluation, and creation (Chaojing, 2023).

This perspective is in line with the constructivist view that places students as active builders of knowledge (Bhattacharjee, 2015). In the context of chemistry, misconceptions often arise due to the inability to integrate macroscopic, submicroscopic, and symbolic representations simultaneously. Therefore, learning requires media that is able to bridge the three levels of representation dynamically and interactively (Bhattacharjee, 2015). In line with these needs, the integration of digital technology in chemistry learning offers opportunities to present a more comprehensive conceptual representation (Lilian, 2025). Simulation-based media and three-dimensional visualization allow students to observe the relationship between molecular structure, electron distribution, energy change, and reaction mechanisms in a more concrete way (Brown et al., 2021). Thus, concepts that were previously abstract can be represented visually and manipulatively, thus helping students build connections between levels of representation more systematically.

In this context, chemical computing software acts as a cognitive tool that supports the process of knowledge construction (Brown et al., 2021). Through features such as molecular modeling, geometry optimization, energy calculation, and reaction dynamics simulation, students not only receive information, but also actively explore the concepts learned (Alharbi, 2025). This activity encourages the process of reflection and restructuring of understanding, which is the core of meaningful learning. When students can manipulate parameters, compare simulation results, and test hypotheses independently, they have an easier time understanding cause-and-effect relationships in chemical systems. Furthermore, the use of interactive media also contributes to reducing misconceptions that often arise due to symbolic interpretations that are separate from real phenomena (Mukhlis et al., 2026). Dynamic visualization allows students to see how structural changes affect chemical properties, or how variations in reaction conditions affect the course of the mechanism (Elmqaddem, 2019). With exploratory and contextual learning experiences, the learning process is no longer just about memorizing problem-solving procedures, but rather developing deeper scientific reasoning skills.

Technological developments have presented Computational Chemistry Software (CCS) such as Gaussian, Avogadro, ChemDraw, and Spartan which were initially widely used in computational chemistry research (Lehtola & Karttunen, 2022). The software allows for three-dimensional molecular visualization, reaction simulation, as well as accurate calculation of physicochemical properties. In the context of education, CCS has the potential to be a cognitive tool that helps students build conceptual understanding through exploration and simulation (Watson, 2022). Software-generated spatial visualization has been proven to improve the reasoning ability of reaction mechanisms and strengthen the relationship between theory and real phenomena (Gather et al., 2024). The use of CCS in the classroom has not been fully integrated as part of a systematic pedagogical strategy. Much software is still complex, research-oriented, and not yet tailored to learning needs. This shows that the existence of technology alone is not enough; What is needed is an integration that is pedagogically designed to support deep understanding and development of high-level thinking skills.

2.2 Student Needs Analysis as the Foundation for Developing Technology-Based Chemical Computing Software

The development of effective learning software must depart from the analysis of the needs of users, in this case students (Maulana et al., 2025). In higher education, students have different digital characteristics from the previous generation. They are accustomed to interactive technology, dynamic visualization, and quick access to information (Ariyatun et al., 2025). However, technological literacy is not always in line with conceptual literacy. Therefore, the development of technology-based chemical computing software needs to comprehensively consider the cognitive, technological, pedagogical, and contextual needs of students (Brown et al., 2021). From the cognitive side, students need media that is able to visualize abstract concepts clearly and allow direct manipulation of variables. From a technological point of view, the software developed must be intuitive, lightweight, compatible with student device specifications, and not rely on expensive commercial licenses (Arkader et al., 2025). Meanwhile, from the pedagogical side, software needs to support inquiry-based learning and problem-based learning approaches, where students can explore data, test hypotheses, and draw conclusions independently or collaboratively (Shengqiang et al., 2025). This approach is in line with the demands of 21st century competencies that emphasize science literacy, technological literacy, and critical and creative thinking skills.

In the Indonesian context, most of the available CCS still use foreign languages, are research-oriented, and are not fully aligned with the national curriculum and characteristics of local students (Raes et al., 2012). This creates a gap between the potential of technology and the real needs in the classroom. Therefore, an exploratory study of student needs is a fundamental step in this research. A comprehensive identification of needs will be the basis for designing chemical computing software that is adaptive, relevant, and sustainable. Thus, the theoretical framework of this research places the analysis of student needs as the main foundation in the development of technology-based chemical computing software. The integration between deep conceptual understanding and needs-based design is expected to be able to produce software that is not only technically innovative, but also effective in improving the quality of chemistry learning in higher education (Demir & Kayaoğlu, 2022).

In addition, the analysis of student needs not only serves to identify desired technical features, but also to understand the barriers to use that may arise in implementation in the classroom. Factors such as confidence in using technology, previous experience with chemical software, and campus infrastructure support are important variables that affect the effectiveness of software integration (Kiernan et al., 2021). Without a thorough needs mapping, software development risks not being utilized optimally despite being technically sophisticated. Furthermore, the needs analysis approach also allows developers to accommodate the diverse learning preferences of students. Some students may be more helpful with interactive three-dimensional visualizations, while others may need step-by-step guidance or automated feedback to reinforce procedural understanding (Wu et al., 2000). By integrating the results of the exploration of these needs, the software design can be designed to be more flexible and adaptive, for example through structured tutorial features, free exploration modes, and online collaboration support.

3. RESEARCH METHOD

3.1. Data Collection Design and Procedures

This study uses a mixed-method approach with a descriptive exploratory design. The quantitative approach was chosen to obtain an overview of the level of students' needs for features in chemical computing software, while the qualitative approach was used to explore more deeply the reasons, expectations, and recommendations of students for the development of the software. With the combination of these two approaches, the research is expected to be able to provide a more complete picture of user needs. The participants in this study are 117 students of the Chemistry and Chemistry Education study program from three universities in Indonesia. The selection of respondents was carried out by purposive sampling technique which considered active students who had taken at least one basic chemistry course or courses related to chemical computing. The characteristics of the respondents recorded included gender, the origin of the study program, and the semester or batch taken.

Table 1. The distribution of response

	Variance	Frequency	Percent	Valid Percent	Cumulative Percent
Female	.256	53	45.5	45.5	45.5
Male		64	54.5	54.5	100.0
Chemistry Education	.246	71	60.6	60.6	60.6
Chemistry		46	39.4	39.4	100.0
1-2 semesters	1.028	57	48.5	48.5	48.5
2-3 semesters		35	30.3	30.3	78.8
4-5 semesters		18	15.2	15.2	93.9
6-7 semesters		4	3.0	3.0	97.0
<7 semesters		3	3.0	3.0	100.0
Total		117	100.00	100.00	

Based on Table 1, the respondents were dominated by male students (54.5%), while female students accounted for 45.5% of the total sample. In terms of study program, the majority of participants were enrolled in the Chemistry Education program (60.6%), followed by students from the Chemistry program (39.4%). Regarding academic level, nearly half of the respondents (48.5%) were in the early stages of their studies (1–2 semesters). Students in the 2–3 semester group constituted 30.3% of the sample, while those in the 4–5 semester group represented 15.2%. Only a small proportion of respondents were in advanced semesters (6–7 semesters and above), accounting for a combined total of 6.0%. Overall, this distribution indicates that the sample represents a diverse range of academic backgrounds and study stages, with a stronger representation of early- to mid-semester students who are actively engaged in foundational chemistry courses relevant to chemical computing.

Of the total 117 respondents, all participants were included in the quantitative analysis using descriptive statistics to examine students' needs for features in chemical computing software. In addition, a qualitative component was conducted to enrich and contextualize the quantitative findings. A purposive subsample of 12 students was selected from the quantitative respondents to participate in the qualitative phase. The selection considered variations in study program and semester level to capture diverse perspectives. Qualitative data were collected through open-ended questionnaire responses and follow-up semi-structured interviews focusing on students' experiences, expectations, and recommendations regarding technology-based chemical computing software. The qualitative data were analyzed thematically and used to support, explain, and elaborate the quantitative results.

3.2. Data Analysis Techniques

Data from the questionnaire were analyzed using descriptive statistics to see the distribution of frequency, average, and standard deviation of students' perception of the need for features in the development of technology-based chemical computing software. This analysis was used to determine the priority level of features such as interactive 3D molecular visualization, simple reaction simulation, integration of materials with animations, interactive exercises, automatic assessment features, cross-device access, and the availability of Indonesian content according to the national curriculum. In addition, a qualitative analysis was carried out through semi-structured interviews with several selected respondents to explore more deeply the experiences, constraints, and expectations of students after participating in software use training. The results of the interviews were thematically analyzed and revealed that students found visualization and interactive features helpful in understanding abstract chemistry concepts, but still needed clearer usage guides, simple interface displays, and support for auto-feedback features to improve independent learning. These qualitative findings complement the quantitative results by providing an empirical picture of the real needs of students as the basis for the development of technology-based chemical computing software that is more adaptive and effective.

.

4. RESULT AND DISCUSSION

4.1. Results of Quantitative Data Analysis

The research instrument is in the form of an online questionnaire consisting of two parts. The first part is in the form of a closed statement with a four-point Likert scale, ranging from "unnecessary" to "very necessary", which contains aspects of the need for interactive 3D molecular structure visualization, simple reaction simulations, integration of materials with animations, interactive exercises, automatic assessment features, cross-device access, and the availability of Indonesian content that is in line with the national curriculum. The second part is an open-ended question that allows students to provide input on ideal features, usage constraints, and suggestions related to the interface and content.

Table 2. Descriptive Statistics Questionnaire

Statement Items	N	Mean	Std. Deviation	Variance
The need for interactive 3D molecular structure visualization	117	4.09	.805	.648
Simple reaction simulation	117	4.03	.770	.593
Integration of material with animation	117	4.09	.765	.585
Interactive exercises	117	4.06	.788	.621
Auto-scoring feature	117	4.03	.770	.593
Cross-device access	117	3.76	.708	.502
Availability of Indonesian content that is in line with the national curriculum	117	3.55	.711	.506
Valid N (listwise)	117			

The results of the analysis in Table 2. showed that students urgently needed interactive 3D molecular visualization features and material integration with animation ($M = 4.09$), followed by interactive exercises, simple reaction simulations, and automated assessments ($M > 4.00$). This confirms that the visualization and interactivity aspects are top priorities. Meanwhile, cross-device access ($M = 3.76$) and Indonesian content according to the curriculum ($M = 3.55$) were considered important but relatively less dominant. These findings show that students emphasize the need for interactive and visually understandable learning media. The ethical aspect of the research is maintained by ensuring that student participation is voluntary, data confidentiality is guaranteed, and personal identity is not included in the report. All data is stored on password-protected institutional storage media and is only accessed by the research team. However, this study has limitations in non-probability sampling techniques so that the generalization of findings needs to be done carefully, as well as the potential for perception bias because the instrument is self-reported.

The results of the frequency distribution in Figure 1 show that the majority of students consider the interactive 3D molecular structure visualization feature to be very important, with 71.8% of respondents choosing the category of very necessary and only 1.7% stating that it is not necessary. These findings show the urgency of developing media that is able to present molecular concepts in a more real and interactive way. A similar pattern was seen in the indicators of material integration with concept animation (70.1% very necessary) and interactive exercises (67.5% very necessary), which indicated that students expected software to not only present information, but also facilitate understanding through dynamic visualization and self-study activities. The simple reaction simulation feature also received high appreciation, where 64.9% of students considered it very necessary. This confirms the need for students to be able to see the representation of chemical processes directly even in the form of simple simulations. Similarly, the automated assessment feature was considered important by 66.7% of students, indicating an expectation for instant feedback as part of the learning evaluation process.

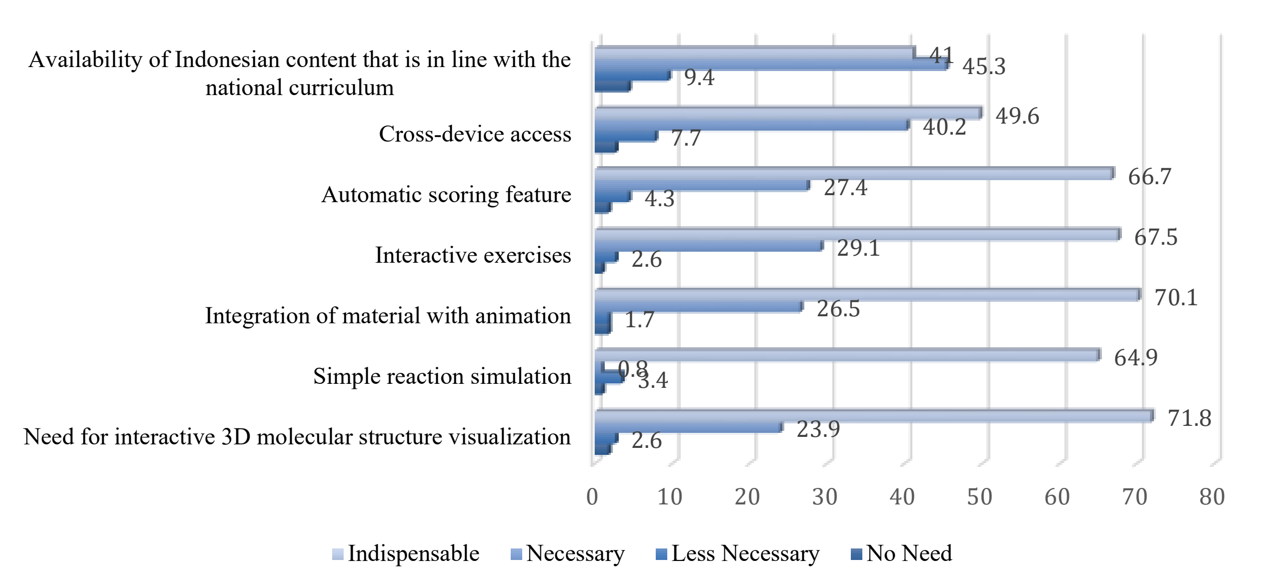

Figure 1. Distribution of Frequency of Student Questionnaires

In contrast to the previous indicator, cross-device accessibility and availability of Indonesian-language content obtained a lower proportion of essential content, 49.6% and 41.0%, respectively. Despite this, more than 85% of respondents still put both in the category of necessary to very necessary, so this aspect remains relevant to pay attention to. These results show that students' top priorities are features that support conceptual understanding and interactivity, while technical aspects such as accessibility and language are considered important but not the most urgent needs.

4.2. Qualitative Data Results

The results of interviews with several respondents who participated in the training on the use of chemical computing software showed a number of important findings related to students' perceptions, experiences, and needs for technology-based software development. Most students state that the use of software helps them understand abstract chemical concepts, especially on the topic of molecular structure and geometry. 3D molecular visualization is considered very helpful in depicting atomic orientation and chemical bonds in real life. In summary, the analysis of the interview data findings is presented in Table 3.

Table 3. Analysis of student needs based on interview results

Indicator	Description of Data Findings
The need for interactive 3D molecular structure visualization	Students consider the 3D molecular visualization feature to be very important for understanding the shape, orientation, and binding between tomes. They find it easier to visualize abstract concepts such as hybridization, molecular geometry, and interparticle interactions through a three-dimensional display that can be rotated and magnified.
Simple reaction simulation	Respondents expect a simple chemical reaction simulation feature that can show energy changes, bond formation and breaking, and reaction direction. This feature is considered to be able to bridge the understanding between reaction theory and experimental phenomena
Integration of material with animation	Students want theoretical material that is complemented by visual animation to make difficult concepts such as reaction mechanisms or molecular dynamics easier to understand. Animation is considered more interesting and helpful in independent learning.
Interactive exercises	Most respondents proposed simulation-based exercises that could test understanding directly. Students feel that interactive exercises can increase engagement, motivation to learn, and help them assess the extent of their understanding.
Auto-scoring feature	It is hoped that there will be an automatic assessment system that provides auto-feedback after the exercise or quiz is completed. This feature is considered to help students learn independently without always having to wait for evaluation from lecturers.

Indicator	Description of Data Findings
Cross-device access	Students emphasized the importance of software that can be accessed through various devices (laptops, tablets, and mobile phones). This ease of access allows learning to be done anywhere without depending on a computer lab.
Availability of Indonesian content that is in line with the national curriculum	Almost all respondents highlighted the need for an easy-to-understand language of instruction and the suitability of the content with the national curriculum. They hope that the software can use chemical terms that are in accordance with national standards to be more contextual for Indonesian students.

The results of the interviews showed that students needed chemical computing software that could provide interactive 3D visualizations, simple reaction simulations, and automated feedback-based exercises to help understand abstract concepts in chemistry. The three-dimensional visualization feature is considered important because it makes it easier for students to imagine the structure and geometry of molecules, in line with the theory of dual coding and multimedia learning that emphasizes the role of visuals in building conceptual understanding (Mayer, 2024). Students also assessed that reaction simulations can strengthen the relationship between theory and real phenomena as described by Gilbert & Treagust (2009) (Bílgín et al., 2017; M. M. W. Cheng & Gilbert, 2017; Mayer, 2024). In addition, the need for interactive exercises and auto-feedback shows the importance of independent learning according to the theory of self-regulated learning (Supiyanti, 2022). Other findings indicate the need for cross-device access to make learning more flexible and Indonesian-language content that is in line with the national curriculum to be more contextual. Overall, these results support previous research that the development of technology-based computing media needs to be designed with a user-centered approach that integrates pedagogical, visual, and contextual aspects to improve students' conceptual understanding and technological literacy in the 21st century (Muthmainnah et al., 2022; Panda, 2024).

The results of the study show that chemistry education students place visualization of interactive 3D molecular structures as a major need in the development of chemical computing software. This is in line with previous findings that visual representation can reduce the level of abstraction in chemistry learning, making it easier for students to understand the relationship between molecular structure and the chemical properties it derives from (Muthmainnah et al., 2022; Panda, 2024). Three-dimensional visualization also allows students to build a more powerful mental model than just two-dimensional text or images (Wainman et al., 2018). In addition to visualization, students also show a high need for the integration of materials with concept animations, interactive exercises, and simple reaction simulations. These features underscore the importance of technology-based learning approaches that are interactive and student-centered. As revealed by Maulana et al., (2025) the use of interactive multimedia can improve knowledge retention and transfer because it involves visual and verbal channels simultaneously. Thus, chemical computing software not only serves as a visualization tool, but also as an active learning medium that allows students to learn through simulated experiences.

Furthermore, the need for an automated assessment feature indicates that students expect instant feedback in the learning process. Automatic assessments not only function to measure learning outcomes, but also as a means of reflection that encourages students to improve themselves independently (G. Cheng, 2017). Thus, this feature can support independent learning and strengthen student learning motivation (Ho et al., 2019; Stuart & Sutrisno, 2022). On the other hand, although cross-device access and the availability of Indonesian content scored lower than other indicators, both were still considered important. This can be understood because students need flexibility in accessing software anytime and anywhere, and want materials that are in accordance with the context of the national curriculum. Research by Gombert et al., (2024) confirms that the accessibility and relevance aspects of content have a great influence on the sustainability of the use of technology in learning.

This research makes an important contribution in the field of chemistry education by presenting an empirical picture of students' needs for the development of technology-based chemical computing software (Kabudi et al., 2021; Rincon-Flores et al., 2024). The main finding of this study is the high need for students to feature interactive 3D molecule visualization, concept animation, and interactive exercises accompanied by automatic feedback (Abdo et al., 2024; Hoai et al., 2023). This emphasizes that students not only need technology-based learning media that are informative, but also educational, adaptive, and interactive, so that they can improve conceptual understanding and scientific thinking skills (Honke & Becker-Genschow, 2025; Ipinnaiye & Risquez, 2024). The implications of these findings are particularly relevant for educational technology developers, curriculum designers, and higher education institutions. For developers, the results of the research can be used as a guide in designing software that suits the real needs of users, including paying attention to aspects of cross-device accessibility and the availability of content in Indonesian. For curriculum designers, these findings provide direction to integrate technology-based media in chemistry learning to be more contextual and in accordance with student characteristics. Meanwhile, for universities, this research emphasizes the importance of institutional support in providing digital means that support innovative, inclusive, and sustainable learning processes.

Despite its contributions, this study has several limitations that should be acknowledged. First, the study relied on self-reported data obtained through questionnaires and interviews, which may be influenced by respondents' subjective perceptions and potential response bias. Second, although the quantitative sample involved students from three universities, the use of purposive sampling limits the generalizability of the findings to broader populations of chemistry students in different institutional or regional contexts. Third, this research focused on identifying perceived needs rather than evaluating the actual effectiveness of existing chemical computing software, so causal conclusions regarding learning outcomes cannot be drawn. In addition, the qualitative component involved a limited number of participants, which, while appropriate for an exploratory study, may not fully capture the diversity of student experiences.

Nevertheless, the findings of this study offer important implications for future research and practice. From a research perspective, the results provide a foundation for subsequent design-based or experimental studies that examine the impact of technology-based chemical computing software on students' conceptual understanding, problem-solving skills, and learning motivation. Future studies are encouraged to involve larger and more diverse samples, apply more advanced statistical analyses, and integrate learning analytics to strengthen empirical evidence. From a practical perspective, the identified priority features such as interactive 3D visualization, concept animation, interactive exercises, and automated feedback can serve as concrete design guidelines for developers and educators in developing contextually relevant, accessible, and student-centered chemical computing software. These implications highlight the potential of needs-based software development to support more effective and sustainable chemistry learning in higher education.

5. CONCLUSION

This study shows that chemistry education students have a high need for the development of technology-based chemical computing software, especially in the interactive 3D molecular structure visualization feature, integration of materials with concept animation, and interactive exercises equipped with automatic assessment features. These results confirm that the aspects of visualization and interactivity are the main priorities in supporting the understanding of abstract chemical concepts. In addition, although the need for cross-device access and the availability of Indonesian content according to the national curriculum are relatively low, both are still considered important in supporting learning effectiveness. These findings show that the chemical computing software developed should not only focus on visual appearance, but also be educational, adaptive, contextual, and according to user needs. Thus, the implications of this study emphasize the need for collaboration between educational technology developers, curriculum designers, and higher education institutions in designing innovative, inclusive, and sustainable technology-based chemistry learning media, so as to strengthen the quality of publications and the quality of science education in Indonesia.

ACKNOWLEDGMENTS

I would like to sincerely thank Universitas Negeri Jakarta and the research team for their invaluable support, collaboration, and contributions to the completion of this study.

REFERENCES

Abdo, S. N., Hsu, J. L., Kapetanakis, C., Newman, D. L., Wright, L. K., & Bailey, J. (2024). An Exploration of Spatial Visualization Skills: Investigating Students' Use of 3D Models in Science Problems during Think-Aloud Interviews. Journal of Chemical Education, 101(9), 3624–3634. https://doi.org/10.1021/acs.jchemed.3c01355

Agustian, H. Y., Teinholt, L., Tarp, J., Maja, J., Pedersen, I., Voetmann, F., Bente, C., & Nielsen, J. A. (2022). Learning outcomes of university chemistry teaching in laboratories : A systematic review of empirical literature. *Review of Education*, *June*, 1–41. https://doi.org/10.1002/rev3.3360

Alharbi, A. A. (2025). Journal of Radiation Research and Applied Sciences Cognitive learning approach to enhance university students ' visualization of molecular geometry in chemical compounds : A case study in Saudi Arabia. *Journal of Radiation Research and Applied Sciences*, *18*(1), 101283. https://doi.org/10.1016/j.jrras.2024.101283

Allouche, A. (2012). Software News and Updates Gabedit — A Graphical User Interface for Computational Chemistry Software. Journal of Computational Chemistry, 32, 174–182. https://doi.org/10.1002/jcc

Ariyatun, Sudarmin, Rahmawati, A., Winarto, & Wibowo, T. (2025). Reconstruction of the Engineering Design Project (EDPj) Learning Model based on Ethno-ESD to Actualize Students ' Sustainable Environmental

Literacy. *LUMAT: International Journal on Math, Science, and Technology*, *12*(4), 1–28. https://doi.org/https://doi.org/10.31129/LUMAT.12.4.2300

Arkader, A., Schardong, G., Schirmer, L., Perazzo, D., Novello, T., & Velho, L. (2025). Computers & Graphics Democratizing Interactivity : An Overview of Interfaces for Multimedia Machine Learning. *Computers & Graphics*, *15*(2). http://www.elsevier.com/locate/cag

Arsyad, M., Mujahiddin, & Syakhrani, A. W. (2016). the Efficiency of Using Visual Learning Media in Improving the Understanding of Science Concepts in Elementary School Students. Indonesian Journal of Education, 4(3), 1–23.

Bhattacharjee, J. (2015). Constructivist Approach to Learning – An Effective Approach of Teaching Learning. International Research Journal of Interdisciplinary & Multidisciplinary Studies, 7969(65), 65–74. http://www.irjims.com/

Bílgín, A. K., Yürükel, F. N. D., & Yígít, N. (2017). The effect of a developed REACT strategy on the conceptual understanding of students: "Particulate nature of matter." Journal of Turkish Science Education, 14(2), 65–81. https://doi.org/10.12973/tused.10199a

Brown, C. E., Alrmuny, D., Williams, M. K., Whaley, B., & Hyslop, R. M. (2021). Visualizing molecular structures and shapes : a comparison of virtual reality , computer simulation , and traditional modeling. Chemistry *Teacher International*, *3*(1), 69–80. https://doi.org/10.1515/cti-2019-0009

Byusa, E., Kampire, E., & Mwesigye, A. R. (2022). Game-based learning approach on students' motivation and understanding of chemistry concepts: A systematic review of literature. Heliyon, 8(5), e09541. https://doi.org/10.1016/j.heliyon.2022.e09541

Chakravartty, A. (2023). Scientific Knowledge vs. Knowledge of Science. *Science & Education*, *32*(6), 1795–1812. https://doi.org/10.1007/s11191-022-00376-6

Chaojing, M. (2023). A Study on Strategies for Cultivating Higher-Order Thinking Skills in Primary and Secondary School Students. *Frontiers in Educational Research*, *6*(20), 67–71. https://doi.org/10.25236/FER.2023.062011

Cheng, G. (2017). The impact of online automated feedback on students' reflective journal writing in an EFL course. Internet and Higher Education, 34, 18–27. https://doi.org/10.1016/j.iheduc.2017.04.002

Cheng, M. M. W., & Gilbert, J. K. (2017). Modelling students' visualisation of chemical reaction. International Journal of Science Education, 39(9), 1173–1193. https://doi.org/10.1080/09500693.2017.1319989

Demir, N., & Kayaoğlu, M. N. (2022). Multi-dimensional foreign language education : the case of an eTwinning project in Turkey. *Computer Assisted Language Learning*, *35*(9), 2201–2238. https://doi.org/10.1080/09588221.2020.1871027

Du, D., Baird, T. J., Bonella, S., & Pizzi, G. (2023). OSSCAR, an open platform for collaborative development of computational tools for education in science. Computer Physics Communications, 282. https://doi.org/10.1016/j.cpc.2022.108546

Elmqaddem, N. (2019). Augmented Reality and Virtual Reality in Education . Myth or Reality ? *International Journal Emergenci Technology Learning*, *14*(3), 234–242. https://doi.org/10.3991/ijet.v14i03.9289

Gather, S. M. C., Zysman-colman, E., & Lee, O. S. (2024). Digichem : computational chemistry for everyone. *Digital Discovery*, *3*(16). https://doi.org/10.1039/d4dd00147h

Erümit, A. K., & Sarıalioğlu, R. Ö. (2025). Artificial intelligence in science and chemistry education: a systematic review. Discover Education, 4(1). https://doi.org/10.1007/s44217-025-00622-3

Fombona-Pascual, A., Fombona, J., & Vicente, R. (2022). Augmented Reality, a Review of a Way to Represent and Manipulate 3D Chemical Structures. Journal of Chemical Information and Modeling, 62(8), 1863–1872. https://doi.org/10.1021/acs.jcim.1c01255

Gholam, A. (2019). Inquiry-Based Learning: Student Teachers' Challenges and Perceptions. Journal of Inquiry & Action in Education, 10(2), 112–133.

Gombert, S., Fink, A., Giorgashvili, T., Jivet, I., Di Mitri, D., Yau, J., Frey, A., & Drachsler, H. (2024). From the Automated Assessment of Student Essay Content to Highly Informative Feedback: a Case Study. International Journal of Artificial Intelligence in Education, 34(4), 1378–1416. https://doi.org/10.1007/s40593-023-00387-6

Ho, L. H., Sun, H., & Tsai, T. H. (2019). Research on 3D painting in virtual reality to improve students' motivation of 3D animation learning. Sustainability (Switzerland), 11(6), 1–17. https://doi.org/10.3390/su11061605

Hoai, V. T. T., Son, P. N., Em, V. V. D., & Duc, N. M. (2023). Using 3D molecular structure simulation to develop chemistry competence for Vietnamese students. Eurasia Journal of Mathematics, Science and Technology Education, 19(7). https://doi.org/10.29333/ejmste/13345

Honke, N., & Becker-Genschow, S. (2025). Adaptive learning in bionics: transforming science education. Frontiers in Education, 10(February), 1–21. https://doi.org/10.3389/feduc.2025.1427083

Indolia, S., Goswami, A. K., Mishra, S. P., & Asopa, P. (2018). Conceptual Understanding of Convolutional Neural Network- A Deep Learning Approach. Procedia Computer Science, 132, 679–688. https://doi.org/10.1016/j.procs.2018.05.069

Ipinnaiye, O., & Risquez, A. (2024). Exploring adaptive learning, learner-content interaction and student performance in undergraduate economics classes. Computers and Education, 215(March), 105047. https://doi.org/10.1016/j.compedu.2024.105047

Kabudi, T., Pappas, I., & Olsen, D. H. (2021). AI-enabled adaptive learning systems: A systematic mapping of the literature. Computers and Education: Artificial Intelligence, 2(December 2020), 100017. https://doi.org/10.1016/j.caeai.2021.100017

Kiernan, N. A., Manches, A., & Seery, M. K. (2021). Research and Practice The role of visuospatial thinking in students ' predictions of molecular geometry. Chemistry Education Research and Practice, 22(13), 626–639. https://doi.org/10.1039/d0rp00354a

Kiernan, N. A., & Seery, M. K. (2024). Research and Practice Resources for reasoning of chemistry concepts : multimodal molecular geometry. Chemistry Education Research and Practice, 25(24), 524–543. https://doi.org/10.1039/d3rp00186e

Kozlíková, B., Krone, M., Falk, M., Lindow, N., Baaden, M., Baum, D., Viola, I., Parulek, J., & Hege, H. C. (2017). Visualization of Biomolecular Structures: State of the Art Revisited. Computer Graphics Forum, 36(8), 178–204. https://doi.org/10.1111/cgf.13072

Kuit, V. K., & Osman, K. (2021). Eficacia del módulo electrónico CHEMBOND3D para mejorar el conocimiento de los estudiantes sobre el concepto de enlace químico y las habilidades visoespaciales. European Journal of Science and Mathematics Education, 9(4), 252–264.

Lehtola, S., & Karttunen, A. J. (2022). Free and open source software for computational chemistry education. Wiley Interdisciplinary Reviews: Computational Molecular Science, 12(5), 1–33. https://doi.org/10.1002/wcms.1610

Lilian, A. V. (2025). Challenges of Integration of Information and Communication Technology (ICT) in Chemistry Teaching in Secondary Schools in Bayelsa State. *FUO-Journal of Educational Research*, *4*(2), 219–227. https://doi.org/10.5281/zenodo.14885888

Maulana, I., Supriyadi, E., Wijanarka, B. S., Ariyatun, & Winarto. (2025). Coding learning innovation: Interactive programming experience with virtual lab platform. Multidisciplinary Science Journal, 7(6). https://doi.org/10.31893/multiscience.2025262

Mayer, R. E. (2024). The Past, Present, and Future of the Cognitive Theory of Multimedia Learning. Educational Psychology Review, 36(1), 1–25. https://doi.org/10.1007/s10648-023-09842-1

Mukhlis, Ariyatun, Septiana, I., Wijayanto, & Arifianti, I. (2026). Integrating Ethnopedagogy and Virtual Reality in Research-Based Learning for Regenerative Education.pdf. *Journal of Cultural Analysis and Social Change*, *11*(1), 873–881. https://doi.org/https://doi.org/10.64753/jcasc.v11i1.3988

Muthmainnah, Ibna Seraj, P. M., & Oteir, I. (2022). Playing with AI to Investigate Human-Computer Interaction Technology and Improving Critical Thinking Skills to Pursue 21stCentury Age. Education Research International, 2022. https://doi.org/10.1155/2022/6468995

Panda, D. R. (2024). Human Computer Interaction Strategies for Effective Digital Learning Experiences: From Classroom to Screen. Interantional Journal of Scientific Research in Engineering and Management, 08(008), 1–5. https://doi.org/10.55041/ijsrem37370

Raes, A., Schellens, T., Wever, B. De, & Vanderhoven, E. (2012). Computers & Education Scaffolding information problem solving in web-based collaborative inquiry learning. *Computers & Education Journal*, *59*, 82–94. https://doi.org/10.1016/j.compedu.2011.11.010

Retnawati, H., Djidu, H., Kartianom, Apino, E., & Anazifa, R. D. (2018). Teachers' knowledge about higher-order thinking skills and its learning strategy. Problems of Education in the 21st Century, 76(2), 215–230. https://doi.org/10.33225/pec/18.76.215

Rincon-Flores, E. G., Castano, L., Guerrero Solis, S. L., Olmos Lopez, O., Rodríguez Hernández, C. F., Castillo Lara, L. A., & Aldape Valdés, L. P. (2024). Improving the learning-teaching process through adaptive learning strategy. Smart Learning Environments, 11(1). https://doi.org/10.1186/s40561-024-00314-9

Schulz, H., & FitzPatrick, B. (2016). Teachers' understandings of critical and higher order thinking and what this means for their teaching and assessments. Alberta Journal of Educational Research, 62(1), 61–86. https://doi.org/10.55016/ojs/ajer.v62i1.56168

Shengqiang, L., Nankhantee, A., & Srikhao, S. (2025). Combining Inquiry-Based Learning and Collaborative Learning : A New Model for Improving Students ' Teamwork and Problem-Solving Skills. *Journal of Education and Educational Development*, *12*(1), 13–38. https://doi.org/10.22555/joeed.v12i1.1296

Serhan, M., Sprowls, M., Jackemeyer, D., Long, M., Perez, I. D., Maret, W., Tao, N., & Forzani, E. (2019). Total iron measurement in human serum with a smartphone. AIChE Annual Meeting, Conference Proceedings, 2019-Novem. https://doi.org/10.1039/x0xx00000x

Supiyanti, Iriyadi, F. (2022). Journal of Technology and Science Education. Journal of Technology and Science Education, 4(4), 215–227. http://www.jotse.org/index.php/jotse/article/view/110/142

Üce, M., & Ceyhan, İ. (2019). Misconception in Chemistry Education and Practices to Eliminate Them: Literature Analysis. Journal of Education and Training Studies.

Vosniadou, S. (2019). The Development of Students' Understanding of Science. Frontiers in Education, 4(April), 1–6. https://doi.org/10.3389/feduc.2019.00032

Wainman, B., Wolak, L., Pukas, G., Zheng, E., & Norman, G. R. (2018). The superiority of three-dimensional physical models to two-dimensional computer presentations in anatomy learning. Medical Education, 52(11), 1138–1146. https://doi.org/10.1111/medu.13683

Watson, C. A. (2022). CCS Predictor 2.0: An Open-Source Jupyter Notebook Tool for Filtering Out False Positives in Metabolomics. *Anal Chem*, *94*(50), 17456–17466. https://doi.org/10.1021/acs.analchem.2c03491.CCS

Whatoni, A. S., & Sutrisno, H. (2022). Development of A Learning Module Supported by Augmented Reality on Chemical Bonding Material to Improve Interest and Motivation of Students Learning for Senior High School. Jurnal Penelitian Pendidikan IPA, 8(4), 2210–2218. https://doi.org/10.29303/jppipa.v8i4.2057

Wu, H., Krajcik, J. S., & Soloway, E. (2000). Using Technology to Support the Development of Conceptual Understanding of Chemical Representations. *Fourth International Conference of the Learning Sciences*, 121–128.

Zendler, A., & Greiner, H. (2020). The effect of two instructional methods on learning outcome in chemistry education: The experiment method and computer simulation. Education for Chemical Engineers, 30, 9–19. https://doi.org/10.1016/j.ece.2019.09.001