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A Review of Pedagogical Strategies for ICT Integration in Chemistry Teaching and Learning in Higher Education

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Abstract

The use of ICT in chemistry education involves a completely new pedagogy rather than just minor adjustments to the traditional instruction model. Students participate in shared learning resources and ICT-based learning environments to learn autonomously, actively and collaboratively, rather than following the traditional model of knowledge transformation. The use of computer-based communication and technological-based instruction in regular classroom activities is a component of ICT integration in education. This makes significant contribution to the pedagogical aspects of how ICT use promotes successful chemistry learning. The utilization of Information and Communication Technologies (ICT) in the teaching and learning of chemistry is inevitable due to the use of computers and software such as ChemWindow, Chem3D Pro and Avogadro which are used to draw chemical structures and visualize molecules in chemistry laboratories and classrooms. The theory and practice of teaching chemistry in the presence of ICT is governed by the pedagogical integration of ICT which intern improves the effectiveness of chemistry learning in higher education. This work discusses pedagogical theories for incorporating information and

communication technology in chemistry higher education teaching and learning, pedagogical theories, impact of ICT integration and the challenges associated with ICT in chemistry teaching.

Key words: chemistry teaching and learning, ICT integration, pedagogical approaches ICT, ICT integration challenges in chemistry teaching and learning

1. Introduction

There are several pedagogical approaches that can be used to integrate ICT in chemistry higher education teaching and learning. These methods of instruction seek to augment student involvement, encourage active education, and expedite the cultivation of critical thinking and problem-solving proficiencies. Some of the commonly used pedagogical approaches for ICT integration in chemistry education include blended learning, flipped classroom, inquiry-based learning and collaborative learning. Blended learning integrates both conventional face-to-face instruction with online learning activities [1,2]. In chemistry education, this approach involves using online simulations like ChemReaX, virtual labs such as ChemCollective, and multimedia resources including LabXchange and Concord Consortium to supplement in-class lectures and discussions. Providing teaching material before class time is best described by the flipped classroom approach [3]. The learners are introduced to new chemistry concepts and materials through online resources such as Moodle and Blackboard before coming to class. Class time is then solely dedicated to active pedagogy including group discussions and laboratory experiments. ICT tools such as online videos, interactive tutorials, and discussion forums can be used to deliver pre-class content and facilitate student engagement during in-class activities. A study by Aidoo and co-workers [4] revealed that teachers found it tough and complicated to switch from their usual pedagogical method to online teaching when integrating ICT into organic chemistry teaching and learning utilizing the flipped classroom approach. The study suggests that flipped classroom approach could present opportunities for educators to enhance their ICT skills and pedagogical practices.

According to Gillies and co-workers [5] teaching science through inquiry-based learning helps learners to explore and discover solutions through independent investigation. Hence, chemistry students must use this intricate and multidimensional method to explain their understandings in a way that is logical, well-reasoned, and seen as justified. They must also be able to reconcile their understandings of an issue with the information gathered from an inquiry. This approach promotes critical thinking, problem-solving skills, and scientific inquiry in chemistry education [6,7] highlighted that science students are better equipped to handle the challenges and changes in the world when they use an inquiry-based approach. In the field of chemistry education, collaborative learning fosters peer-to-peer learning, teamwork, and communication skills[8]. ICT tools such as online collaboration platforms, video conferencing, and shared document editing can facilitate communication and collaboration among students, even in remote or asynchronous learning environments.

In a normal chemistry class, the teacher tries to transform abstract chemistry content through verbal means, symbolic explanation and non-verbal. According to Marchak and co-workers[9] there is a gap when teaching chemistry between verbal an non-verbal competences which often brings challenges to learners of understanding and making sense of the abstract chemistry content. The use of arts-integration approach for teaching chemistry as a pedagogical tool coupled with strategies such as visual thinking, creative elaborations, modular teaching that stimulates general motivation and social learning that promotes the application of chemistry is an active teaching approach for teaching chemistry. The experiential learning theory, which states that learning is most effective when students actively participate in practical situations and reflect on their observations, is closely related to the arts-integration approach [10]. Experiential learning can be enhanced through the use of simulations, virtual reality, and other immersive technologies that provide students with authentic and interactive learning experiences. Pedagogical diversity and flexibility brings an active chemistry learning strategy for higher education learning in the classroom and it can also be implemented through online learning.

2. Pedagogical theories in ICT integration

The study of the theory and practice of education is known as the pedagogical theory [11]. They are various pedagogical theories and they consider learners' behavior, range of techniques during teaching, assessment of learners and inclusivity of a diverse range of leaners [12]. The aforementioned pedagogical theories offer for the fundamentals for comprehending the effective implementation of ICT integration in teaching and learning, while considering the distinct requirements and attributes of students. This literature review section discusses constructivism theory; connectivism theory, Technology Acceptance Model and Technological Pedagogical Content Knowledge (TPACK) framework just to mention a few.

2. 1 Constructivism and Connectivism theory

Constructivism theory emphasizes that through interacting with their surroundings, students actively create their own knowledge and understanding [13]. To integrate ICT into chemistry teaching, constructivism theory suggests that students should be engaged in hands-on activities using technology to explore and discover new concepts. Connectivism theory is another theory which focuses on the idea that learning is a process of connecting and networking with others and resources [14]. Hence, students should be encouraged to use technology to connect with peers, experts, and online resources to enhance their learning. It can be implemented by shifting from teacher-centered to student-centered pedagogy [15]and incorporating technology with readily-available devices such as WhatsApp. This theory is closely related to social learning theory that suggests that technology can be used to enable communiqués, teamwork, and knowledge sharing.

2. 2 Technological Pedagogical Content Knowledge (TPACK) framework, Technology Acceptance Model and Unified Theory of Acceptance and Use of Technology

Technological Pedagogical Content Knowledge (TPACK) framework proposes that active education with technology involves a the blending of high-tech acquaintance, pedagogic understanding, and content knowledge[16]. It emphasizes the significance of understanding how to incorporate technology appropriately into specific subject areas and teaching strategies. The teacher depends on content knowledge, technical knowledge and pedagogical knowledge for effective integration of ICT into the teaching and learning process [17].

Perceived benefit and ease of use are the two variables that [18] focused on when developing the Technology Acceptance Model (TAM), with the user or potential user in mind. The TAM model states that a user's behavioral objective to implement technological system directly influences how they use it. The attitude toward using the technology and its perceived utility determine the behavioral intention to use it. A few examples of the variables that affect TAM are system characteristics, development process, and training [17].

Behavioral intention drives the Unified Theory of Acceptance and Use of Technology theory. The direct effects of facilitating conditions, performance expectancy, social influence, and effort expectancy determine the perceived likelihood of adopting the technology [19]. The theory supports the notion that teaching strategies and resources ought to be created with the various needs and preferences of every student in mind. It implies that a variety of representational, interactive, and expressive mediums can be facilitated by technology in order to promote customized learning.

3.0 ICT integration in higher education chemistry learning

ICT utilization in the higher education sector is the utilization of educational technology for the teaching and learning process including transacting curricular content. Its usage is not limited to lesson delivery and learning process but it is also used for assessment purposes. The integration of ICT is characterized by its efficiency, effectiveness and innovation aspects. A case study conducted by Rana and co-workers[20] in Nepal revealed that there was lack of strategy to implement ICT at the university in Nepal. A study on ICT integration in the educational system of Philippines school revealed that curriculum standards revealed that there is still need to train teachers, provide infrastructure for ICT based curriculum and strategies for ICT integration are still lacking [21]. A study by Goldhaber and co-workers [22] on ICT integration in secondary schools in the USA revealed that ICT integration substantially and positively affects the quality of education in USA secondary schools. The study also revealed that the government needs to put in place relevant policies for ICT integration in schools. Another study on ICT integration [23] at Adama Science and Technology University, Ethiopia, revealed that ICT integration is yet to be done though the educators have positive attitude towards ICT integration. A study in Czech Republic [24] revealed that it is important to get the views of university students on the implementation of ICT in their learning before the actual implementation since they are the end users.

3.1 ICT integration in Botswana teaching and learning process

A case study of Botswana junior secondary school on the incorporation of ICT in curriculum revealed that the integration of ICT in the teaching and learning process is very low or not yet started [25].The major barriers were found to be lack of confidence in the use of technology by teachers, lack of funds, lack of skills and ICT equipment in the schools. Another study [26] revealed that to integrate ICT in Botswana schools it requires creating and using new teaching pedagogy which is not any easy task as it questions the existing teaching pedagogy. A study on the factors affecting ICT integration in Botswana senior secondary schools reveal that teachers understand the value of ICT in the teaching and learning process and are willing to teach using ICT tools however, they have inadequate resources, insufficient technical support and they lack support from the management and administrators [27]. Another study [28] also revealed that shortage of teaching tools act as an impediment to ICT accessibility in teaching mathematics curriculum in classrooms in Botswana.

The universities in Botswana are integrating ICT in their teaching and learning process. A study conducted on Botswana Open University business students revealed that most students have the ability to navigate through the educational technology tools and applications and understand the basic functions of computer hardware[29] The study also revealed that the students lacked adequate training on how to use ICT tools relevant to their subject matter and this was attributed to lack of poor ICT skills in the teaching and learning process. Another study on the role of ICT for enhanced teaching carried out within the University of Botswana revealed that teachers are aware of the role technology plays in the teaching and learning process[30]. They also appreciate that the use of technology enables the managing of large classes, makes learning interactive with reduced pressure on having face-to-face teaching. The author also highlights that some instructors are not keen on using ICT tools in their instructional activities.

3.2. Impact of ICT integration in higher education chemistry learning

ICT has a significant impact on the pedagogy of learning in higher education due to its use as a platform and tool. ICT platforms include application platforms operating systems, database platforms, , computing platforms storage platforms and mobile platforms. The common ICT tools for teaching and learning chemistry are Moodle, BlackBoard, Google Classroom and Microsoft Teams. The integration of these tools and platforms in the teaching and learning process has increased due to the availability of telecommunication devices and internet access to the world at large. The ICT facilities have made teaching and learning chemistry content to be accessible through the data base, easy to use and learning chemistry manageable. ICT helps teachers to constantly monitor the progress and productivity of students constantly without seeing the student face-to –face. The students also learn to find, explore, analyse and exchange information through independent learning. The students become global citizens due to multisensory delivery, active learning, cooperative learning and multicultural aspects which come with the integration of ICT.

3.2.1 Improved Student Engagement

Chemistry classes in higher education have changed as a result of ICT integration. Learning management systems and online discussion forums have made it possible for students to engage in more dynamic and cooperative interactions with their instructors, fellow students, and course material. These platforms encourage students to ask questions, share their knowledge, and seek clarification on difficult subjects by facilitating active involvement and discussion[31].

Furthermore, chemistry education is now available outside of the traditional classroom because to the usage of social media, webinars, and virtual laboratories. Students can take part in live conversations, network with subject matter experts, and watch webinars on innovative research. Their comprehension of chemistry is enhanced by this degree of involvement, which also enhances their curiosity and enthusiasm for the topic.

3.2.2 Accessibility and Inclusivity

One of the most notable effects of ICT integration in higher education chemistry instruction is the increased accessibility and inclusivity it provides. Digital resources and online learning platforms can be accessible from anywhere, giving students with other commitments, such as employment or family duties, more freedom. This accessibility has benefited non-traditional and distant learners in particular, as they can now pursue higher education in chemistry without regard to geography [32]. Integrating ICT improves inclusivity as well. Closed captions, screen readers, and other content formats make educational resources more accessible to students with learning impairments. This ensures that all students, regardless of their physical or cognitive ability, can fully participate in chemistry education.

3.2.3 Customized Learning Paths

ICT integration in higher education chemistry instruction allows students to follow personalised and adaptable learning paths. Instructors can use learning analytics and data-driven insights to track individual progress, highlight areas for growth, and modify their teaching techniques accordingly. This adaptable strategy ensures that each student receives the assistance and resources necessary for success [33]. Furthermore, ICT technologies enable the design of customised assignments, quizzes, and assessments that respond to the individual requirements and interests of pupils. Adaptive learning platforms can modify the difficulty and topic of questions based on the student's performance, ensuring that they are challenged at the right level. This personalised learning strategy has been found to increase student engagement and overall performance.

3.2.4 Enhanced Learning Resources

ICT integration in higher education chemistry instruction has given students access to a variety of digital materials and these resources provide numerous advantages, including the flexibility to adapt to different learning styles and levels of knowledge. Furthermore, multimedia presentations and interactive simulations have proven to be effective tools in conveying complex chemical concepts. These visual and interactive resources engage students in a way that traditional lectures or static textbooks may not. For example, online simulations allow students to experiment with chemical reactions, observe molecular structures, and engage in virtual laboratories, all of which enhance their comprehension and retention of chemical principles [34].

However, this significant transformation has changed the curricula such that chemistry learners at higher education level are assessed on their ICT competency-based skills with special interest on knowledge of the use of drawing and chemical reactions visualization tools such as ChemDoodle, Avogadro, MolView and MarvinSketch. When designing the curricula integrated with educational technology, educators should carefully design and scaffold technology-based activities to avoid overwhelming students with excessive cognitive demands. The Substitution, Augmentation, Modification, Redefinition (SAMR) taxonomy-based approach can be used for selecting, using, and evaluating the level of technology integration in teaching and learning [35,36]. The implementation of this framework encourages educators to move beyond simply substituting traditional tools with technology and instead aim for transformative uses that redefine the learning experience.

3.3 Challenges associated with ICT integration in Chemistry learning

The integration of ICT in the higher education sector is accompanied by the proper infrastructure elements such as resources, services and management. Hence, ICT should be easily accessed by the learners and teachers and this requires formal skills, trainings, planning and ways to link ICT to the community. The institutional educational information services should be in a position to work together with the teachers to have the curricula according to the educational policy be suitable to be integrated with ICT tools and platforms. This exercise is important such that the learning process is interactive, provides understanding of the concepts and processes in chemistry helps learners to gain valuable computer skills and caters for different learning skills.

The challenges associated with the integration of ICT in higher education especially when it comes to teaching chemistry are related to institutional financial constraints because the chemistry data base and software requires subscriptions hence, they are termed expensive. Another challenge are related to teachers' attitude and approach which is a micro-level barrier or a teacher-level barrier. This is when a teacher resists change, lacks confidence in the usage of the tool, lacks time to understand the tool and sometimes lacks the effective training in solving the chemical problems and technical problems associated with the ICT tool. For example, learners find it challenging to draw complex molecular structures using ChemDraw which is an ICT tool for drawing molecules hence, the teacher would require adequate training to solve the problems encountered by learners.

3.3.1 Teacher Preparedness, Content Quality and Content Relevance

For ICT integration in chemistry education to be effective, teachers must be adept at using the technology and modify their teaching strategies accordingly. It's possible that many teachers lack the knowledge and abilities needed to use ICT technologies in the classroom [37]. Teachers may find it difficult to successfully integrate technology into their curricula without the right guidance and assistance, which would limit the technology's ability to improve student learning process (Ghavifekr and Rosdy, 2015).

The success of chemistry teaching is dependent on the quality of digital content used. Many digital resources may be inaccurate, out of date, or irrelevant, which might impede students' comprehension of chemistry subjects. Before employing online materials in their classrooms, educators must assess their reliability and quality. To maximise the benefits of ICT integration in chemistry learning, it is critical to ensure and secure the availability of high-quality digital content. It might be difficult to ensure that the ICT content and resources employed correspond with the chemistry curriculum and learning objectives because not all digital materials are appropriate for the curriculum.

3.3.2 Access to ICT Resources, Student Engagement and Distractions

Providing equal access of materials for all students is a major obstacle when it comes to ICT integration in chemistry teaching. Not all students have access to computers, internet access, or mobile devices; all of which are frequently necessary in order to use interactive tools, simulations, and online chemical content [38]. Students in such predicaments are disadvantaged by ICT integration in their learning processing.

ICT might potentially increase student engagement in the classroom, yet it can also cause distractions. In addition to offering educational resources, the same gadgets can lure students in with games, social networking, and other non-academic content [38]. Instructors need to figure out how to stop pupils from getting distracted by digital devices and maintain their attention on the lesson material.

There are a lot of chances to improve the educational experience when ICT is included into chemistry classes. To guarantee the efficacy of this integration, it is imperative to tackle the related obstacles. Some of the most important issues that educators and institutions need to think about include student involvement, material quality, teacher preparation, access to ICT resources, and assessment techniques. Through overcoming these challenges, the field of chemistry education may fully utilise ICT to improve accessibility, effectiveness, and engagement of instruction.

Conclusion

Overall, integrating ICT in chemistry higher education teaching and learning requires careful consideration of the pedagogical approaches that best align with the learning objectives and needs of students. By leveraging the potential of ICT tools, educators can create interactive and immersive learning experiences that enhance student engagement and promote active learning. Good teaching is still good teaching in the presence and absence of ICT. Various pedagogical theories are implemented in ICT integration teaching approach. The perspectives of both students and teachers are important for the effective implementation of ICT in higher education teaching and learning.

Authors contribution

Nyasha Makuve drafted the review including interpreting the relevant literature and Jane Iloanya revised it critically for important intellectual content.

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