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Assistive Learning Technology in Chemistry Education: A Study of the Interests and Preferences of Visually Impaired Students

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ABSTRACT

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Chemistry learning for students with visual impairment remains challenging because many chemical concepts are presented through visual representations, limiting access to abstract concepts, chemical symbols, and laboratory activities. This study aims to explore the interests, learning barriers, and technology preferences of students with visual impairment as a basis for developing accessible assistive learning technology in chemistry education. A qualitative phenomenological approach was employed, involving six senior high school students selected through purposive sampling from two schools in Surabaya, Indonesia. The participants consisted of four students with blindness and two students with low vision. Data were collected through preliminary observations and semi-structured interviews and analyzed using thematic analysis. The findings indicate that all six participants had a strong interest in chemistry, particularly when learning was connected to everyday-life phenomena. However, they experienced difficulties in understanding abstract concepts, chemical symbols and formulas, and participating in laboratory activities. Students with blindness relied more heavily on auditory and tactile information, while students with low vision could access some visual information but still required appropriate adaptations. The participants also reported using digital technologies, such as smartphones, laptops, e-books, and AI-based tools, for independent learning, although these tools were not specifically designed for accessible chemistry learning. All six participants expressed positive preferences for assistive learning technology integrating Braille, tactile representations, interactive audio, and adaptable visual support. These findings highlight the need for user-centered assistive learning technology that accommodates different levels of visual functioning and provides multisensory access to chemistry concepts and learning activities.

INTRODUCTION

Chemistry education is a vital component of science education, as it helps students understand abstract concepts and develop scientific thinking skills. Chemistry relies heavily on abstract concepts and visual representations such as molecular structures, graphs, and chemical symbols, making it challenging to implement in inclusive learning settings, particularly for students who are blind or visually impaired (Rashid & Chehadeh, 2023). Consequently, these students face significant challenges in the chemistry learning process. This reliance on visualization limits access to chemical concepts and hinders the active participation of blind or visually impaired students in learning activities, especially during laboratory practical work (Fuentes Anton, 2025).

Visual impairment encompasses different levels of visual functioning, including blindness and low vision, which may result in different learning experiences and accessibility needs (Dreamerson & Saitta, 2025). In chemistry education, students with blindness may rely more heavily on auditory and tactile representations, while students with low vision may benefit from appropriately adapted visual information in

combination with nonvisual modalities. Conventional chemistry instruction often presents symbolic, spatial, and visual information in formats that blind and low-vision students cannot readily access, creating barriers to equitable participation in classroom and laboratory activities (D'Agostino, 2022). Therefore, inclusive chemistry learning should not assume that all visually impaired students have identical accessibility needs. Recognizing differences in visual functioning is important for designing assistive learning technologies that provide multiple and flexible modes of access, including tactile, auditory, and appropriately adapted visual representations.

This situation results in limited engagement and unequal learning opportunities for visually impaired students in chemistry education. Several studies indicate that students with visual impairments are often not optimally involved in experimental activities due to limitations in instructional media and a lack of teacher preparedness to provide inclusive instruction (Miyauchi, 2020). Yet, hands-on experience through experiments is a crucial factor in enhancing conceptual understanding and interest in learning chemistry (Pamenang & Ratri, 2025).

With technological advancements, various innovations in the form of assistive learning technologies have been developed to enhance learning accessibility for visually impaired students. Technologies such as screen readers, audio-based devices, and tactile media enable students to access chemical information non-visually and with greater independence (Hidayat, 2020). Furthermore, the implementation of adaptive technologies utilizing audio and sensors has been shown to increase the active participation of visually impaired students in chemistry experiments (Supalo et al., 2016).

Although various studies have developed learning media and technologies for visually impaired students, most research has focused on the development and effectiveness testing of these media, without deeply exploring the students' needs, interests, and learning experiences as the primary users. This situation does not fully align with the learner-centered design approach, which emphasizes the importance of understanding students' preferences, characteristics, and learning experiences as a foundation for designing effective learning interventions (Eliza Putri et al., 2024). Consequently, the potential of the developed assistive learning technology to enhance the quality of chemistry education for visually impaired students has not been fully realized (Charles et al., 2026). Furthermore, research examining the relationship between the learning interests, needs, and experiences of visually impaired students and the design of assistive learning technology for chemistry education remains very limited. Most studies prioritize technical aspects and technological effectiveness, failing to explore user perspectives through qualitative approaches such as in-depth interviews (Fernández-Batanero et al., 2022).

Addressing this gap, this study offers a novel contribution by identifying the interests, needs, and learning experiences of visually impaired learners while considering differences between students with blindness and low vision. Rather than focusing only

on the technical development or effectiveness of assistive media, this study examines the experiences and preferences of the intended users as a foundation for designing assistive learning technology that is inclusive, adaptive, and responsive to different levels of visual functioning in chemistry education.

RESEARCH METHOD

This study employs a qualitative approach with a phenomenological design to explore the experiences, interests, and needs of visually impaired students in chemistry learning (Harfiani & Setiawan, 2021). The phenomenological approach was selected because it can deeply examine participants' lived experiences, providing a comprehensive understanding of the obstacles and genuine needs of students in chemistry education (Alhazmi & Kaufmann, 2022). Through this approach, the study not only describes students' experiences but also interprets their meaning, providing a basis for developing assistive learning technology tailored to user characteristics.

Study participants were selected using purposive sampling, a method of choosing respondents based on specific characteristics aligned with the research objectives (Tajik et al., 2024). The participant criteria included: (1) being a visually impaired student currently enrolled in senior high school; (2) having received chemistry instruction at school; and (3) being willing to participate in the entire research process. Based on these criteria, six participants were selected, comprising one student from SMAN 8 Surabaya and five students from SMA YPAB Surabaya. Regarding visual impairment, four participants had blindness and two participants had low vision with partial visual ability. This distinction was considered when interpreting participants' learning experiences because differences in visual functioning may influence access to visual representations, chemical symbols, written formulas, and practical activities. The selection of these two schools aimed to capture a variety of learning experiences from schools implementing inclusive education in different ways.

Table 1. Characteristics of research participants

Participant	School	Visual impairment
P1	SMAN 8 Surabaya	Blindness
P2	SMA YPAB Surabaya	Blindness
P3	SMA YPAB Surabaya	Blindness
P4	SMA YPAB Surabaya	Blindness
P5	SMA YPAB Surabaya	Low vision
P6	SMA YPAB Surabaya	Low vision

Data collection was conducted in two stages. The first stage involved preliminary observations to identify how chemistry instruction is implemented, the available learning facilities, and the learning environment conditions for visually impaired students. The second stage involved in depth interviews using a semi-structured interview guide developed based on the research objectives. Interview questions focused on four key aspects: student interest in chemistry learning, obstacles encountered during the learning

process, the use of technology as a learning medium, and student needs regarding more accessible learning materials. The researcher used a semi-structured approach to ensure the information aligned with the research focus while allowing participants the flexibility to share their learning experiences in greater depth.

The collected data were transcribed verbatim and analyzed using thematic analysis. The analysis process involved rereading all interview transcripts, coding information with similar meanings, grouping codes into several main themes, and interpreting the relationships between themes to gain insight into the interests, learning experiences, obstacles, and needs of visually impaired students regarding chemistry learning. The analysis results were then compared with previous studies to provide a comprehensive discussion on the implications of the findings for the development of Assistive Learning Technology.

To enhance the credibility of the research results, methodological triangulation was employed combining observations and interviews alongside "member checking," where interview summaries were confirmed with participants to ensure the information accurately reflected their shared experiences (Nurfajriani et al., 2024). Furthermore, the interpretation of the results was supported by current scientific literature, thereby strengthening confidence in the findings.

RESULTS AND DISCUSSION

This study is based on interviews with six visually impaired students selected through purposive sampling. The selected students had previously received chemistry instruction in school, allowing for a further examination of their interests and needs regarding chemistry learning. The participants consisted of four students with blindness and two students with low vision. This difference in visual functioning was considered when interpreting their learning experiences and accessibility needs.



Figure 1. Interview with the respondent

Students' interest in chemistry learning

Interview results indicate that all six participants possess a high level of interest in learning chemistry, despite acknowledging various limitations encountered during the learning process. This interest arises primarily when chemistry topics are linked to phenomena found in everyday life. One student remarked:

"*I enjoy learning chemistry, even though it is challenging for the visually impaired; however, I become interested in the subject when studying topics related to daily life.*"

These findings demonstrate that the low participation of visually impaired students in chemistry learning is not due to a lack of interest, but rather to limited access to inclusive learning experiences. In other words, while the students demonstrated strong interest in learning chemistry, the learning environment did not adequately accommodate their accessibility needs.

These results align with the concept of contextual learning, which emphasizes that linking subject matter to real-life experiences can heighten students' interest in the learning process (Minarni et al., 2025). Furthermore, these findings reinforce the research of Rashid & Chehadeh (2023), which indicates that visually impaired students maintain a strong interest in science when provided with learning experiences tailored to their specific needs.

These findings imply that the development of inclusive chemistry instruction should not merely focus on simplifying the material but must also provide meaningful learning experiences through media accessible to students with different levels of visual functioning.

Differences in Learning Experiences Based on Visual Impairment Level

The six participants demonstrated a generally strong interest in chemistry learning; however, their learning experiences were influenced by differences in visual functioning. The four participants with blindness relied primarily on auditory and tactile information during chemistry learning. In contrast, the two participants with low vision retained partial visual ability and could access some visual information. Nevertheless, both groups reported difficulties when chemistry content relied heavily on visual representations, particularly for abstract concepts, chemical symbols, formulas, and practical activities.

The distinction between students with blindness and those with low vision suggests that assistive learning technology should provide flexible modes of information access rather than relying on a single accessibility feature. For students with blindness, tactile and auditory representations are particularly important for accessing information that is normally presented visually. Students with low vision may benefit from a combination of tactile and auditory features alongside appropriately adapted visual or digital representations.

Therefore, the findings indicate that visual impairment should not be treated as a homogeneous condition in chemistry learning. Assistive learning technology needs to accommodate differences in visual functioning while maintaining the same learning objectives. This user-centered approach is important to ensure that the technology addresses the actual experiences and preferences of students rather than relying solely on general assumptions about visual impairment.

Barriers to learning chemistry

Despite having a strong interest in learning, all six participants reported facing various obstacles during chemistry instruction. However, the nature of these obstacles was influenced by their level of visual impairment. Students with blindness relied predominantly on auditory and tactile information and experienced substantial difficulties when learning materials were presented only through visual representations. Students with low vision could access some visual information but still experienced difficulties when materials were presented in formats that were not sufficiently adapted to their visual abilities.

Across both groups, the major barriers included difficulties in grasping abstract concepts presented via visual media, limitations in participating in practical laboratory activities, and challenges in learning chemical symbols and formulas. One participant remarked:

"*I cannot study chemistry in depth due to my limited vision, especially when it comes to practical sessions that I am unable to join.*"

Furthermore, chemistry instruction that tends to emphasize rote memorization poses a distinct challenge. Students stated that they spent more time memorizing than understanding concepts:

"*I enjoy learning chemistry, but it mostly involves listening and memorizing.*"

This situation indicates that the instruction does not yet support a multisensory learning approach. Research shows that visually impaired students require multisensory, experience-based approaches such as the use of tactile and audio media to build a better understanding of concepts (Tombaugh, 1981).

Another barrier relates to chemical literacy, particularly regarding the writing of chemical symbols and formulas. Students expressed difficulty in writing chemical formulas using digital devices:

"*When the teacher teaches chemical formulas, I can only listen to them; I don't know the correct way to write them down.*"

This demonstrates that the limitations extend beyond mere information access; they stem from the dominance of visual representations in chemistry education. Most chemistry

concepts are conveyed through images, diagrams, graphs, and visual demonstrations, making them difficult for visually impaired students to access.

Consequently, students miss out on opportunities for direct learning experiences through practical laboratory activities. Yet, practical work is a crucial component in developing conceptual understanding, scientific thinking, and science process skills. When access to practical work is limited, students tend to memorize concepts without truly grasping their scientific significance.

These findings align with research by Supalo et al. (2014) and Rashid & Chehadeh (2023), which explains that visually impaired students often have fewer opportunities for practical work compared to their peers due to limitations in media and a lack of accessible learning facilities. The implication of these findings is the need to develop learning media capable of transforming visual representations into tactile or audio representations, enabling learners to construct chemical concepts through multiple senses.

Utilization of technology as a learning medium

To overcome these limitations, students utilize various simple technologies—such as laptops, mobile phones, and e-books as learning media. One respondent stated:

"For taking notes during chemistry lessons, I usually use a laptop or mobile phone, as well as e-books provided by the teacher."

Additionally, students utilize the internet and Artificial Intelligence (AI)-based technologies to search for information regarding chemical elements:

"I usually study chemical elements using Google or AI to identify the elements, though I still do not fully understand mass numbers and atomic numbers."

These findings indicate that visually impaired students have independently utilized technology as a learning aid. This is supported by research stating that assistive technology can enhance access to information, reading skills, and learning independence among visually impaired students (Prabhu et al., 2023). However, the use of such technology remains general in nature and has not yet been specifically designed for chemistry instruction. Other research also indicates that while assistive technology holds great potential, its implementation in formal education remains suboptimal and requires more systematic integration (Taxiarchis, 2024).

All respondents reacted positively to the development of assistive learning technology media. Students stated that the availability of media tailored to their needs would boost their motivation and enthusiasm for learning:

"If there were a highly engaging assistive tool for chemistry—something that made learning the subject easier—I would feel more enthusiastic about studying it."

Specifically, students expressed a desire for media that integrates both Braille and audio elements: *"It would be interesting if the media included both Braille and audio."*

This indicates that visually impaired students require a multisensory learning approach that combines tactile (braille) and auditory (audio) aspects. This approach aligns with the principles of universal design for learning (UDL), which emphasize the importance of providing multiple representations of information to ensure accessibility for all students (Al-Azawei et al., 2016). Furthermore, research in STEM education indicates that inclusive technologies designed with interactive and multisensory features can significantly enhance the engagement and understanding of visually impaired learners (Castaneda et al., 2025). In the context of chemistry education, the use of technologies such as audio-based sensors and tactile tools has been shown to increase the participation of visually impaired learners in practical activities and help them grasp abstract concepts in a more concrete manner (Rashid & Chehadeh, 2023).

This interpretation reinforces the findings of Fernández-Batanero et al. (2022), which state that the success of assistive technology is determined by its alignment with user needs, rather than merely by the sophistication of the technology employed.

Implications for the development of assistive learning technology

Based on the research findings, the characteristics of assistive learning technology required by visually impaired students for chemistry learning can be outlined as follows:

1. capable of presenting information in clear audio format;
2. providing tactile representations via Braille or three-dimensional models;
3. interactive in nature, enabling students to receive immediate feedback;
4. supporting the understanding of chemical symbols, formulas, and abstract concepts;
5. easy to use independently, both at school and at home; and
6. adaptable to different levels of visual functioning, including blindness and low vision.

These characteristics demonstrate that developing assistive learning technology requires more than merely adopting modern technology; it must be designed around students' actual needs and differences in visual functioning. In particular, the technology should provide flexible accessibility features that can support both students with blindness and students with low vision. Thus, this research not only identifies learning barriers but also establishes a conceptual foundation for developing inclusive, adaptive, and user-centered chemistry learning media.

These findings represent the study's primary contribution, as they provide a reference for teachers, media developers, and researchers in designing chemistry learning innovations that enhance accessibility, participation, and conceptual understanding for visually impaired students.

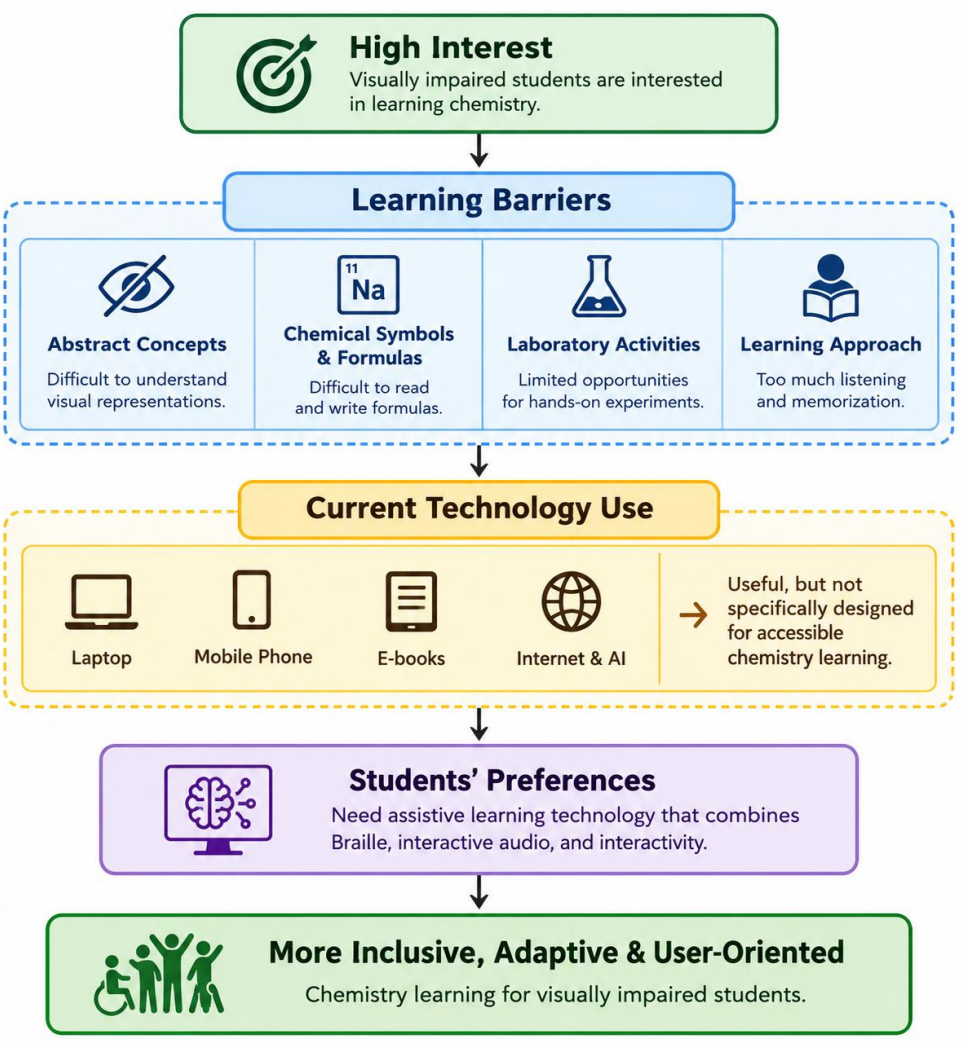


Figure 2. Conceptual model for developing assistive learning technology for inclusive chemistry education.

CONCLUSION

This study shows that students with visual impairment have a strong interest in learning chemistry, particularly when learning content is connected to everyday-life phenomena. However, their learning experiences remain constrained by the predominantly visual nature of chemistry instruction, particularly in understanding abstract concepts, chemical symbols and formulas, and participating in laboratory activities. The participants consisted of four students with blindness and two students with low vision. Although both groups experienced similar barriers, their access to learning information differed according to their level of visual functioning. Students with blindness relied more heavily on auditory and tactile information, whereas students with low vision could access some visual information but still required appropriate adaptations. The findings also indicate that students independently use digital technologies, including smartphones, laptops, e-books, and AI-based tools, to support their learning. However, these technologies are not specifically designed to address the accessibility requirements of chemistry education.

All six participants expressed positive preferences for assistive learning technology that integrates Braille, tactile representations, interactive audio, and adaptable visual support. Therefore, the development of assistive learning technology for inclusive chemistry education should adopt a user-centered and multisensory approach that accommodates different levels of visual functioning and promotes independent access to chemistry concepts and learning activities. Given the limited number of participants and the unequal distribution between the blindness and low-vision groups, this study should not be interpreted as a comparative study between the two groups. Further research involving a larger and more diverse sample is needed to validate these findings and to develop and evaluate assistive learning technologies that are responsive to the varied accessibility needs of students with visual impairment.

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