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INFORMATION AND COMMUNICATION TECHNOLOGIES AS TOOLS FOR REDUCING THE ABSTRACTIONS AND DIFFICULTIES OF SOME CHEMISTRY CONCEPTS

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Abstract
Chemistry faces a significant challenge due to the inherently abstract nature of core concepts like atomic structure, bonding, and reaction mechanisms. This often leads to difficulties for students in visualizing, understanding, and applying these concepts. Hence, chemistry students often perform poorly in their academic endeavors. Information and Communication Technologies (ICTs) offer a powerful solution to bridge this gap. This review explored the potential of ICTs, such as simulations, visualizations, animations, online resources, and collaborative tools, in transforming the learning experience for chemistry students. ICTs can enhance visualization and spatial reasoning by providing interactive and dynamic representations of abstract concepts, making these concepts concrete and visible. This shift moves students from passively receiving information to actively participating in constructing their understanding. Additionally, ICTs present information in an engaging and visually appealing way, thereby reducing cognitive load. Interactive simulations and virtual labs fostered by ICTs can help students develop critical thinking and problem-solving skills. By making the abstract concrete and the complex comprehensible, ICTs pave the way for a more engaging and successful learning journey, ultimately fostering a deeper appreciation for the fascinating world of chemistry.

Keywords: Abstractness, difficulty, chemistry concepts, ict tools, academic achievement

Introduction
From the fabric of our clothes to the medicine we take, chemistry shapes our world in countless ways. Chemistry, the scientific discipline concerned with the composition, structure, properties, and changes of matter, deals with explaining everyday chemical phenomena (Kolumuc & Terkin, 2011). Chemistry knowledge finds applications in a wide range of specialized disciplines. According to Aji (2022), chemistry plays a crucial role in tackling various challenges, as evidenced by the importance of chemical knowledge, the application of fundamental principles, and the utilization of diverse chemical products. For instance, according to research by Abukari (2023) and Umate, Eya, and Okebanama (2019), chemistry knowledge plays a significant role in various specialized fields, including agriculture, energy production, pharmaceutical development, medical practices, clothing production, and water treatment. Achimugu (2016) reports that chemistry is a mandatory science subject in Nigerian senior secondary education. Students pursuing science or science-related fields must achieve at least a credit on the SSCE chemistry exam (as set by JAMB) for program admission.

Given the vital role chemistry plays in national development, strong student performance in this subject is essential. However, in Nigeria, students' achievement in chemistry has been reported to be unsatisfactory (Kyado, Achor & Adah, 2021; Nartey &

Hanson, 2021). The WAEC Chief Examiners' report from 2017–2021 revealed that chemistry students' performance was fluctuating, and performance for most has been below 50%. Researchers from other African countries reported similar results. For instance, in Uganda, Sibomana, Karegeya and Sentongo (2021) reported that chemistry students' academic achievement has been low. Manyilizu (2022) reported that Tanzanian students' academic achievement in chemistry has been below average. Nkadimeng and Ankiewicz (2022) reported that South African chemistry academic achievement has been poor.

At the global level, research reports revealed that students' academic achievement in chemistry has been unsatisfactory. Aquino and Bautista (2022) disclosed that the chemistry students' academic achievement in chemistry is low. Teplá, Teplý, and Šmejkal (2022) reported that chemistry students' academic achievement in the Czech Republic has been low. Sausan, Saputro, and Indriyanti (2020) reported that 7th grade chemistry students' academic achievement in Indonesia has been unsatisfactory, likely because students perceive chemistry as difficult and abstract (Umate, Abubakar, & Abonyi, 2022). According to researchers, the reason why chemistry is perceived as difficult and abstract is the way it is being presented to students (Ezeliora, 2019). The abstract nature of chemistry calls on chemistry teachers to make the subject concrete and real to students by using a variety of information and communication technologies (ICT), as reported by Umate, Abubakar and Abonyi (2022).

In the 21st century, rapid advances in information and communication technology (ICT) have dramatically transformed society and our standards of living. Information and Communication Technology (ICT) refers to the integration of telecommunications, software, computers, and audio-visual systems. This technology empowers users to create, store, access, manipulate, and transmit information (Otieno, 2017; Ngbongha, Yaro & Thomas, 2020). Youssef, Dahmani and Ragni (2022) emphasize that by incorporating technology into classrooms, teachers can create a more enriching learning environment. The role of teachers is changing with technology. Instead of just lecturing, they are becoming guides for students using tech in the classroom (Geladze, 2015; Bayuo et al., 2022). Face-to-face interaction is moving online, and traditional boards are being replaced by interactive whiteboards (Geladze, 2015).

ICT plays a vital role in the teaching and learning of chemistry. Gupta (2023) reported that ICT tools and software help in better understanding the concepts of chemistry because they help visualize the chemical structures in 3D. Igboanugo, Igboegwu, Attah and Georgina (2020) and Abdulrahaman et al. (2020) argued that the use of ICT in the teaching and learning of chemistry can reduce the abstract nature of most chemistry concepts. For instance, animation could be used to demonstrate the movement of ions during electrolysis. Ameyaw (2020) disclosed that ICT tools are good at reducing the difficulty of some chemistry concepts. Byusa, Kampire, and Rwekaza (2022) discovered that ICT-integrated instructional strategies enhance students conceptual understanding of chemistry, thereby reducing the abstractness and difficulty of some chemistry concepts. Furthermore, integrating ICT into chemistry lessons allows teachers to stay current with the latest content, teaching methods, and assessment tools (Achimugu, 2016; Umate, Aminu, & Hamza, 2018). This ensures a more dynamic and effective learning experience for students. There are many researchers conducted on the use of ICT in reducing abstractness and difficulty of some concepts in teaching and learning. At a global level, Youssef, Dahmani, and Ragni (2022) discovered that the ICTs were efficient in reducing the difficulty of some abstract and difficult concepts in learning science, thereby improving their academic performance. Sausan, Saputro, and Indriyanti (2020) reported that chemistry multimedia helped improve the conceptual understanding of 7th grade students in Pekalongan regency, Central Java, Indonesia. Teplá, Teplý and Šmejkal (2022) disclosed that 3D models and animation made science concepts easy, thereby reducing the abstractness and difficulty of these concepts for high school students in the Czech Republic. Hussain, Suleman, Naseerud-Din, and Shafique (2017) reported that ICT tools are effective in reducing the difficulty of some concepts in science, thereby enhancing Pakistani students' academic performance.

There are also studies conducted at the continental level that demonstrate the positive impact of ICTs on students' conceptual understanding of chemistry concepts. Ameyaw (2020) found that ICTs helped Ghanaian students grasp chemistry concepts by reducing their abstractness. Similarly, Manyilizu (2022) reported from Tanzania that virtual laboratories significantly improved students' academic performance by making difficult and abstract chemistry concepts easier to understand. Otieno (2017) discovered that computer-assisted instruction for organic chemistry concepts led to significant improvement in students' conceptual understanding and performance, again highlighting the ability of ICTs to reduce the abstractness and difficulty of the subject. Finally, Nkadimeng and Ankiewicz (2022) found that video-based games made atomic structure less abstract and difficult for South African high school students, resulting in a significant increase in their academic performance. These studies collectively point to the effectiveness of ICTs in enhancing students' learning experiences in chemistry. There are also studies conducted at the continental level. Ameyaw (2020) found that ICTs helped in improving Ghanian students' conceptual understanding of chemistry concepts. This is because the abstractness of chemistry concepts has been drastically reduced by ICTs. Manyilizu (2022) reported from Tanzania that the virtual laboratory significantly improved students' academic performance as a result of its ability to reduce the difficulty and abstract of some chemistry concepts. Otieno (2017) discovered that students taught organic chemistry concepts with computer-assisted instruction performed satisfactorily, and their conceptual understanding significantly improved. This indicates that the abstractness and difficulty of some organic chemistry have been reduced. Nkadimeng and Ankiewicz (2022) conducted a study with a sample of South African high school students on the use of video-based games as a learning tool. It was found that the video-based game made atomic structure less abstract and difficult for the students, and their academic performance significantly increased.

In Nigeria, there are few studies conducted on the use of ICTs to reduce concept difficulty and abstractness. Igboanugo et al. (2020) discovered that ICT integration in the teaching of chemistry enhances students' academic performance and reduces the abstractness and difficulty of some chemistry concepts. Similarly, Dave-Ugwu, Eya and Nwobodo (2023) revealed that the periodic board-scrabble game teaching approach enhanced secondary students' academic performance. Njoku and Eze-odurukwe (2015) disclosed that the use of computer simulation animation as a as a teaching strategy reduced the widespread learning difficulties experienced by chemistry students in nuclear chemistry. Onasanya, Nuhu, Oladipupo, Samuel and Ishola (2019) reported that undergraduate chemistry education students exposed to learning apps performed better and had a greater conceptual understanding of chemistry concepts. This suggests that learning the app has helped in concretizing the abstract nature of some chemistry concepts, thereby reducing their difficulty.

Research revealed that there are many studies carried out at global and continental levels on the potential of ICTs in reducing the abstractness and difficulty of concepts, both in chemistry and other areas of specialization. The results of these studies, however, may be difficult to generalize to the Nigerian context as most of them involved participants from foreign countries. Some of these studies involved samples of undergraduate students, while others involved only secondary school students. However, if these ICT tools could be adopted for teaching chemistry from the secondary school level up to the university level, it would help in resolving unsatisfactory students' academic achievement both at the local and international levels. Furthermore, in Nigeria, only a few studies have adopted ICT-based instructional strategies or ICT tools for teaching and learning chemistry, mostly at the secondary school level rather than implementing them at both secondary and tertiary levels. From the foregoing, the persistent problem of unsatisfactory academic achievement among chemistry students, both in Nigeria and abroad, has worried educational stakeholders. This is concerning because chemistry is a vital tool for national development and technological advancement. The use of ICT tools and innovative teaching strategies, such as simulations, virtual reality labs, games, and learning apps, may help reduce the abstractness and difficulty of some chemistry concepts. By making these concepts more concrete and easier to grasp, these tools might lead to improved academic achievement and conceptual understanding for students, potentially resolving the issue of unsatisfactory performance in chemistry.

State of art in the teaching of Chemistry with ICT Tools

Chemistry is an essential instrument for the technical development of any country and the global community, as was previously reported by researchers. Despite the roles chemistry plays in national development and daily activities, reports from previous studies across the nations revealed that students' performance in chemistry at secondary school has not been satisfactory. Researchers reported that the abstractness and difficulty of some chemistry concepts are the leading factors in the unsatisfactory academic achievement of chemistry students in Nigeria and around the globe. The field of Information and Communication Technology (ICT) offers a wealth of tools that are revolutionizing the way chemistry is taught. Much research across nations has been conducted on the effectiveness and efficacy of information and communication technologies in reducing the abstractness and difficulty of some chemistry concepts in a bid to improve students' academic achievement in the subject. Most of these studies used foreign samples, whose findings might not be generalizable to Nigerian samples. In Nigeria, only a few studies (Onasanya, Nuhu, Oladipupo, Samuel & Ishola, 2019; Igboanugo et al., 2020; Dave-Ugwu, Eya & Nwobodo, 2023) employed ICT-based instructional strategies or ICT tools for teaching chemistry, mostly in secondary schools. These are the gaps that this study uncovers for chemistry education researchers to fill by carrying out empirical studies using ICT tools as instruments for reducing the abstractness and difficulty of some chemistry concepts

This study argues that if ICT tools could be adopted for teaching chemistry from the secondary school level up to the university level, it would help in reducing the abstractness and difficulty of some chemistry concepts as reported by earlier studies. This helps in resolving unsatisfactory students' academic achievement both at the local and international levels. In conclusion, ICT tools offer a powerful arsenal for educators to make chemistry more engaging, interactive, and visually stimulating. By leveraging these tools, teachers can effectively address the abstract nature of the subject and make even the most challenging concepts more comprehensible for students.

Abstractness and Difficulties of Some Chemistry Concepts

The abstractness of some concepts in chemistry refers to the difficulty in understanding them due to their nature: invisible, theoretical, or symbolic. As Milenković, Segedinac and Hrin (2014) point out, chemistry's many abstract and complex concepts pose a challenge for learners due to limitations in abstract thinking. This struggle manifests as difficulty in grasping the material, leading to the formation of incorrect ideas or misconceptions. Examples of abstract concepts in chemistry include atomic structure, chemical bonding, and chemical equilibrium, as reported by Tima and Sutrisno (2018) and Priyasmika (2021). According to Permatasari, Rahayu and Dasna (2022), the abstractness of these concepts leads to several difficulties: understanding them, developing misconceptions, and applying knowledge to real-life situations. The difficulty of some chemistry concepts stems from a combination of factors related to the subject matter itself and how it is presented. Uzezi, Ezekiel, and Auwal (2017) identified several factors contributing to this difficulty, including the abstract nature of concepts like the microscopic world, symbolic representations, and the need for prior knowledge. The language used in chemistry and the way it is presented can also play a role (Uzezi et al., 2017). Examples of challenging chemistry concepts include electrochemistry, atomic structure, and chemical thermodynamics (Njoku & Nzewi, 2010; Uchegbu et al., 2016; Uzezi et al., 2017). In conclusion, the abstract nature and complexity of some chemistry concepts, along with how they are presented, can make learning them difficult for students.

Researchers reported various strategies that could be adopted for the reducing abstractness and difficulties of some chemistry concepts. For instance, using Multiple Representations of chemical concepts could lead to reducing of abstractness and difficulty of some chemistry concepts (Tima & Sutrisno, 2018; Priyasmika, 2021; Permatasari, Rahayu, & Dasna, 2022). Umate, Abubakar and Ansleem (2022) reported ICTs could used for concretizing some abstract chemistry concepts thereby simplifying them. Other strategies include: Analogies and metaphors via relating abstract concepts to familiar experiences so as to make them more relatable (Tima & Sutrisno, 2018). Hands-on activities through laboratory experiments and practical exercises allow students to connect the theoretical with the observable (Taber, 2020). Clear explanations by breaking down complex concepts into smaller steps and using clear language is crucial for building understanding (Priyasmika, 2021). Visualization tools through use of models, animations, and simulations can help students visualize the microscopic world of atoms and molecules (Gupta, 2023). This review focused on use of ICT tools to reduce abstractness and difficulty of some chemistry concepts. ICTs have the potentials to implement various strategies suggested by the researchers for reducing abstractness and difficulty of those concepts

Information and Communication Technology in Science Teaching

Information and Communication Technology (ICT) plays a significant role in teaching and learning science subjects such as biology, chemistry, physics, mathematics, and others. Research has shown that using ICT in educational settings improves students' educational efficiency by enhancing their learning ability, helping them prepare assignments and projects, and contributing to the development of productive knowledge related to their studies (Otieno, 2017). Aina (2013) further argued that ICT is beneficial for effective teaching and learning of science education because it facilitates the learning of abstract concepts in biology, chemistry, and physics. Researchers reported many ways of using ICTs for teaching and learning science. Umate, Aminu and Hamza (2018) classified use of ICT in science education into two (2) categories namely; Use of tool software and learning through ICTs. ICT can be used in science teaching as tool when the students and teachers utilized available set of software to accomplish their tasks in an effective way. Example of those software are word processing software e.g. MS Word, spreadsheet packages e.g. MS. Excel, presentation software e.g. MS. power points. learning through ICTs is also categorized into three (3) which are: Computer Assisted Instructions (CAI), Computer Assisted Inquiry (CAI) and Distant Learning Approach.

Computer-Assisted Instruction (CAI), also sometimes called Computer-Aided Instruction, is a type of learning that uses computers to deliver educational content and interact with students. Computer Assisted Inquiry refers to using computers to facilitate and support student inquiry. Distant learning, also known as distance education, is an educational approach where students and teachers are separated geographically and often learn asynchronously (at different times). This is done with the aid of ICT tools such as electronic mails, videoconferencing, chat rooms, WhatsApp and Facebook groups e.t.c are used in exchanging lecture notes, messages, assignments and others among individuals in a different location. Science educators are excited about the potential of ICT in their classrooms. It offers a vast amount of engaging content, perfectly suited for the information age and boosting student learning. Studies have shown that ICT tools can motivate students and improve learning outcomes. These tools also help teachers develop their TPACK skills, which are key to using technology effectively. Ultimately, ICT can help students develop a deeper understanding of science, hone their research skills, and become better problem solvers. Teachers can incorporate ICT throughout their lessons, making science learning more engaging and technology a seamless part of the classroom. Considering the importance of ICTs in science teaching, there is a need to look at their abilities as powerful tools for reducing abstractness and difficulty of some chemistry concepts.

ICTs as Powerful Learning Tools in Chemistry

Chemistry deals with concepts like atomic structure, bonding, and reaction mechanisms that are inherently abstract and difficult to visualize. Researchers reported that traditional methods of teaching often rely on textbooks and diagrams, which can leave students struggling to grasp the true nature of these concepts. The concept of ICTs as powerful learning tools in chemistry revolves around the ability of technology to bridge the gap between abstract concepts and concrete understanding (Gupta, 2023; Teplá, Teplý & Šmejkal, 2022). Umate, Abubakar and Abonyi (2022) and Hussain et al. (2017) reported that ICTs offer a range of tools that can transform abstract concepts into more concrete and engaging experiences. Some of the ways in which ICTs transform chemistry abstract and difficult concepts into more concrete and easier ones, as reported in the earlier studies (Byusa, Kampire, & Rwekaza, 2022; Nkadimeng & Ankiewicz, 2022; Otieno, 2017), include: simulations and molecular modeling; interactive visualizations; animations and gamification; and online resources and collaboration.

Simulations and Molecular Modeling

Simulations and molecular modeling allow visualization of atoms, molecules, and reactions in 3D space. According to Hoai, Son, Duyen-Emand Duc (2023), simulations allow students to manipulate molecules, observe interactions, and witness complex structures in a dynamic way, leading to a deeper understanding of their behavior. The 3D visualization tools used for teaching and learning geometry include software like ChemDraw, Avogadro, and PyMOL, among others (Listyarini, 2021; Rayan & Rayan, 2017). These 3D visualization tools allow students to build and manipulate 3D models of molecules. This, in turn, provides a clear picture of molecular geometry, bonding arrangements, and spatial relationships between atoms,thereby reducing the abstractness and difficulty of these concepts (Hoai et al., 2023).

Interactive Visualizations

Abstract and difficult concepts like orbitals, energy levels, and bonding could be represented through interactive visualizations. Lamoureux and Ogilvie. (2021) reported that interactive visualization tools allow students to rotate, zoom in or out, and explore these concepts in real-time, fostering a more intuitive grasp. Some interactive visualizations include periodic table applications known as Ptable, which provide detailed information on each element, including its properties, electron configuration, and reactivity trends (Nsabayezu et al., 2023). Students can explore these features dynamically, making connections between atomic structure and chemical behavior. Another example of an interactive visualization tool is orbital visualizations like Molecular Orbital Viewer, which allows students to visualize the shapes and energies of atomic orbitals, a challenging concept to grasp traditionally (Li et al., 2022). The authors further reported that these visualization tools help students understand how electrons are distributed around atoms and how they participate in bonding.

Animations and Gamification

Animations provide step-by-step visual representations of chemical processes, making reaction sequences easier to follow. Animated representations of chemical reactions, like those found in online resources or educational software, break down complex reaction sequences step-by-step. Winter et al. (2023) argued that simulations help students follow the flow of electrons, understand the role of intermediates, and visualize the overall reaction pathway. For instance, tools like PhET Interactive Simulations offer simulations of chemical reactions, allowing students to observe the process in real-time, visualize the formation and breaking of bonds, and understand the reaction mechanisms. Gamified learning experiences add a layer of fun and interactivity, motivating students and reinforcing their grasp of concepts (Alsawaier, 2018). Gamified learning platforms like "Mystery Science" or "Chemicool" present chemistry concepts in a fun and interactive way (Dave-Ugwu, Eya, & Nwobodo, 2023). Previous studies reported that through gamified learning, experienced students can solve puzzles, participate in challenges, and learn through gameplay, reinforcing their understanding in a more engaging manner (Lutfi, Aftinia, & Permani, 2023; Chans & Portuguez-Castro, 2021).

Online Resources and Collaboration

Access to online resources like educational websites, databases, and virtual labs provides students with a vast amount of information and interactive experiments. Sawant, S. (2021) reported that collaborative tools facilitate peer learning and knowledge sharing, enriching the learning experience and fostering critical thinking skills. For instance, online platforms like "Labster" or "Virtual Chemistry Labs" provide simulated laboratory environments where students can conduct virtual experiments, collect data, and analyze results (Zamiri & Esmaeili, 2024). This offers a safe and accessible alternative to traditional lab work, allowing students to explore various experiments without the limitations of physical resources. Several educational websites and databases, such as Khan Academy, Chemguide, and the National Center for Biotechnology Information (NCBI), offer comprehensive explanations, tutorials, and databases of chemical information (Bacolod & Bacolod, 2020). Students can access a wealth of material for self-paced learning and explore specific topics in greater depth. Online forums and discussion boards such as

Reddit's "Chemistry" subreddit or online forums dedicated to chemistry education provide opportunities for students to connect with peers, ask questions, share their understanding, and learn from each other's experiences (Iyamuremye et al., 2022). These are some examples of how ICTs can be utilized in chemistry education. By incorporating these diverse tools, educators can create a more engaging and effective learning environment, ultimately fostering a deeper understanding and appreciation for the fascinating world of chemistry.

Benefits of Using ICTs in Chemistry Education

The integration of ICTs in chemistry education offers a multitude of benefits for both students and educators, leading to a more effective and engaging learning experience. ICT tools make abstract concepts more concrete. By providing interactive learning experiences and fostering critical thinking skills, ICTs can transform chemistry education into a more engaging and successful journey for students. Previous studies (Zamiri & Esmaeili, 2024; Lutfi, Aftinia, & Permani, 2023; Chans & Portuguez-Castro, 2021) reported that the benefits of ICTs in the teaching and learning of chemistry include:

Improved Conceptual Understanding: Visualizations and simulations make abstract and difficult concepts like atomic structure, bonding, and reaction mechanisms more tangible, easier and relatable, leading to a deeper grasp of fundamental principles. Students can actively manipulate models, observe interactions in real-time, and visualize complex structures, solidifying their understanding.

Enhanced Problem-Solving Skills: Interactive tools and simulations provide opportunities for students to apply their knowledge in practical scenarios. Students can analyze data, manipulate models, and experiment virtually, developing critical thinking and problem-solving abilities.

Developed Critical Thinking and Analytical Abilities: Engaging with online resources, simulations, and collaborative tools encourages students to analyze data, interpret results, and draw conclusions. This fosters critical thinking skills and the ability to think logically and scientifically.

Fostered Interest in Chemistry: The interactive and engaging nature of ICT-based learning can spark curiosity and motivate students to explore the world of chemistry further. Gamified experiences and simulations can make learning enjoyable, leading to a more positive attitude towards the subject.

Increased Accessibility: Online resources and virtual labs provide access to learning materials beyond physical limitations, offering opportunities for self-paced learning and exploration.

Personalized Learning: ICTs can cater to individual learning styles and pace, allowing students to progress at their own comfort level.

Collaboration and Communication: Online platforms facilitate peer interaction and knowledge sharing, promoting collaboration and communication skills.

Conclusion

In conclusion, the integration of information and communication technologies (ICTs) has revolutionized the way we approach chemistry education. Through their ability to transform abstract concepts into concrete and interactive experiences, ICTs offer a powerful solution for overcoming the inherent difficulties associated with learning chemistry. Through simulations, visualizations, animations, online resources, and collaborative tools, ICTs can significantly improve student engagement, conceptual understanding, problem-solving skills, and critical thinking abilities. While acknowledging potential challenges like access limitations and the need for proper integration, the overall impact of ICTs on chemistry education is undeniably positive. By making the invisible visible and the complex comprehensible, ICTs pave the way for a more engaging and successful learning journey, ultimately fostering a deeper appreciation for the fascinating world of chemistry.

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