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Impact of ICT-Enabled Tools on Chemistry Education

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Abstract: ***The integration of Information and Communication Technology (ICT) in Chemistry education enhances both teaching and learning effectiveness, particularly for complex topics like reaction mechanism, stereochemistry, bio-molecules and IUPAC nomenclature. Even though conventional chalk-and-talk techniques are still useful, ICT tools offer many benefits, particularly when it comes to visualizing intricate chemical concepts and 3D molecular structures. In this context, ICT tools refer to a variety of digital resources, such as video content, online resources, computer-based learning materials, and conferencing technologies. These resources provide more interesting ways to teach difficult chemical concepts while overcoming the constraints of the traditional classroom. Commercial software packages offer attractive teaching solutions, they are increases teaching flexibility. The crucial task is finding a balance between conventional and ICT-based teaching strategies by ensuring teachers have proper support and recognition for implementing these innovative teaching approaches. The ultimate goal is to transform chemistry education pedagogy to attract and retain talented educators while enhancing student learning outcomes through effective technology integration. This article helps in creating policies that prioritise financial and infrastructural needs to HEIs for educational technology tools that are beneficial for the students and teachers to improve the ICT enabled teaching-learning process.***

Keywords: ICT, Chemistry Softwares, Tools in Chemistry education, Computational tools, Molecular Structures, Virtual lab

1. Introduction

Integration of Information and Communication Technology (ICT) has transformed education in Chemistry. ICT resources empower advanced molecular visualization, data handling, and simulation-based experimentation, making advanced concepts in Chemistry understandable to students. ICT resources promote 3D visualization of molecules, enable distant learning via virtual labs, and allow real-time and asynchronous teacher-student communication [1].

For successful implementation, teachers need to acquire the skills of applying ICT tools in teaching Chemistry and research. The extensive resources accessible through ICT, such as web-based materials and virtual simulations, need to be integrated into chemistry education across the country [2]. This ICT enabled teaching has been promoted in NEP 2020 to create skill enhancement among the students. This aligns with contemporary educational research that indicates students learn best by active participation, extension of prior knowledge, and the acquisition of computational skills. With ICT developing faster in the 21st century, it raises numerous possibilities to revolutionize traditional education and achieve lifelong learning. After COVID 19 pandemic, there is incremental growth observed in ICT enabled educational methods, as the access is encouraged and motivated by educational bodies and HEIs. The crisis changed education systems around the world, especially in disciplines that had previously depended on face-to-face learning, experiential laboratory exercises, and immediate student-teacher contact. As the system shifted, institutions deliver online education, wherein teachers and learners interact virtually at predetermined times with the aid of digital platforms. This maintains much of the advantage of the old classroom-based learning but takes education to students located in different areas [3]. This transformation of conventional educational methods, makes use of ICT by creating inclusive and accessible learning environments to all the students on one platform. With emphasis on the instruments and technologies igniting this transformation, their influence on learning results, as well as the opportunities and challenges they bring in education. This paper aims to investigate how digital transformation is transforming chemistry education, a holistic overview of the ICT based transition [4] in chemistry education and its implications for students, teachers, and policymakers and future trends.

Objectives:

National Education policy 2020 encouraged all HEIs for the ICT enabled methods [5] in the teaching learning to create skill based human resource, good entrepreneurs, educationists, scientists by the provision of more accessible learning methods.

1) To examine the extent of ICT tool utilization in supplementing chemistry education among students.
2) To assess the updates, frequency and patterns of ICT tool usage in accessing resources
3) To deliver information of ICT for chemistry studies.
4) To explore the opportunities, engagement and peer collaborations facilitated by ICT tools in chemistry education.
5) To evaluate the achieved effectiveness of ICT methods in inculcating conceptual understanding and comprehension among the students.
6) To integrate ICT on student academic performance compared to traditional teaching methods.
7) To focus on student's interest toward chemistry when taught using ICT tools
8) To develop professional development support to the Chemistry teachers.
9) To develop student's written communication skills by the use of ICT.
10) To develop Chemistry education pedagogies to attracts the best talents towards Chemistry and retains them for their professional development.

2. Materials and Methods

ICT in Chemistry Education: The chalk-and-talk method of conventional chemistry teaching has several disadvantages, such as time limitations to finish syllabi and inability to clarify intricate molecular ideas. ICT makes major advances in teaching Chemistry in many respects:

1) **Visualization and Modeling:** ICT helps students to represent complicated molecular structure, chemical processes, and arrangement of atoms as 3D models and simulations, rendering difficult concepts concrete and easier to grasp.
2) **Interactive Learning:** Online resources give interactive experiments and virtual labs in which students can conduct safe chemical processes and reactions that would be risky or unsuitable to work with in the actual lab.
3) **Increased Engagement:** Interactive activities, animations, and multimedia materials keep students engaged with chemistry concepts and make learning enjoyable.
4) **Customized Learning:** ICT tools enable students to learn at their own pace, revise concepts several times, and refer to additional resources when necessary.
5) **Assessment and Feedback:** Online platforms support instant feedback and assessment, assisting teachers in monitoring student progress and areas requiring more attention.

The incorporation of ICT in chemistry education [6] thereby overcomes many of the weaknesses of conventional modes of instruction and offers more effective and efficient means of teaching chemical concepts [5]. This technological mode supplements conventional methods of instruction, and it provides educators with additional resources to aid in student understanding and participation. STEM education programmes [4] frequently organized for a high level of competency with digital technology. It enables to understand, how the use of digital technologies in STEM courses helps students to get prepared for the demands of the job sector.

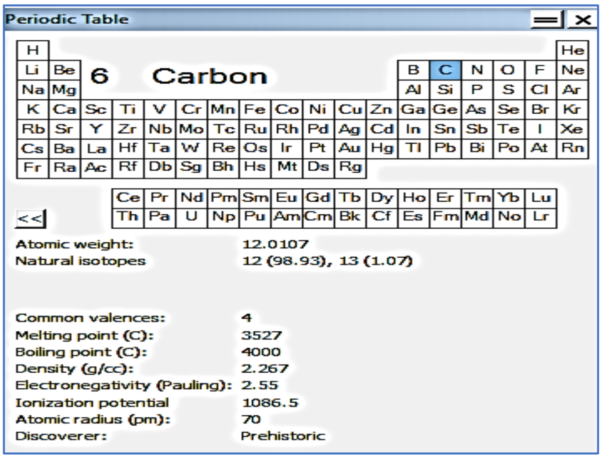
Essential Software Tools in Chemistry:
Information technology has transformed chemistry education and research using a range of specialized software tools [7]. Some of the important applications are as follows:

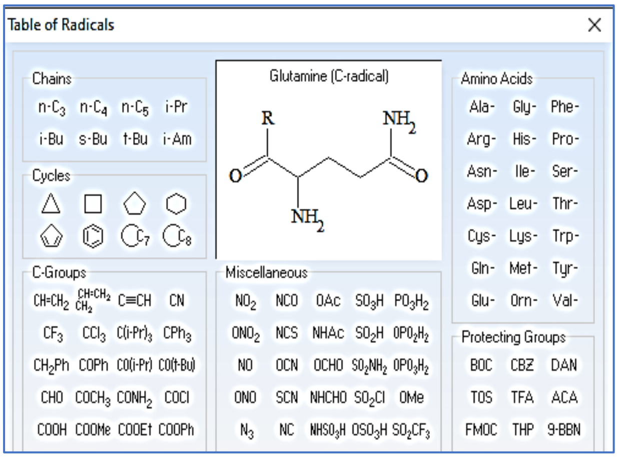
Drawing and Visualization Tools:

a) **ChemDraw:** It is the chemical drawing program in the ChemOffice suite. It is available for both Mac and Windows and allows structure drawing, property calculation, 3D visualization, and automated IUPAC naming from chemical structures and vice versa.
b) **ChemSketch:** It is a powerful molecular editor used by more than 2 million people around the globe. It is great for drawing organic, organometallic, and polymer structures and computing diverse molecular properties such as weight, density, and so on. The software has both 2D and 3D visualization functions.
c) **ChemWindow:** It is published by John Wiley & Sons, is concerned with chemical structure drawing and process flow diagrams. It offers tools for 2D and 3D visualization and accurate measurement of molecular properties such as bond lengths and angles.
d) **Chem3D Pro:** It is another part of the ChemOffice suite, is dedicated to 3D molecular visualization and property analysis. This Windows application provides extensive tools for structure drawing and molecular property calculations.
e) **ChemDoodle:** It is expertise in sophisticated mechanism drawing, with special functionality for electron notation and chemical text layout. Its most distinct characteristic is the built-in subscript and superscript formatting for atomic notations.
f) **Jmol:** This excels in the area of 3D molecular visualization, which can handle multiple file formats as well as output from quantum chemistry. Its cross-platform nature ensures that it is easily accessible.
g) **Avogadro:** It is a robust 3D molecular editor and visualizer, especially worth it in computational chemistry usage.
h) **ChemWriter:** It specializes in web-based chemical structure design, hence its utility in online applications.
i) **ISIS/Draw:** It is built by MDL Information Systems, is superior in 2D drawing with some 3D functionality, especially useful in the representation of stereochemistry and geometric isomers.
j) **BKChem:** It is developed with Python, allows for free-of-cost chemical drawing with a focus on simple structure building and associating elements with it. BKChem gives molecule chart templates as well as has the ability to do bond-by-bond drawing.
k) **JChemPaint:** It is built by the Chemistry Development Kit, is a freely available 2D molecular editor that supports various operating systems. It has simple bond manipulation capabilities and ring templates of sizes 3 to 8 atoms.

All of these tools provide special features that serve the variety of requirements of chemical education and research, ranging from simple structure drawing to sophisticated computational analysis.

Some of the features available on online tools [7, 8]:





Periodic table and properties Types of radicals available on tools

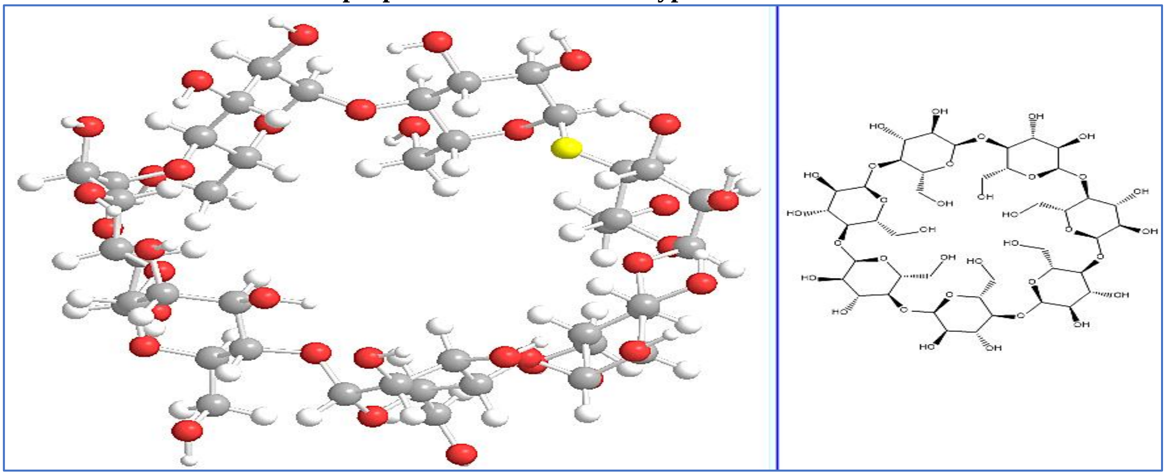
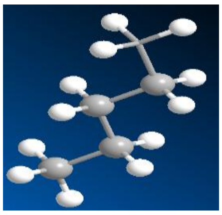
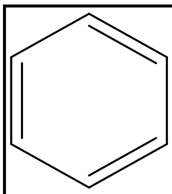
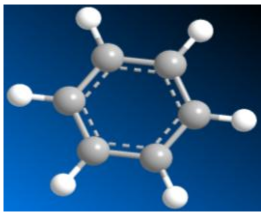


Figure: 3D Structure of Cyclodextrins





Benzene
Chemical Formula: C_6H_6
Exact Mass: 78.05
Molecular Weight: 78.11
m/z: 78.05 (100.0%), 79.05 (6.6%)
Elemental Analysis: C, 92.26; H, 7.74



n-pentane Benzene structure and properties

Figure: Various Possible Structure of compounds on ICT Tools in Chemistry

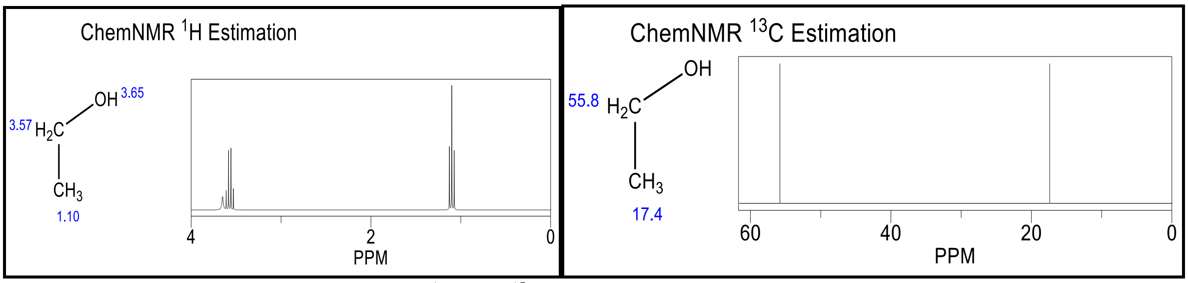


Figure: NMR (^{1}H and ^{13}C) predictions from online Softwares

Virtual Chemistry laboratories:

Virtual chemistry labs [9] are web-based systems that mimic actual lab experiments, enabling students to carry out practical work online at their own convenience. Under India's National Training Mission, these labs include interactive 3D visuals, animations, and extensive learning materials such as video lectures and self-testing tools. The virtual world enables students to visualize chemical concepts and acquire hands-on skills through simulated lab experiments. Major advantages are enhanced access to quality laboratory experiments, better learning facilitated by visualization, and easier collaboration options. The system features an animated teaching assistant to assist users, enhancing the learning process to be more interactive and productive.

These virtual labs act as useful additions to conventional laboratory facilities, mainly helping institutions and students with insufficient access to such facilities. They offer an inexpensive means of practical science education delivery without compromising the quality of education.

Integration of virtual labs: For the integration of Virtual laboratories [10] following steps to be considered for effectiveness in understanding of experiments.

Pre-lab Activities: These pre-experimental activities are important in preparing students for success in virtual lab experiments. They generally involve explicit instructions, background theory, safety procedures (even in virtual environments), and anticipated learning outcomes. Students can observe demonstrations through animations illustrating correct techniques and procedures. Interactive simulations enable students to become acquainted with the virtual equipment and interface prior to actually performing the experiment. This preparation serves to decrease cognitive load in the main experiment and increase student's confidence.

Performance-Based Virtual Labs: Virtual labs are standardized, all students work with the same equipment and conditions, having no variables that could influence outcomes in physical labs. Standardization facilitates more equal assessment. Virtual labs can monitor the student's behaviour, thought processes, and solution strategies in real time. They can offer instant feedback and enable students to practice procedures until proficiency is obtained. The controlled laboratory also allows the instructors to come up with elaborate scenarios that could be too expensive, hazardous, or time-consuming in actual laboratories.

Post-lab Discussions: This reflective period is essential to enhance understanding and build critical thinking. Students are able to present their experimental data, compare and discuss results, and collectively discuss any differences in their results. The virtual lab's digital platform facilitates the easier compilation and visualization of data for productive discussion. Students can investigate why alternative methods may have resulted in varied outcomes, enhancing analytical thinking. These conversations may occur both synchronously in class and asynchronously using internet forums to permit longer contemplation and learning among peers.

Digital Transformation in Education: NEP 2020's Vision

The National Education Policy 2020 [11]is a turning point in Indian education in that it adopts digital transformation [12] without losing sight of a balanced integration of technology. The policy structure recognizes the transformative power of digital tools as well as the imperative to address the challenges that come with it.

Core Digital Initiatives:

1) **Research-Based Implementation:** The policy requires systematic pilot studies by leading institutions such as IITs, NITs, IGNOU, and NETF to assess the efficacy of digital education. The studies analyse important parameters such as most suitable e-content forms, and methods to enhance benefits while avoiding detriments.
2) **Digital Infrastructure Development:** A strong, future-proof digital ecosystem provides the foundation for NEP 2020's vision for technology. The emphasis is on developing open, interoperable infrastructure that can adapt to technological progress and support India's varied education needs.
3) **Improve Teaching Platforms:** The policy expands on already available platforms [13, 14] such as SWAYAM and DIKSHA with enhanced monitoring systems and two-way communication features. The COVID-19 pandemic situation has especially shown the need for these interactive options for successful online learning.
4) **Rich Digital Content Repository:** A wide digital repository containing various learning content is being prepared such as Interactive classes, Education games and simulations, Augmented and Virtual Reality experiences, Cultural learning applications in many Indian languages, User rating systems for quality assurance, etc.
5) **Bridging the Digital Divide:** Recognizing uneven digital access across India, like television and radio to ensure educational continuity. Content is being developed in various Indian languages, with 24/7 accessibility to accommodate diverse learning schedules.
6) **Virtual Laboratory Experience:** The policy focuses on encouraging practical training using virtual labs. Platforms such as DIKSHA and SWAYAM are being upgraded to offer hands-on experimental learning, with special arrangements for socio-economically weaker sections.
7) **Teacher Empowerment:** Comprehensive teacher training programs are made for digital pedagogy [15] and content generation skills, with a focus on interactive learning and student participation in the digital platform.

Impact on Chemistry Education:

The digital revolution holds specific significance in chemistry education, where contemporary learners invest considerable time-consuming digital media. Embedding multimedia [16] tools holds a number of benefits:

- Increased visualization of molecular structures and chemical reactions
- Interactive chemical reaction simulations
- Periodic table exploration and chemical calculations on the go via mobile apps
- Virtual lab experiences for secure experimentation
- Customized learning pathways through learning apps

Topics which can be covered with the help of ICT Chemistry Tools:

- 3D structure optimization
- Auto renumbering
- Calculation of Molar Refractivity, Surface tension, Index of refraction, Density, polarizability and dielectric constant.
- IUPAC Nomenclature: Drawing structures from names and vice versa.
- Import and export of molecule
- Conversion of 2D into 3D
- Advance form of periodic table and all periodic properties

- Structure of Carbohydrate, amino acids etc.
- Structure of bigger and giant molecule
- Editing of molecule structure.
- Tautomeric forms
- Spectral elucidations of compounds
- Conformational and Stereoisomers etc.

This online strategy is in line with contemporary learners' preferences for learning and yet keeps educational standards intact. Chemistry learning apps promote systematic investigation and experiential knowledge, going beyond mere theoretical understanding to process-based learning. The NEP 2020's digital vision is a holistic strategy for renewing Indian education, with especially advantageous implications for science education. By blending heritage pedagogic strengths with digital creativity, the policy seeks to produce a more interactive, accessible, and efficacious learning climate for all.

3. Conclusion

Information and Communication Technology has become a necessity in modern education, especially in colleges, as it assists in making learning more interactive. Educators have identified that ICT allows teachers to provide more authentic and holistic knowledge to students. The capability of the technology to display three-dimensional visualizations of molecules assists in capturing students' attention and increasing their motivation to learn Chemistry. ICT has made it easier to understand complex chemical principles and enhanced student participation through interactive learning. Especially in Chemistry education, ICT has revolutionized conventional teaching. ICT implementation in education results in cost savings for governments and HEIs and enhance the quality of education. The institutions have resource limitations that are overcome through the adoption of these ICT based technologies. However, a number of challenges must be overcome in order to effectively utilize ICT in education such as Limited access to resources and infrastructure, Lack of expertise to operate digital tools. A multi-faceted strategy is required to increase awareness regarding the significance of ICT in Chemistry education and to establish concise guidelines for the development of knowledge and skills to build sustainable implementation. ICT integration makes students with improved educational opportunities and ready them for successful careers in the world of growing technology.

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