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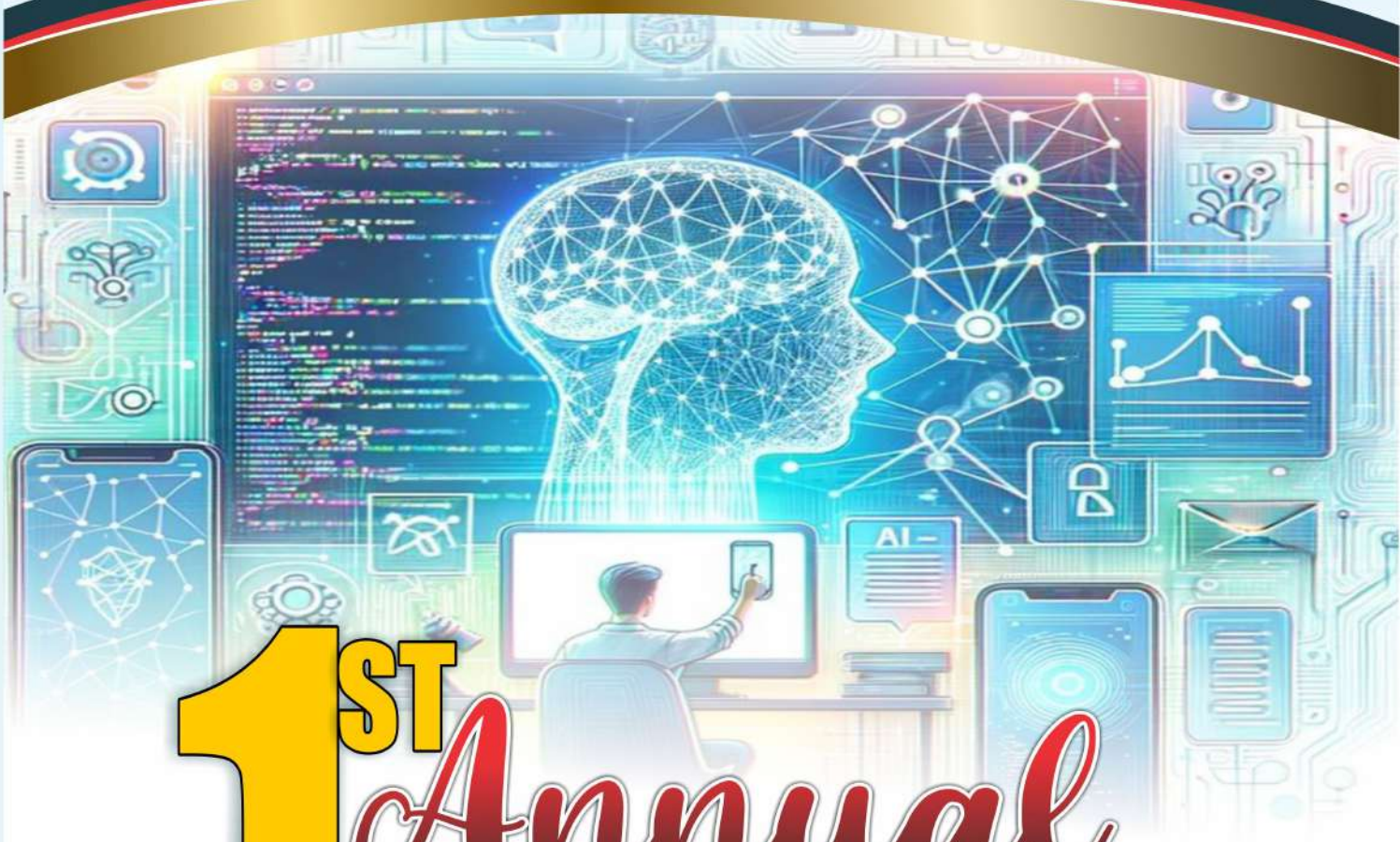
SCIENCE EDUCATORS AND DIGITAL LITERACY IN THE 21ST CENTURY



1ST Annual CONFERENCE

PROCEEDINGS 2025

Editor
Prof. Josephine N. Okoli

SCIENCE EDUCATORS AND DIGITAL LITERACY IN THE 21ST CENTURY
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ASSOCIATION OF SCIENCE EDUCTORS ANAMBRA (ASEA)

THEME: SCIENCE EDUCATORS AND DIGITAL LITERACY IN THE 21ST CENTURY

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MERITORIOUS AWARD
CITATION OF Dr SAMUEL ALFAYO BOH

It is my pleasure and singular honour to be called upon to read a citation on one of the eminent Doctor that the family of Alfayo has ever produced.

People are not chosen for their comfort, they most often to prepare for a life of self sacrifice and even sufferings on behalf of other. And most often their calling is not for privilege but for service. Whichever prism you use in view him, Dr Samuel Alfayo Boh a class teacher of high repute, a man of integrity and fear of God, sacrifices and service for the betterment and advisement of humanity.

May, 18, 1969 marked the beginning of the steadily progressive son of Boh colored mother and the Shongomite father. This account of this childhood and youth in Gombe State shows the prince he had to pay for such a birth. It did not take long before he was revealed as a man of vision and mission as every step he took in both early life and now was clogged with success, and a wide breath of accomplishment.

Dr.Samuel Alfayo Boh spends is early life in Boh with his parent. He attended Boh primary school from 1976 to1984 exposed his qualities as a gifted child enable him to proceed to Government Science Secondary School Kaltungo 1984 to 1987,Teachers College Gombe 1988 to 1990 the exceptional this qualities made way for him to enlist to College of Education Azare 1993 where he bagged National Certificate in Education (NCE) while in Azare, he was elected parliamentary student union 1994 to 1995 session and thereafter in the year 1987, he proceeded to famous University of Maiduguri Borno State and had a Bachelor of Education and passed with flying colours in 2000. Diploma in World Evangelism Mission Training Institute in Borno State in 1999. In 2001, the indefatigable Samuel was drafted in to the National youth service scheme in Tsafe, Zamfara State his service witnessed a continued story of one success after another like the Nehemiah of the Holy Bible. As a man who fully understand what benefits education could bring his way when tapped. Dr Samuel did not hesitate to define where he was headed for in that direction. In 2004, he gain admission to University of Maiduguri, Borno States as an intelligent

student, he graduated in 2008 with Master of Education in Curriculum and Instruction (M.ED).Diploma and Certificate in computer 2009. In the year between 2013 to 2016 he bagged Masters in Guidance and Counseling in Theological Seminary College Kaltungo in Gombe State. Moreover, the influence this celebrated academia exerted on him equipped him to master the techniques of research, the canons of interpretation and reconstruction of academic research, the craft and skills involved and teacher – students relationship in 2010 he proceeded to one of the best University in Nigeria University of Nigeria Nsukka in Enugu State and come out with Doctor of philosophy (Ph.D) in Curriculum and Instruction.

A man with a formidable profile charismatic personality, Dr Samuel is indeed an achieve per excellence he has not only carved a niche for himself, but has also made name and reputation in Nigeria. He has always impacted positively in the lives of everyone he meets. He has also shown high sense of professionalism and dedication to the service of humanity. On several occasion Samuel has interrupted his travels to attend to civilian, accident victims and he has truly saved a lot of lives.

Dr. Samuel Alfayo Boh started his civil service career as a classroom teacher; he had a little starting with the noble teaching profession. In 1996 he took appointment with Boh primary school, Labeke primary school in 1997, Kulishin primary school 1999, Pivotal Teachers Training Programme Lapan in 1999. In 2000 He moved to Government Day Secondary School Boh. In 2000 Tutor Senator T.U. Wada Educational Emancipation Scheme. Presently, lecturer with Federal University Kashere, in the Department of Educational Foundations

Dr. Samuel is a versatile personality of note and a man of many parts. He is fondly referred to as sport, Author and a born teacher of good repute. In his romance with great academics, he has received more than twenty awards, member of many associations, he has presented more than thirty academic papers in both international and national journals, he has published Ninety journals, sixteen book chapters, he has written eight books, presently chairman board of governors Jim Collis Kufai, fellow members of more than seven associations, former permanent commissioner sports commission Gombe State, chairman and secretary of many association, He is happily married to Mrs. Abigail Samuel and blessed with many children.

Having described himself as an enterprising person who has excellence attached to his name, Dr Samuel Alfayo Boh evinces a friendly disposition towards his students. He is a strong advocate of treating students with understanding and affection, Dr. Samuel incontestably mentors, counsels, reprimands, sympathizes and assists his young and old alike. Some of his students describe him as a luminous teacher whose passion for academic scholarship is infectious and whose pedagogical principle skills and friendly disposition are so admirable and endearing that attendance at his lectures is always high and far outstrips most others.

Ladies and gentlemen, Dr. Samuel Alfayo Boh is a small figure on the physical appearance. It is my great honour and privilege to call on this academic repute, erudite, scholar, indefatigable and inspirational mentor, community lover, and motivator ardent love of Shongomite culture and humanist to graciously joint the chairman and other for the formal presentation of this fabulous awards to acknowledge to celebrate his hard word, disciplines, kindness, humanness and commendable role he is playing in the academic careers and character-building

FOREWORD

It is with profound pride and optimism that I write this foreword to the maiden Book of Conference Proceedings of the Association of Science Educators Anambra State a timely and significant academic documentation that captures the robust engagements, research contributions, and transformative ideas presented at the 1st Annual Conference of the Association, scheduled for July 10, 2025, in Awka, Anambra State, Nigeria.

The conference, with the theme "Science Educators and Digital Literacy in the 21st Century," could not have come at a more opportune moment. In an age where digital transformation is rapidly redefining education, economy, and society, the role of science educators in equipping learners with not only scientific knowledge but also digital competencies has become more critical than ever. The conference offered a strategic platform for scholars, researchers, policy makers, and practitioners to interrogate, share, and shape new pedagogical paradigms that incorporate digital literacy into the fabric of science education.

In his address of welcome, the Acting President of ASEA, Dr. Johnbosco O.C. Okekeokosisi, delivered a compelling call to action. He set the tone by acknowledging the historical importance of the event and the noble mission of ASEA to champion science education across Anambra State and beyond. His words reflected a clear vision of collective progress, innovation, and institutional synergy. Most notably, Dr. Okekeokosisi emphasized that digital literacy in science education is not merely about embracing technological tools but about empowering both educators and learners to critically engage, create, and transform scientific knowledge for societal advancement.

This compilation of conference proceedings is more than a record of presentations—it is a testimony to the enduring commitment of Nigerian science educators to adapt to global educational trends. With insightful keynote and lead paper presentations by eminent scholars such as Prof. Cecilia O. Ekwueme and Prof. Telima Adolphus, participants were exposed to a breadth of ideas, models, and classroom innovations. These contributions are now immortalized in this volume, accessible to researchers, policymakers, and education stakeholders worldwide. The articles by contributors are of quality standard and intimately related to the conference theme.

The proceedings are also a celebration of collective effort. Dr. Okekeokosisi rightly acknowledged the contributions of past leaders of STAN, the Executive Principal of Igwebuike Grammar School, the Local Organizing Committee, and institutional partners who ensured the success of this pioneering event. Their efforts reflect a shared belief in the transformative power of science education when driven by vision, collaboration, and strategic digital integration.

This book also symbolizes the maturity and forward-thinking disposition of ASEA. With its proceedings published online in the Association's official website (www.jisepublications.org), ASEA is setting a benchmark for academic visibility, accessibility, and global relevance. The initiative aligns perfectly with the conference theme—leveraging digital platforms for knowledge dissemination.

As readers engage with the rich content within this publication, it is my hope that they find not only knowledge but also inspiration to further the cause of digital transformation in science education. May this volume serve as a resource, a reference, and a rallying point for continued innovation, research, and excellence in digital literacy, science teaching and learning.

Prof. Marcellinus C. Anaekwe
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National Open University of Nigeria,
Abuja.

PREFACE

Digital literacy in the 21st century is crucial for science educators to effectively teach and prepare students for a rapidly evolving scientific and technological world. Science educators must embrace digital tools and resources to enhance their teaching methods and foster students' scientific literacy, critical thinking and problem-solving skills. This includes leveraging online platforms, using educational technologies and digital content to create engaging and meaningful learning experiences.

In this conference proceedings efforts has been made towards promoting the use of digital tools in science education.

Prof. Josephine N. Okoli
Science Education Department
Nnamdi Azikiwe Universitry, Awka,
Anambra State, Nigeriascience

ADDRESS OF THE ACTING PRESIDENT OF ASSOCIATION OF SCIENCE EDUCATORS ANAMBRA (ASEA), DR. JOHNBOSCO O.C. OKEKEOKOSISI, AT THE OPENING CEREMONY OF THE 1ST ANNUAL CONFERENCE HELD IN AWKA, ANAMBRA STATE, NIGERIA ON 10TH JULY, 2025

Theme: "Science Educators and Digital Literacy in the 21st Century"

Distinguished Guests,
Mother of the Day, and Executive Provost of the Federal College of Education (Technical), Umunze, Prof. Tessy O. Okoli
Past and Immediate Past Chairmen of the Anambra State Chapter of the Science Teachers Association of Nigeria (STAN), Prof. C.V. Nnaka, Dr. Christiana U. Ezenduka Past and Immediate Past Secretary of the Anambra State Chapter of the Science Teachers Association of Nigeria (STAN), Dr. Chinwe B. Njelita, Mr. Kingsley N.C. Ezeokeke
The Executive Principal of Igwebuike Grammar School, Awka, Mrs. Amaka Ifebili
Our Esteemed Keynote and Lead Paper Presenters, Profs: Cecilia O. Ekwueme, Telima Adolphus
Meritorious Awardee, Dr. Samuel Alfayo Boh
Representatives of Educational Institutions, Pharm. Adauzoh C. Joe-Obasi
The Conference Planning Committee
The Local Organizing Committee (LOC),
My Fellow Science Educators,
Ladies and Gentlemen.

It is with deep humility and immense pleasure that I stand before you today as the Acting President of the Association of Science Educators Anambra (ASEA), to welcome you all to this historic gathering — the **1st Annual Conference** of our noble Association, taking place here in the vibrant capital city of Awka, Anambra State.

This moment marks a milestone in the life of our Association and in the educational landscape of our dear state. Today, we have gathered not just to deliberate on academic issues, but to collectively reflect on and shape the role of science educators in a rapidly changing digital world. The presence of each one of you here is a testament to your dedication to the advancement of science education in Nigeria, and in particular, in Anambra State.

Let me begin by extending heartfelt gratitude to our **Mother of the Day**, the erudite and distinguished **Executive Provost of the Federal College of Education (Technical), Umunze**, for honoring our invitation. Your presence is a great source of inspiration, and we are immensely grateful for your unwavering support towards science and technical education in the state. The Host and Board of Directors, Prof. Josephine N. Okoli, Prof. Isaac N. Nwankwo, Prof. M.C. Anaekwe

Chairman of the occasion Ass. Prof. Peter I.I. Ikokwu

To the **Past Chairman and Immediate Past Chairman of Anambra State STAN**, we salute you. You laid the foundation for excellence and integrity in science education upon which ASEA continues to build. We are proud to carry forward the torch of progress you lit. Your legacies continue to motivate and guide our mission as science educators.

We also sincerely appreciate the **Executive Principal of Igwebuike Grammar School, Awka**, for the enormous and selfless support towards the successful hosting of this conference. Your generosity and logistical assistance have played a crucial role in bringing this vision to reality. We are proud to host this conference within your institution, and we thank you for embracing the ASEA family.

Special thanks also go to our **Keynote and Lead Paper Presenters**, whose scholarship and insight will surely enrich our understanding of the conference theme: *"Science Educators and Digital Literacy in the 21st Century."* You are the thought leaders that will help us navigate this complex but exciting intersection between pedagogy and technology.

Meritorious Awardee, **Dr. Samuel Alfayo Boh**, whose contributions to teaching and learning in tertiary institutions lead to the foundation of our members.

The **representatives of educational institutions**, both public and private, we acknowledge your partnership and presence. Your contributions, ideas, and institutional support are essential in sustaining quality science education. Together, we can foster a generation of scientifically literate citizens equipped for the demands of the 21st century.

Let me also specially recognize the tireless efforts of the **Local Organizing Committee (LOC)**. You have worked round the clock, attending to logistics, communications, hospitality, and a host of behind-the-scenes responsibilities. This conference would not be possible without your selfless commitment. I say, "Well done!"

This conference has its theme **"Science Educators and Digital Literacy in the 21st Century".** The theme is very apt considering the fact that we are in the digital age. Thus, the committee on conference looked inward to provide this conference theme for science educators to understand, educate, re-educate, write and deliberate on the effective use of digital tools – technologies in our present time for effective instructional delivery. Participants will be taken through hands-on and minds-on activities in various sessions and they will find the conference package very rewarding. I invite you to pay attention during keynote address to be presented by Prof. Cecilia O. Ekwueme, the Dean Faculty of Science Education, University of Calabar, Cross-River State, Nigeria. Your continuous attention is also needed during the lead paper presentation of Prof. Telima Adolphus of Rivers State University, PortHarcourt, Nigeria.

To all **participants** – educators, researchers, students, policy makers – thank you for making out time to be here. Your presence signifies hope for the future of science education. I urge you to make the most of this gathering by networking, exchanging ideas, and exploring new strategies to embed digital literacy in science classrooms and curricula.

As we delve into this conference theme, let us remember that digital literacy is not just about the use of devices or softwares. It is about empowering both teachers and learners to navigate, create, and critically evaluate digital content. It is about transforming science education into an interactive, engaging, and accessible experience that prepares our students for global competitiveness. We must rise to this responsibility with courage, collaboration and innovation.

As we officially declare this conference open, let us do so with a shared sense of purpose and vision. Let us reflect deeply, discuss intelligently and leave this gathering better equipped to build a technologically savvy and scientifically vibrant society.

Ladies and Gentlemen, it may interest us to note that this young growing association has an online Journal, Electronic Book (e-book) and Conference Proceedings. The E-Book and Conference Proceedings were hosted online at the association's website (jisepublications.org) for its visibility. It is obvious that this association has come to stay. To God be the glory.

Once again, I welcome you all to the 1st Annual Conference of the Association of Science Educators Anambra (ASEA). May our deliberations be fruitful, and may the bonds we forge here today grow stronger for the benefit of science education in our state and beyond.

Thank you, and God bless you all.

Dr. Johnbosco O.C. Okekeokosisi
Federal College of Education (Tech) Asaba,
Delta State, Nigeria
Acting President, ASEA
10th July, 2025

PAPER 21

EMPOWERING CHEMISTRY EDUCATORS WITH DIGITAL LITERACY FOR 21ST CENTURY CLASSROOMS

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Abstract

The 21st century classroom is marked by rapid technological transformation, compelling educators to integrate digital literacy into their pedagogical practices to meet evolving learner needs. This paper explores how digital literacy empowers chemistry educators to create more engaging, effective, and student-centered learning environments. It examines the application of digital tools such as virtual laboratories, simulations, and collaborative platforms that make abstract chemistry concepts more tangible and accessible. The study also explores the role of ongoing professional development in equipping teachers with the necessary competencies to navigate digital platforms confidently. Particular attention is given to curriculum redesign, aligning instructional strategies with global educational trends and the digital realities of today's learners. Furthermore, the paper highlights the persistent challenges faced in low-resource educational settings, especially within developing countries like Nigeria, where infrastructure and digital access remain uneven. Through a review of policy documents, literature, and best practices, the paper advocates for a strategic and inclusive framework that ensures chemistry educators are digitally competent. This approach is essential not only for improving chemistry instruction but also for fostering the critical thinking, collaboration, and digital fluency skills necessary for success in the 21st-century knowledge economy. Ultimately, the study underscores the urgency of embedding digital literacy into chemistry education to bridge gaps in science learning and position students for future Science, Technology, Engineering, and Mathematics (STEM) opportunities.

Keywords: Empowering, Chemistry Educators, Digital Literacy,

Introduction

The 21st century has brought with it a significant transformation in educational paradigms, notably influenced by digital technologies. For chemistry educators, digital literacy is not only a skill but a necessity to remain relevant and effective in the modern classroom (Prensky, 2001). As science education evolves to include collaborative, inquiry-based, and technology-driven practices, the role of the chemistry educator must adapt accordingly. This paper aims to explore the empowerment of chemistry educators through digital literacy, assessing the opportunities, requirements, and implications for pedagogy. To effectively educate students in the 21st century, chemistry educators need to be digitally literate. This means they should be proficient in using various digital tools and resources to enhance teaching and learning in chemistry, including simulations, online platforms, and interactive software. Digital literacy also encompasses understanding how to evaluate online information, protect personal data, and engage with technology in a safe and responsible manner

Statement of the Problem

The 21st-century educational landscape demands a paradigm shift in instructional delivery, especially in science subjects like chemistry, where abstract concepts often challenge student comprehension. While digital literacy offers transformative opportunities to enhance teaching and learning, many chemistry educators, particularly in developing contexts like Nigeria, struggle to integrate digital tools effectively into their classroom practices. This gap is worsened by limited access to digital infrastructure, inadequate professional development, and rigid curricula that do not support the integration of modern instructional technologies.

Despite the global emphasis on digital fluency as a core competency for learners and educators alike, chemistry instruction in many low-resource settings remains largely traditional, teacher-centered, and disconnected from the digital realities of students. As a result, students are often deprived of the interactive, student-centered experiences that foster deeper understanding, critical thinking, and engagement in Science, Technology, Engineering, and Mathematics (STEM) disciplines.

There is an urgent need to examine how digital literacy can empower chemistry educators to transform their pedagogical approaches, adapt to curriculum reforms, and overcome contextual challenges. Without strategic intervention, the digital divide in education will continue to widen, leaving both educators and learners ill-equipped for the demands of the 21st-century knowledge economy.

Purpose of the Study

The purpose of this study is to review the role of digital literacy in enhancing the pedagogical practices of chemistry educators in the 21st-century classroom. Specifically, the study aims to;

1. explore how the integration of digital tools such as virtual laboratories, simulations, and collaborative platforms can transform chemistry instruction into more engaging, effective, and student-centered learning experiences.
2. investigate how ongoing professional development contributes to building educators' digital competencies, enabling them to navigate emerging technologies with confidence.
3. assess the extent to which curriculum redesign aligns with global educational trends and addresses the digital realities of today's learners.
4. highlight the systemic challenges that hinder the integration of digital literacy in low-resource settings, with a particular focus on developing countries like Nigeria.

Understanding Digital Literacy in Education

Digital literacy refers to the ability to use digital tools, resources, and platforms effectively and responsibly to access, analyze, create, and communicate information (Hague & Payton, 2010). In education, digital literacy encompasses a broad spectrum of skills that include information literacy, media literacy, Information and Communication Technology (ICT) competence, and the ethical and safe use of digital environments (Ng, 2012; Belshaw, 2011).

According to the International Society for Technology in Education (ISTE, 2016), digital literacy in the classroom extends beyond basic technical skills and includes the capacity to evaluate digital content, collaborate using digital platforms, and apply technology to solve real-world problems. For chemistry educators, digital literacy is crucial for integrating tools such as virtual laboratories,

simulations, multimedia presentations, and collaborative platforms that make abstract scientific concepts more tangible and engaging.

In the Nigerian context, the National Policy on Education underscores the role of ICT in transforming the educational landscape and enhancing teaching and learning outcomes (Federal Republic of Nigeria, 2014). However, gaps still exist in the digital competencies of many educators due to limited access to training, infrastructure, and support systems (Nwana, 2012; Olakulehin, 2007).

Furthermore, digital literacy enables chemistry educators to create student-centered learning environments that encourage inquest, experimentation, and critical thinking—hallmarks of effective science education (Lawless & Pellegrino, 2007). When properly harnessed, digital literacy supports differentiated instruction, real-time feedback, and inclusive learning experiences that accommodate diverse learner needs (Adebayo & Salawu, 2020).

Overall, building the digital literacy capacity of chemistry educators is foundational to improving science education outcomes and preparing learners for participation in the 21st-century knowledge economy.

Importance of Digital Literacy for Chemistry Educators

Enhanced Instructional Delivery: Digital tools such as simulations, virtual laboratories, and interactive periodic tables significantly enrich instructional content by offering dynamic representations of complex chemical phenomena. For example, computer-based molecular modeling tools enable students to visualize atomic interactions and chemical bonding in real time, which are typically abstract and difficult to comprehend through textbooks alone. Virtual laboratories provide opportunities for students to conduct experiments safely and repeatedly, even when physical resources such as reagents or equipment are limited. These tools enhance teacher demonstrations and reduce the cognitive load on learners by integrating visual, auditory, and kinesthetic elements into instruction. As Rutten, van Joolingen, and van der Veen (2012) noted, incorporating simulations in science education fosters deeper understanding and improves conceptual retention, especially in topics like chemical kinetics, thermodynamics, and reaction mechanisms.

Improved Student Engagement: Engagement is a critical factor in the success of any educational intervention, and digital technologies play a vital role in capturing and maintaining students' interest. Interactive tools such as smartboards, clicker systems, and digital quizzes offer immediate feedback and allow real-time participation, making classroom activities more lively and participatory. Platforms like Google Classroom, Moodle, and Edmodo enable educators to assign personalized tasks, monitor progress, and provide differentiated support based on learners' abilities and pace. This not only increases students' motivation but also nurtures autonomy and self-directed learning habits. According to Johnson et al. (2016), the integration of such technologies enhances collaborative learning and improves both academic performance and classroom behavior.

Fostering Inquiry and Critical Thinking: The incorporation of digital tools in science education promotes higher-order thinking skills such as analysis, synthesis, and evaluation. With access to data loggers, graphing software, and simulation programs, students can design experiments, test hypotheses, and analyze results in a scientific manner. These activities align well with the inquiry-based learning model, which encourages students to pose questions, investigate solutions, and

derive conclusions through critical reflection. For instance, using a virtual titration simulator, students can adjust variables like acid concentration or volume to observe the impact on neutralization curves—allowing for meaningful experimentation without the limitations of a physical laboratory. Savery (2006) emphasizes that problem-based and inquiry-driven learning strategies supported by technology enhance students' critical thinking and problem-solving capabilities, particularly in scientific disciplines like chemistry.

Digital Tools and Platforms for Chemistry Education

Several digital resources have become central to effective chemistry teaching;

- PhET Interactive Simulations – Enables visualization of molecular behavior.
- ChemCollective Virtual Labs – Facilitates hands-on virtual experiments.
- YouTube Channels and MOOCs (Massive Open Online Courses) – Offer supplementary instruction for complex topics.
- Data Analysis Software (e.g., Excel, Logger Pro) – Supports interpretation of experimental data.

These tools promote learner independence and provide immediate feedback, enhancing the learning experience.

Benefits of Digital Literacy for Chemistry Educators:

- **Enhanced Teaching and Learning:** Digital tools can make complex chemistry concepts more accessible and engaging for students through interactive simulations, animations, and virtual laboratories.
- **Improved Student Engagement:** Incorporating digital technologies can foster a more dynamic and interactive learning environment, potentially increasing student interest and motivation in chemistry.
- **Development of 21st Century Skills:** Digital literacy empowers students with skills like critical thinking, problem-solving, and collaboration, which are crucial for success in the modern world.
- **Preparation for Future Careers:** Familiarity with digital tools and technologies equips students with the skills needed for various careers in science, technology, engineering, and mathematics (STEM) fields.
- **Access to a Wider Range of Resources:** Digital platforms provide access to a vast array of learning materials, including online textbooks, research articles, and educational videos.

Challenges and Considerations

- **Teacher Training:** Providing adequate training and professional development opportunities for chemistry educators to integrate digital tools effectively is essential.
- **Infrastructure and Resources:** Ensuring that schools have the necessary technology infrastructure, including reliable internet access and appropriate hardware, is crucial.
- **Equity and Access:** Efforts should be made to ensure that all students, regardless of their background or location, have access to the digital resources and tools needed for effective learning.
- **Curriculum Integration:** Digital tools should be integrated thoughtfully into the chemistry curriculum, aligning with learning objectives and pedagogical goals.
- **Evaluation and Assessment:** Teachers need to be able to assess student learning effectively in digital environments, using appropriate assessment methods and tools.

Moving Forward in Digital Literacy for Chemistry Educators

- **Professional Development:** Training programs for chemistry educators should focus on enhancing their digital literacy skills, including the use of specific software, online platforms, and pedagogical strategies for online and blended learning.
- **Collaboration and Networking:** Encouraging collaboration among educators, researchers, and technology specialists can foster innovation and knowledge sharing in the field of digital chemistry education.
- **Curriculum Development:** Curriculum developers should consider how digital tools and resources can be integrated into the chemistry curriculum to enhance learning and engagement.
- **Research and Evaluation:** Further research is needed to investigate the effectiveness of digital tools and technologies in chemistry education and to identify best practices for their implementation.

By embracing digital literacy, chemistry educators can transform their classrooms into dynamic, engaging, and effective learning environments, preparing students for success in the 21st century and beyond.

Challenges to Digital Literacy Integration

1. **Limited Infrastructure:** One of the most significant barriers to digital literacy integration in education—especially in developing regions such as Sub-Saharan Africa—is the lack of foundational infrastructure. Many schools struggle with unreliable or nonexistent internet connectivity, outdated computers, insufficient digital devices, and frequent power outages. These infrastructural deficits create a digital divide between urban and rural learners and inhibit consistent use of educational technology tools in the classroom. Even when devices are available, the absence of maintenance support or technical personnel results in underutilization. According to UNESCO (2020), equitable access to ICT in education remains a major concern globally, with nearly half of all students lacking access to digital learning during school closures related to the COVID-19 pandemic.
2. **Lack of Professional Development:** While access to technology is crucial, the effectiveness of digital integration largely depends on the teachers' ability to use these tools pedagogically or instructionally. Many educators are not provided with sufficient training in digital pedagogy, which includes not only how to operate devices but also how to integrate them meaningfully into lesson plans. Without targeted professional development programs, teachers may feel overwhelmed or resistant to adopting technology, resulting in minimal impact on student learning. Koehler and Mishra (2009) argue that understanding the intersection of content knowledge, pedagogy, and technology—through the TPACK framework—is vital for successful technology integration. In contexts like Nigeria, teacher training institutions often lack structured ICT modules, leaving new teachers underprepared for 21st-century classrooms. The TPACK framework, which stands for Technological Pedagogical Content Knowledge, is a theoretical model that outlines the knowledge teachers need to effectively integrate technology into their teaching. It emphasizes the intersections and interactions between three core knowledge domains: Content Knowledge (CK), Pedagogical Knowledge (PK), and Technological Knowledge (TK). The framework, developed by Mishra and Koehler, suggests that successful technology integration requires teachers to understand not only their subject matter, but also how to teach it effectively and how to utilize technology to enhance learning.

3. **Curriculum Inflexibility:** Another constraint lies in rigid, examination-oriented curricula that prioritize memorization over exploration, creativity, or critical thinking. Such curricula leave little room for the flexible, student-centered approaches that digital tools often support. As a result, even when teachers are willing and able to use technology, the structure and pressure of completing the syllabus can limit their ability to integrate innovative digital strategies. In chemistry education, for example, traditional assessments may not evaluate digital competencies or inquiry-based skills, discouraging educators from incorporating simulations, virtual experiments, or collaborative tools. For digital literacy to flourish, there must be curricular reforms that align with modern teaching methodologies and allow for adaptive, technology-enhanced learning models (Olakulehin, 2007).

Strategies for Empowering Chemistry Educators

1. **Ongoing Professional Development:** Workshops, online courses, and collaborative learning communities should be established to keep educators abreast of technological trends (Lawless & Pellegrino, 2007).
2. **Policy Support and Funding:** Governments and institutions must prioritize ICT integration by providing adequate infrastructure and funding for educational technology.
3. **Curriculum Redesign:** Incorporating digital skills within the chemistry curriculum ensures students and teachers alike develop competencies relevant to modern scientific practices.
4. **Mentorship and Peer Learning:** Experienced digital educators can mentor less experienced colleagues, fostering a culture of digital competence within schools.

Case Studies and Success Stories

In Nigeria, platforms like uLesson and EduTech are revolutionizing science education through app-based learning and virtual classes. Similarly, the Royal Society of Chemistry (UK) offers extensive online teacher resources and training. These examples illustrate how digital literacy initiatives can be successfully implemented.

Conclusion

Empowering chemistry educators with digital literacy is pivotal for achieving quality education in the 21st century. It requires a multidimensional approach involving professional development, infrastructure support, policy alignment, and innovative curriculum design. Digital literacy not only enhances the teaching of chemistry but also prepares learners for a technologically driven world. The transition may be challenging, but the long-term educational and societal benefits are substantial.

Recommendations

Based on the discoveries and discussions presented in this study, the following recommendations are proposed to effectively empower chemistry educators with digital literacy for 21st-century teaching and learning:

1. *Invest in Continuous Professional Development (CPD) for Educators:* Targeted and sustained professional development programs should be instituted at national, regional, and institutional levels to build educators' digital pedagogical competencies. Training should move beyond basic ICT skills to include instructional design, the effective integration of digital tools into chemistry curricula, and the use of virtual laboratories and simulations. Professional

development must also incorporate frameworks such as TPACK to help educators align content, pedagogy, and technology meaningfully

2. *Improve Technological Infrastructure in Schools:* Governments and educational stakeholders must prioritize the provision of adequate and reliable infrastructure such as internet connectivity, electricity, digital devices, and modern laboratory equipment in all learning environments, especially in rural and underserved areas. This should be accompanied by maintenance systems and technical support personnel to ensure sustainability.
3. *Integrate Digital Literacy into Teacher Education Curricula:* Pre-service teacher training institutions should embed digital literacy modules into their core curricula. These modules must include practical, hands-on exposure to digital tools used in science education, online collaboration platforms, safe internet practices, and methods for fostering inquiry-based learning through technology.
4. *Redesign the Chemistry Curriculum to Foster Digital Integration:* National curriculum developers should revise and update existing chemistry curricula to allow for flexible, technology-enhanced instructional models. Assessment strategies must also evolve to evaluate students' digital competencies, problem-solving skills, and collaborative abilities, in line with global STEM education trends.
5. *Promote Inclusive Access to Digital Resources:* Efforts should be made to bridge the digital divide by ensuring equitable access to digital tools and learning resources for all students, regardless of geographic or socioeconomic background. Open educational resources (OERs), mobile learning platforms, and low-bandwidth applications should be utilized to reach learners in low-resource settings.
6. *Foster Collaborative Learning Communities and Mentorship Networks:* Chemistry educators should be encouraged to participate in professional learning communities both physical and virtual—where they can share experiences, co-create resources, and learn from one another. Mentorship systems should be established to connect digitally proficient educators with their less experienced peers.
7. *Secure Policy and Institutional Support for Digital Integration:* Ministries of education, school administrators, and policymakers must enact supportive ICT-in-education policies and allocate dedicated funding for digital innovation in teaching. Institutional leadership should prioritize the digital transformation of their schools by incentivizing innovation and recognizing digital teaching excellence.
8. *Support Research and Innovation in Digital Chemistry Education:* Further study should be conducted to evaluate the impact of specific digital tools and teaching strategies on student learning outcomes in chemistry. Such research will inform evidence-based policy decisions and help identify best practices for scalable implementation across diverse educational contexts.
9. *Leverage Public-Private Partnerships (PPPs) for Educational Technology:* Strategic partnerships with edutech companies, telecommunications providers, and non-governmental organizations can help fund, develop, and distribute digital learning platforms tailored to the needs of chemistry educators and students in developing regions.
10. *Encourage the Use of Locally Relevant and Culturally Adaptive Digital Content:* Digital resources should reflect local contexts, languages, and examples relevant to learners' environments. Localization of content ensures greater relatability and enhances student engagement, while still meeting global educational standards.

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