SCIENCE EDUCATORS AND DIGITAL LITERACY IN THE 21ST CENTURY

Editor in Chief
Prof. Josephine N. Okoli

ASSOCIATION OF SCIENCE EDUCATORS ANAMBRA (ASEA)

https://jisepublications.org

INNOVATIONS, DIGITAL TRANSFORMATION AND SUSTAINABLE SCIENCE EDUCATION IN THE 21ST CENTURY

2nd Annual CONFERENCE PROCEEDINGS 2026

Editor in Chief
Prof. Josephine N. Okoli

ASSOCIATION OF SCIENCE EDUCATORS ANAMBRA (ASEA)

THEME:

INNOVATIONS, DIGITAL TRANSFORMATION AND SUSTAINABLE SCIENCE EDUCATION IN THE 21ST CENTURY.

2ND ANNUAL CONFERENCE PROCEEDINGS HELD ON 9th APRIL, 2026 AT ARCHBISHOP ALEXANDER IBEZIM COLLEGE OF EDUCATION NIBO-NISE, ANAMBRA STATE, NIGERIA.

Editor

Prof. Josephine, N. Okoli

Printed in Nigeria by:

Love Isaac Consultancy Services
No 1 Etolue Street, Ifite Awka, Anambra State, Nigeria
+234-803-549-6787, +234-803-757-7391

Published in April, 2026
ISBN: 978-978-68-3066-7

TABLE OF CONTENT

MEMBERS OF CONFERENCE PLANNING COMMITTEE

Dr. Moses, John Billy (Chairman) Science Education Department
Faculty of Education, Niger Delta University
Wilberforce Island, Bayelsa State.

Ahueansebhor Emmanuel Human kinetics and Sports Science Department
Faculty of Science Education,
University of Calabar,
Calabar - Nigeria.

Akanazu, Eze C. Department of Chemistry
Alvan Ikoku Federal University of Education, Owerri,
Imo State, Nigeria

Dr. Ofordum Maryann C. Physical and Health Education Department
Federal College of Education (Tech) Umunze,
Anambra State, Nigeria

Dr. Esther B. Enaregha (Sec.) Isaac Jasper Boro College of Education Sagbama
Bayelsa State, Nigeria

Dr. Njoku Celestine Department of Mathematics and Computer Science Education, University of Calabar Cross River State, Nigeria

LOCAL ORGANIZING COMMITTEE

Mrs. Amaka Grace (Chairman) Physical and Health Education Department
Federal College of Education (Tech) Umunze,
Anambra State, Nigeria

Ogbonna Marachi Samuel (Sec.) Physical and Health Education Department
Federal College of Education (Tech) Umunze,
Anambra State, Nigeria

Usan Peter Chemistry Department
Federal Technical College, Awka,
Anambra State, Nigeria

PROGRAMME OF EVENTS

- Opening Praying
- Chairman's Opening Remark
- Breaking of Kola nut
- Welcome Address by the Provost of the College
- Welcome Address by the acting President of the Association
- Keynote Presentation by Dr.Peter I.I. Ikokwu
- Lead Paper Presentation by Dr. Emmanuel O. Okonta
- About the Electronic Book / Unveiling of Book Chapter – E-Book launch
- Item 7
- Meritorious Award
- Paper Presentations

CHAIRMAN'S ADDRESS VENERABLE NNAMDI B. EMENDU PhD. PRESENTED DURING THE SECOND CONFERENCE OF THE ASSOCIATION OF SCIENCE EDUCATORS, ANAMBRA (ASEA) HELD AT ARCHBISHOP ALEXANDER CHIBUZO IBEZIM COLLEGE OF EDUCATION, NIBO-NISE, ANAMBRA STATE ON 9TH APRIL 2026

THEME: Innovation, Digital Transformation, and Sustainable Science Education in the 21stCentury

Distinguished Professors, Esteemed Researchers, Academic Leaders, Policy Partners, Ladies and Gentlemen,

Introduction

It is my distinct honour and privilege to welcome you to the Second Conference of the Association of Science Educators. I extend warm greetings to our keynote speakers, paper presenters, research scholars, institutional representatives, and valued partners whose presence underscores the importance of this gathering.

Our theme — "Innovation, Digital Transformation, and Sustainable Science Education in the 21st Century" — speaks directly to the evolving mandate of higher education institutions and research communities in shaping scientific literacy, discovery, and societal progress.

The Imperative for Academic Innovation

Higher institutions have historically been the custodians of knowledge creation and dissemination. However, in the contemporary era marked by rapid technological advancement and global interconnectivity, the academy must transcend traditional pedagogical models. Innovation in schools is essential because it prepares students for the future, enhances learning experience, encourages creativity and curiosity, improve teaching methods, promoting problem solving skills, increases students engagement, supports inclusive education and keeps education relevant.

Innovation in science education within academia must be:

1. **Research-driven** – informed by evidence-based pedagogical studies and discipline-based education research.
2. **Interdisciplinary** – integrating science with technology, engineering, social sciences, and humanities to address complex global challenges.
3. **Problem-oriented –** focusing on real-world applications, design thinking, and translational research.

Generally, our curricula must reflect not only foundational theories but also emerging scientific frontiers. We must continuously revise course content to incorporate developments in data science, artificial intelligence, climate science, biotechnology, and other rapidly evolving fields.

Furthermore, innovation in academia demands that we reconsider assessment models. Are our evaluation frameworks measuring deep conceptual understanding, research competence, and critical thinking — or merely factual recall? The 21st century requires scholars who can analyze, synthesize, and innovate.

Digital Transformation in Higher Education

Digital transformation is important for schools bcause it improves how students learn, and how institutions operate. According to Hurb (2020), digital tools improve schools efficacy and enable better decision making through data. It enhances teaching and learning. Study by QECD (2019). shows that technology supports better learning outcome when combined with effective teaching practice. Likewise digital transformation helps to expand access to education. The world bank

(2020). highlight that digital learning helps researcher understands population and ensures during.

Sustainable Science Education: Institutional Responsibility

Sustainability within science education must be understood in both environmental and systemic terms. As academic institutions, we bear responsibility for cultivating graduates who are equipped to confront global challenges such as climate change, biodiversity loss, food security, renewable energy transitions, and public health crises. Science education must therefore embed sustainability principles across curricula rather than isolating them within specialized courses.

Moreover, sustainable science education requires:

1. Strengthened research infrastructure.
2. Long-term funding commitments for scientific inquiry.
3. Mentorship pipelines for early-career researchers.
4. Gender and diversity inclusion in STEM disciplines.
5. Institutional policies that promote environmentally responsible campus practices.

Sustainability also means ensuring that our educational systems remain adaptable, resilient, and responsive to societal needs. Higher institutions must remain spaces where rigorous inquiry, ethical reflection, and innovation coexist harmoniously.

The Role of Academic Leadership in Innovation, Digital Transformation, and Sustainable Science Education

As researchers, and academic leaders, our influence extends beyond lecture halls and laboratories. We must Champion inquiry-based learning and undergraduate research opportunities. We need to foster industry-academia partnerships to enhance experiential learning. We need to advocate for policy reforms that strengthen STEM education nationally and globally. Also, we need to mentor the next generation of scientists with integrity and intellectual humility.

Our scholarly work must bridge theory and practice. Publications, policy briefs, and community outreach must reflect the societal relevance of our research endeavors.

Academic leadership must also prioritize education development programs that enable educators to integrate digital tools, innovative pedagogies, and sustainability frameworks effectively.

Conference Expectations and Scholarly Engagement

This conference provides a vital platform for intellectual exchange. Over the coming sessions, we will engage with research findings, pedagogical innovations, technological applications, and policy perspectives that shape the future of science education.

I encourage participants to:

Share empirical evidence and best practices.

Engage in constructive critique and interdisciplinary dialogue.

Form collaborative research networks that extend beyond this conference.

Let this gathering generate not only discussions, but actionable frameworks and research agendas that inform institutional strategies.

Conclusion

In closing, innovation, digital transformation, and sustainability are not isolated ambitions. They are interconnected imperatives that define the mission of modern academia.

If we are to remain relevant as institutions of higher learning, we must embrace transformation while preserving the core values of scholarship: rigor, integrity, curiosity, and service to humanity. Let us commit to advancing science education that is intellectually robust, technologically empowered, and socially responsible.

I thank you all for your dedication to this cause and wish us a conference marked by insightful deliberations, meaningful collaborations, and lasting impact.
Thank you.

References

Bill & Melinda Gates Foundation. (2015). Early progress: Interim research on personalized learning.

EdTech Hub. (2020). EdTech evidence review.

OECD. (2019). OECD future of education and skills 2030. Organisation for Economic Co-operation and Development.

UNESCO. (2020). Education in a post-COVID world: Nine ideas for public action. United Nations Educational, Scientific and Cultural Organization.

World Bank. (2020). Remote learning and COVID-19: The use of educational technologies. World Bank Group.

World Economic Forum. (2020). The future of jobs report 2020.

A WELCOME ADDRESS PRESENTED TO THE ASSOCIATION OF SCIENCE EDUCATORS ANAMBRA STATE AT ITS SECOND CONFERENCE ON THE THEME: INNOVATIONS, DIGITAL TRANSFORMATION AND SUSTAINABLE SCIENCE EDUCATION IN THE 21ST CENTURY.

REVD CANON DR H. O. N. BOSAH

AG. PROVOST, ARCHBISHOP ALEXANDER IBEZIM COLLEGE OF EDUCATION NIBO-NISE

On behalf of the Proprietor of this citadel of learning, His Grace, The Most Revd Alexander Chibuzo Ibezim, Arcbishop Ecclesiastical Province of the Niger and Bishop, Diocese of Awka, the College Governing Council, College Management and the entire College Community, I cordially welcome the Association of Science Educators, Anambra State and its cream of attracted conferees to Archbishop Alexander Ibezim College of Education, Nibo-Nise: A Centre Par Excellence in Teacher Education.

Conscious of the fact that that we are here for an intentional academic conference - a gathering where scholars and experts have deliberately gathered to foster meaningful discussions, collaborations, and knowledge sharing around a specified theme, quite different from mere traditional conference; engagement, interaction, and outcomes are set to be prioritized over mere presentation of papers. We are therefore here for a curated dialogue, rather than mere series of lecture presentations.

Lead discussions on innovations, digital transformation and sustainable science education in the 21st century shall consequently be interrogated as a theme, across academic seniority levels, diverse experiences, and intellectual interests among the conferees. Focus on how learning, networking, exploring and how digital transformation will impact research areas will be anticipated. Sharing experiences, application discussions, inter disciplinary interactions and collaborative explorations will not be left out .

Research papers will therefore be anticipated from diverse areas of interests, such as data-driven research; digital tools & methods with modeling, computational techniques; collaboration & data sharing enhanced through digital platforms; open science initiatives and impacts on disciplines, simulation and predictive modeling.

Finally, sharing insights, and shaping future development directions would apparently constitute a path finder to the Conference colluding remarks. Panel discussants will constitute the much needed brainstorming in this conference.

We earnestly pray that the conference turns out a huge success, with a scholarly proceeding and publication that will positively project the association in the community of sound academics. This second conference shall not be the last but an improvement on previous ones with sustainable qualitative development in the future.

Revd Canon Dr H. O. N. Bosah

Ag. Provost, Archbishop Alexander Ibezim College of Education Nibo-Nise.

MERITORIOUS AWARD
CITATION OF DR. SULEIMAN DAMBAI MOHAMMED

Dr. Suleiman Dambai Muhammed was born to the family of Mallam Mohammed Ozaki Toto in Toto Local Government Area of Nasarawa State on 2nd June 1961. He attended Government Teachers' College Wukari from 1975-1980. He proceeded to the prestigious Ahmadu Bello University Zaria, first to Institute of Education from 1985-1989 and then Faculty of Education from 1990-1995 where he obtained his NCE and B.Sc Ed. (integrated Science)

After his First Degree, Dr. Suleiman proceeded to University of Jos Plateau State, where he obtained M.Sc (Ed) Biology in 2003. He later enrolled and obtained his Ph.D in Science Education in University of Abuja (Nigeria) in 2016.

Dr. Suleiman started his work Career as a Lecturer III in Nasarawa State College of Education Akwanga from 1998-2002. He later transferred his services to FCT College of Education, Zuba-Abuja as Lecturer II in 2002 and rose through the ranks to the Chief Lecturer in 2017. In 2020 he transferred his services to Federal University of Lafia Nasarawa State as Senior Lecturer. In 2023; he was promoted to the rank of Associate Professor by the University.

During his career, he had served as Head of Department, Member Junior Staff, Appointment Promotion and Disciplinary Committee, Etc in both Colleges (College of Education Akwanga and Zuba).

In recognition of his astute leadership qualities and administrative acumen, he was appointed as Acting Head of Department, Science Education in 2022 by the Vice Chancellor, Professor Shehu AbdulRahman, The position he is still holding till date. He is a Member of the Senate of the University of Lafia.

Dr. Suleiman has some honors and distinctions to his name. Some of them are; The Best Lecturer, the Best Teaching Practice Coordinator and the Best Head of Department of FCT College of Education Zuba 2007, 2009 and 2012 respectively.

Dr. Suleiman has over forty (40) publications in reputable Journals both nationally and internationally, numerous papers presented at National and International Conferences, contributions to chapter in Textbooks and a number of Textbooks

He is a member of the following organizations: International Research and Development Institute (Research and Development Network) from 2012 to date; Academic Staff Union of Universities (ASUU); Teachers' Registration Council of Nigeria (TRCN) etc.

Amongst countries he has visited are Singapore, Saudi Arabia, and Dubai. He is married with Children.

He is now an Associate Professor with the Federal University of Lafia, Nasarawa State.

FOREWORD

It is with great pleasure that I present this conference proceedings, which brings together a rich collection of scholarly works centred on digital literacy and its transformative role in contemporary education. The articles featured in this volume, collectively reflect the growing recognition that digital competence is no longer optional but essential for effective teaching, learning, and sustainable development in the 21st century.

A dominant theme across the contributions is the critical role of digital literacy in enhancing students' academic achievement, particularly in core subject areas such as Mathematics, Chemistry, Biology, and Basic Science. Several studies in this volume establish digital literacy competence as a strong predictor of learners' performance, while also demonstrating how innovative instructional strategies such as science video instruction and virtual learning environments can significantly improve learning outcomes.

The proceedings also highlight the importance of equipping educators with the necessary digital skills. Papers examining teachers' digital competence, awareness, and utilization of educational technologies reveal both progress and gaps, underscoring the urgent need for continuous professional development. Contributions focusing on tools such as Google Classroom and Google Scholar further illustrate how accessible technologies can enrich teaching practices and expand learning opportunities when effectively deployed.

Another notable strand of research in this collection explores personalized and technology-driven learning approaches. Studies on online platforms, personalized learning environments, and digital assessment practices demonstrate how technology can support learner-centred education and foster improved engagement and achievement. These insights are particularly relevant in advancing flexible and inclusive education systems.

Beyond classroom practice, the proceedings also address broader systemic and societal dimensions. Papers examining the sustainability of academic programmes within current economic realities, as well as the role of digital education in promoting national development, provide valuable perspectives for policymakers and educational leaders. Additionally, interdisciplinary contributions such as those linking digital literacy with physical and health education and environmental monitoring systems underscore the expanding scope of digital competence across diverse fields.

Collectively, the papers in this volume make a significant contribution to knowledge by providing empirical evidence, practical insights, and innovative approaches to integrating digital literacy into education. They not only deepen our understanding of current challenges but also offer actionable pathways for improving teaching and learning in Nigeria and beyond.

It is my hope that this compilation will serve as a valuable resource for researchers, educators, policymakers, and all stakeholders committed to advancing education through technology. May it inspire further inquiry, collaboration, and innovation in the pursuit of quality and sustainable education.

Telima Adolphus, *FHEA.*
Professor of Science Education,
Rivers State University.

PREFACE

This years' conference on innovations, digital transformation and sustainable science education in the 21st century is meant to educate and re-educate science educators effectively. It exposed educators towards evolving scientific and technological world. Science educators must embrace digital tools and resources to enhance their teaching methods, re-structure learners' mindset, 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 University, Awka,
Anambra State, Nigeria.

ADDRESS OF THE ACTING PRESIDENT OF ASSOCIATION OF SCIENCE EDUCATORS ANAMBRA (ASEA), DR. JOHNBOSCO ONYEKACHUKWU OKEKEOKOSISI; AT THE OPENING CEREMONY OF THE 2ND ANNUAL CONFERENCE HELD AT ARCHBISHOP ALEXANDER IBEZIM COLLEGE OF EDUCATION NIBO-NISE, ANAMBRA STATE, NIGERIA ON 9TH APRIL, 2026.

The chairman of the occasion, Dr.Ven. Nnamdi Emendu,
Mother of the Day, Dean School of Science Education, Federal College of Education (Technical) Umunze, Dr. Stella O. Okoli.
Special Guest of Honor, Deputy Mayor Anambra East, Hon. Lady Dr. Martina Nwawube
The Executive Provost of ArchBishop Alexander Ibezim College of Education, Nibo- Nise, Revd. Canon Dr. H.O.N. Bosah
Our Esteemed Keynote and lead Paper Presenters, Drs: Peter I.I. Ikokwu, Emmanuel O. Okonta
Meritorious Awardee: Suleiman Dambai Mohammed
The Local Organizing Committee (LOC)
My Fellow Science Educators,
Distinguished Guests,
Ladies and Gentlemen

I am highly delighted to extend awarm royal welcome to you all at the opening ceremony of the 2nd Annual Conference of Science Educators Anambra (ASEA) on the **Theme: Innovations, Digital Transformation and Sustainable Science Education in the 21St Century.**

I welcome most heartily the Executive Provost of ArchBishop Alexander Ibezim College of Education, Nibo- Nise, Revd. Canon Dr. H.O.N. Bosah, the chairman of the occasion Dr.Ven. Nnamdi Emendu, Special Guest of Honour, Deputy Mayor Anambra East, Hon. Lady Dr. Martina Nwawube, our erudite mother of the day Dr. Stella O. Okoli, Dean School of Science Education, Federal College of Education (Technical) Umunze for honoring our invitation. Your presence is a great source of inspiration and we are grateful for your unwavering support towards science education in the state.

To our Host, Board of Directors Prof. Josephine N. Okoli, Prof. Isaac N. Nwankwo and Prof. M.C. Anaekwe, Local Organizing Committee (LOC),I say thank you for you have worked round the clock towards the success of this years' conference.

Special thanks also go to our Meritorious Awardee, Dr. Suleiman Dambai Mohammed whose contributions to teaching and learning in tertiary institutions lead to the foundation of our members.

We have gathered not just to deliberate on academic issues but to collectively reflect and shape our minds on possible ways to educate learners and re-educate ourselves on **"innovations, digital transformation and sustainable science education in the 21st century".** The stated conference theme is very apt considering the fact that we are in the digital age and are advocating for possible ways to educate learners for fast, easy understanding and recall.

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 Dr. Peter I.I. Ikokwu, Nwafor Orizu College of Education, Nsugbe, Anambra State, Nigeria. Your continuous attention is also needed during the lead paper presentation of Dr. Emmanuel O. Okonta, Dean Students Affairs, Federal College of Education (Technical) Asaba Delta State, 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 innovative and digital practices in science classroom and curricula.

As we officially declare this conference open, let us do so with a shared sense of purpose and vision. Let us reflect, discuss intelligently and leave this gathering better equipped. May our deliberations be fruitful and beneficial to all .

Thank you and God bless you all.

Dr. JohnBosco O.C. Okekeokosisi

Ag. President ASEA

9th April, 2026

A KEY NOTE ADDRESS PRESENTED AT 2ND CONFERENCE OF THE ASSOCIATION OF SCIENCE EDUCATORS ANAMBRA ON APRIL 09, 2026

THEME: INNOVATION, DIGITAL TRANSFORMATION AND SUSTAINABLE SCIENCE EDUCATION IN THE 21ST CENTURY.

Harnessing Innovation and Digital Transformation for Sustainable Science Education in the 21st century

I am honored and indeed humbled to speak at this esteemed conference of the Association of Science Educators Anambra . As we gather here today, we recognize the pivotal role science education plays in shaping the future of our nation. The theme of this conference, "Innovation, Digital Transformation and Sustainable Science Education in the 21st century" is particularly apt, as it highlights the need for a paradigm shift in our approach to science education. I also see it as a veritable follow up on the theme of our maiden conference, "Science Education and Digital Literacy in the 21st Century", which provided the tools for the implementation of the obvious demands of this conference. I commend the organizers proper articulation

The Challenge Before Us

Nigeria's science education sector faces numerous challenges, including inadequate infrastructure, outdated curricula, and a shortage of skilled teachers. These challenges hinder our ability to produce globally competitive scientists and innovators. According to UNESCO(2022), Nigeria has one of the lowest science literacy rates in the world, with only 22% of students achieving a minimum level of proficiency in science. This is unacceptable, given the critical role science plays in driving economic growth and development. To give a broader look at the theme, the key factors in the were briefly discussed.

Innovation in Science Education

Innovation is key to driving sustainable science education. We must:

1. ***Foster inquiry-based learning***: Encourage curiosity, creativity, and problem-solving skills. This involves shifting from a teacher-centered to a student-centered approach, where students are encouraged to explore, investigate, and discover concepts on their own.
2. ***Industry-academia collaboration:*** Foster partnerships to develop relevant curricula and provide real-world experiences. This includes collaborations with industries to provide internships, mentorship, and research opportunities for students.
3. ***STEM education:*** Emphasize science, technology, engineering, and mathematics to equip students with skills for the future. This includes promoting interdisciplinary approaches to learning, where students work on real-world problems that require integration of multiple subjects.

Digital transformation

Digital transformation is the strategic integration of digital technologies into all areas of an organization to improve operations, enhance customer experience, a nd sustain competitive advantage.

Definition and Purpose

Digital transformation involves **rewiring an organization** to continuously deplo y technology at scale, enabling improved efficiency, innovation, and value creati on. It is not a onetime project but an ongoing journey that reshapes how businesses operate, inter act with customers, and

deliver products or services. The ultimate goal is to **me et evolving customer expectations** edge in a rapidly changing digital landscape.

Key Components

1. **Strategy and Roadmap**: A clear digital transformation strategy focuses o n specific domains such as customer journeys, processes, or functions that generate significant business value. A detailed roadmap guides the imple mentation of solutions and allocation of resources.
2. **Technology Integration**: Organizations adopt technologies like **cloud co mputing, big data analytics, AI, mobile applications, and social media platforms** to modernize operations and create new revenue streams.
3. **Talent and Culture**: Successful transformation requires a strong inhouse digital talent pool, agile HR processes, and a culture that encourage s innovation and collaboration.
4. **Operating Model**: Scalable operating models, such as digital factories, pr oduct and platform models, or enterprisewide agility frameworks, support cross-functional teams and largescale digital initiatives.
5. **Change Management**: Digital transformation is as much about **organizational change** as technology adoption. Leadership alignment, employee engagement, and continuous monitoring of key performance indicators (KPI s) are essential.

Benefits

- **Enhanced Customer Experience**: Personalized, seamless interactions across channels.
- **Operational Efficiency**: Streamlined processes and reduced costs.
- **Innovation and Growth**: Ability to create new products, services, and business models.
- **Resilience and Agility**: Faster adaptation to market changes and emerging technologies.

Sustainable Science Education

Sustainable science education is a critical component of the 2030 Agenda for Sustainable Development, aiming to equip learners with the knowledge, values and s kills necessary to address complex environmental and social challenges. Taylor in Emendu(2018) presented sustainable development as development that continues to meet today's needs in ways that will not jeopardize future generations. UNESCO(2023) observed that sustainable science education requires a multifaceted approach:

1. Curriculum reform: Develop curricula that address local challenges and global trends. This includes incorporating emerging fields like artificial intelligence, biotechnology, and renewable energy into the curriculum.

2. Teacher training: Provide continuous professional development for educators. This includes training on digital literacy, pedagogical in integrates learning, skills, and knowledge to achieve global goals and promote sustainable development.

3. Development: Invest in modern laboratories and equipment. This includes leveraging public-private partnerships to upgrade infrastructure and provide access to cutting-edge technology. The 2030 agendaintegrates learning, skills, and knowledge to achieve global goals and pro mote sustainable development

UNESCO's ESD for 2030: This program produces and shares knowledge, offers policy guidance, and implements projects on the ground to strength en countries' capacity to provide quality climate change education and 'green' every aspect of learning.

- **Science Education in Nigeria:** Functional science education is urgently required to promote scientific knowledge for sustainable development, with a focus on practical skills for individual and national development.
- **Science on Stage Germany:** This project offers STEM teachers wide range of hands-on teaching materials to develop 21st century skills and promote skills and knowledge in the classroom.

These initiatives reflect a global commitment to integrating sustainability into science education, ensuring that students are equipped to make informed decision s that benefit both the environment and society.

Innovation, Digital Transformation and Sustainable Science Education in the 21st Century

The 21st century is characterized by rapid technological advancements and evolving societal needs, prompting a significant transformation in education systems globally. This includes the integration of technology, the development of essential 21st century skills, and the prioritization of student centered learning. These shifts enhance student engagement and performance while contributing to more inclusive and equitable learning environments. Innovative practices and adaptive strategies are essential for addressing these challenges. They promote creativity, critical thinking, collaboration, and resilience, which are vital for preparing learners to navigate the complexities of a rapidly changing world.

The integration of digital technologies in education is a powerful tool for advancing Sustainable Development Goals (SDGs) and fostering behavioral shifts toward sustainability. Digital education offers opportunities to integrate SDGs across
all levels and forms of education, responding to evolving needs and challenges. UNESCO supports the use of digital innovation to expand access to educational opportunities, advance inclusion, and enhance the relevance and quality of learning. It promotes digital inclusion and guides international efforts to accelerate pr ogress toward education goals.

By embracing these changes, education systems can better equip students for success in a complex, interconnected global landscape. Recent innovations in science education are transforming teaching and learning through technology integration, personalized learning, and immersive experiences**.**

Key Innovations in Science

Technology Integration: The use of **virtual reality (VR)** and **augmented reality (AR)** is becoming increasingly prevalent in science classrooms. These technologies allow students to engage in immersive learning experiences, such as exploring the human body or conducting virtual experiments, which enhance understanding of complex scientific concepts.

Artificial Intelligence (AI): AI driven personalized learning systems are being implemented to tailor educational experiences to individual student needs. These systems can adapt the difficulty of materials based on performance, provide real time feedback, and automate grading, making learning more efficient and effective.

Interactive Simulations: Interactive simulations are being used to create engaging learning environments where students can experiment and visualize scientific phenomena. This handson approach helps students grasp difficult concepts an d fosters critical thinking skills.

Interdisciplinary Approaches: There is a growing recognition of the importance e of integrating science education with other disciplines, such as technology, engineering, and mathematics (STEM). This interdisciplinary approach prepares students for real world challenges and promotes a more holistic understanding of scientific principles.

Focus on Equity and Inclusion: Innovations in science education are also addressing issues of equity and inclusion. Programs are being developed to recruit an d retain diverse educators and to create inclusive learning environments that support all students, particularly those from underrepresented backgrounds.

Science Education Innovations - Full Analysis (Updated 2024)

1. **Babbel - Innovative Language Learning for Science Education**
2. **PIMSLEUR** - Innovative Language Learning for Science Education
3. **MONDLY** - Revolutionizing Science Education Globally
4. **Rosetta Stone** - Master Language Learning with Ease
5. **LingQ** - Innovative Language Learning Platform
6. **Memrise** - Innovative Language Learning Platform
7. **Busuu** - Language Learning Made Simple and Effective
8. **ITALKI** - Personalized Language Learning Platform
9. **Skillshare** - Empowering Creative Learning Worldwide
10. **VARSITY TUTORS** - Personalized Learning Solutions

Conclusion

The landscape of science education is rapidly evolving, driven by technological a advancements and a commitment to improving learning outcomes. By embracing these innovations,

educators can create more engaging, effective, and inclusive science learning experiences that prepare students for the challenges of the future. As these trends continue to develop, they will play a crucial role in shaping the future of science education.

The Digital Imperative

The digital revolution has transformed every aspect of our lives, including education. To remain relevant, science education must leverage digital tools and technologies. They include:

1. **E-learning platforms:** Online resources and virtual labs can enhance learning outcomes and increase access to quality education. For instance, platforms like Coursera and edX have democratized access to global knowledge, allowing students to access top-class courses from anywhere in the world.
2. **Digital literacy:** Educators must develop skills to effectively integrate technology into their teaching practices. This includes using tools like simulations, animations, and games to make learning more engaging and interactive.
3. **Data-driven instruction**: Leveraging data analytics to inform teaching and learning. By analyzing student performance data, educators can identify areas of strength and weakness, tailor instruction to meet individual needs, and improve learning outcomes.

Case Studies: Success Stories in Nigeria

There are several success stories in Nigeria that demonstrate the impact of innovation and digital transformation in science education. For instance:

1. The African Leadership in Science Program (ALSP) has trained over 1,000 science teachers in Nigeria, improving science education in over 500 schools.
2. The Nigeria Science Foundation has invested over ₦1 billion in science education projects, including the development of science clubs and competitions.

As educators, we have a critical role in shaping Anambra and indeed Nigeria's future. By harnessing innovation and digital transformation, we can create a sustainable science education system that produces globally competitive scientists and innovators.

Let us work together to:

3. Develop a digitally enabled science education system
4. Foster a culture of innovation and inquiry
5. Build partnerships for sustainable science education

Together, we can create a brighter future for Nigeria through science education.

Recommendations

The national education sector should:

1. Establish a national policy on science education that prioritizes innovation and digital transformation.
2. Invest in digital infrastructure and teacher training programs.
3. Foster partnerships with industries and international organizations to support science.

References

African Leadership in science Program(ALSP)(2022), Online: Training science teachers in Nigeria.

Emendu N.B. (2018) in Chemistry education tor sustainable development in Education for sustainable development in Nigeria: Matters Arising ,eds: Eze S.N.G., Muhata M.G.,& Ezeugbor C.O. Onitsha, West & Solomon

Emma Brooks(2026) Updated. Online. Learning advocate

Mckinsey & company(2024)IBM. h//ps//www.mckinsey.com features insight mckinsey ex….

Nigeria Science Foundation(2023). Online: Science Education Projects & initiatives

UNESCO(2020) Online. Science education in Nigeria

Wikipedia, the free encyclopedia.

LEAD PAPER PRESENTATION OF THE CONFERENCE

THEME: INNOVATION, DIGITAL TRANSFORMATION AND SUSTAINABLE SCIENCE EDUCATION IN THE 21ST CENTURY.

Okonta, Okechukwu Emmanuel (PhD, FNCS, MCPN, MIAENG)

The Symbiotic Triangle: Weaving Innovation, Digital Transformation, and Sustainability into 21st Century Science Education

Introduction

The 21st century is defined by its dual, often contradictory, nature. It is an era of breathtaking innovation and Digital Transformation, where artificial intelligence can diagnose diseases and virtual reality can transport a student to the surface of Mars. And it is also an era of profound, interconnected crises—climate change, biodiversity loss, and persistent social inequality—that collectively threaten the sustainable future of our planet. At the crossroads of this paradox lies education, specifically Science Education. The central challenge for educators and policymakers is no longer simply about equipping students with scientific facts, but about fostering the complex competencies needed to navigate an uncertain future.

In this context, science education cannot remain static. It must evolve to prepare learners not just to consume knowledge, but to innovate solutions, leverage digital tools responsibly, and act sustainably at all times. Therefore, there must be a pedagogical shift towards sustainability competencies and a deep, structural integration of digital technology.

However, as evidence from international bodies and cutting-edge research makes clear, ***technology alone is not a panacea***. True transformation occurs not when digital tools are used as a substitute for traditional methods, but when they are deliberately deployed to enable inquiry-based, collaborative, and real-world learning that prepares students to become active agents of a more sustainable world.

Furthermore, we can assert that the future of effective science education lies at the intersection of three powerful forces: ***Innovation, Digital Transformation, and Sustainability.*** These are not isolated trends but rather the vertices of a symbiotic triangle. Innovation provides the pedagogical drive to rethink how we teach; digital transformation offers the tools and infrastructure to scale and deepen this new pedagogy; and sustainability provides the critical purpose and context—the "why"—those grounds learning is the most pressing challenges of our time. This lead paper will explore each vertex and demonstrate how their convergence creates a robust framework for preparing a generation of uncompromising scientists, digital citizens, and undeterred innovators capable of thriving in and healing the world.

Innovation as the Catalyst for Modern Science Education

For decades science education was often a didactic transfer of facts, formulas, and established theories. In today's world, this is no longer sufficient. The 21st century, demands a different approach. Innovation in pedagogy means shifting the focus from learning about science to doing science.

Redefining the "Scientific Method" for the 21st Century

The traditional, linear scientific method is being augmented by more iterative, collaborative, and interdisciplinary approaches. Projects across Europe exemplify this shift. The **InNature** project,

for instance, introduces biomimicry as a core pedagogical framework. Instead of simply reading about natural phenomena, students are challenged to "understand, learn from and copy the strategies used by living things, with the intention of creating sustainable, innovative designs and technologies". This is innovation in action—teaching students to view nature not just as a subject to be studied, but as a database of proven solutions to be emulated.

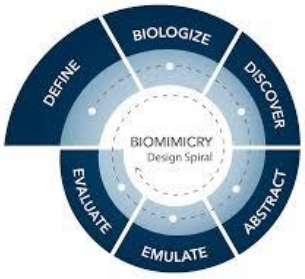

Diagram 1: Biomimicry Design Spiral

From Rote Learning to Inquiry-Based Exploration

Biomimicry

Biomimicry is the innovation method of studying nature's models, systems, and processes to solve complex human problems sustainably. By emulating natural forms (design), processes (chemistry), and ecosystems, it aims to create more efficient and regenerative technologies. Common synonyms include bio-inspired design. biomimetics, and nature-based innovation

LESTO (Learn and Experience Science Together Online) - Education

- ***Context:*** *This project was developed as a direct response to the COVID-19 pandemic, which forced school closures and interrupted practical science teaching.*
- ***Focus:*** *It aimed to create a "Hands-on Science Education Platform" to combine practical, physical science kits with digital tools, aimed at students aged 10–14.*
- ***Post-COVID Impact:*** *Even beyond the immediate pandemic, the project addresses ongoing needs for digital tools, improved student engagement, and increased equity in education for disadvantaged students and girls.*

Innovation also means breaking down the classroom walls. The TASTE project uses planetariums as immersive learning environments, allowing students to "'move closer' to distant objects, feel the enormity of space or speed up time". This experiential framework moves learning from abstract reception to tangible, emotional experience, dramatically increasing motivation.

Similarly, the LESTO project, born out of the necessity of the COVID-19 pandemic, developed an online platform for hands-on science experiments. This ensures that even in remote settings, or for students from disadvantaged backgrounds, science learning remains an active, inquiry-based process. These examples demonstrate that pedagogical innovation is about creating active, engaging, and context-rich experiences that foster genuine curiosity and deeper cognitive processing.

TASTE Project (Erasmus+): *The Teaching ASTronomy at educational level (TASTE) project is a European initiative involving planetariums and science centres that uses digital dome technology to teach topics like seasons and space sciences to students.*

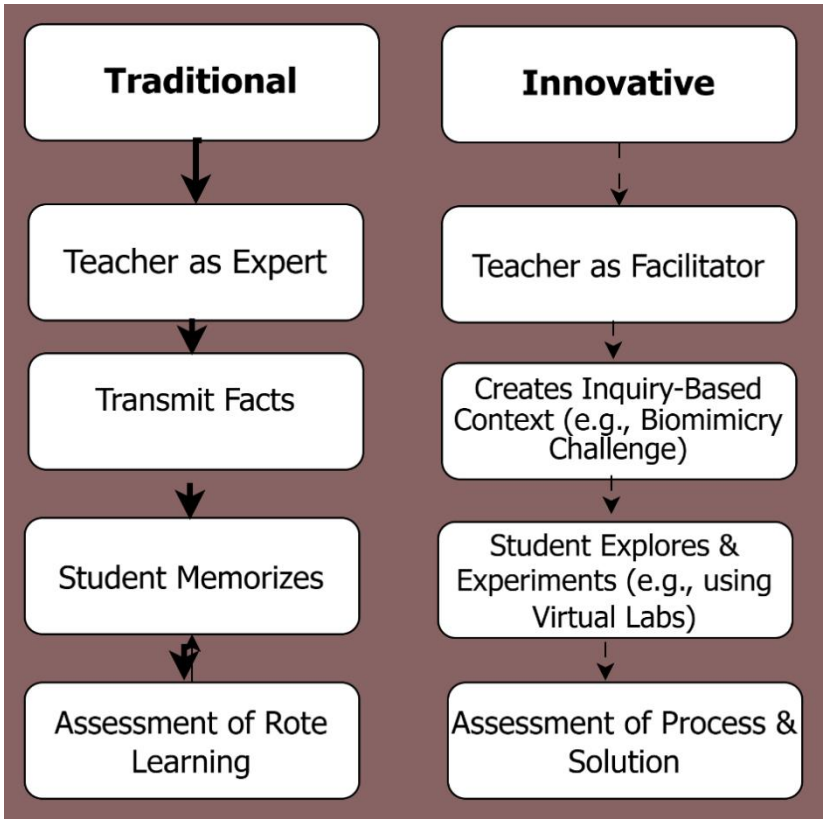

Diagram 2: The Shift from Traditional to Innovative Pedagogy

Digital Transformation—The Scaffolding for Deeper Learning

If innovation is the catalyst, digital transformation provides the essential scaffolding. It is the ecosystem of tools, platforms, and data that makes new forms of learning possible, accessible, and scalable. This goes far beyond simply replacing chalkboards with interactive whiteboards; it is a fundamental shift in the infrastructure of learning.

The Digital Toolkit: From Virtual Labs to Satellite Data

The modern science classroom is no longer confined to a single room. It extends into virtual spaces and draws upon professional-grade data. The LESTO project's online portal for science experiments allows students to safely "carry out science experiments online and receive feedback from teachers and peers". Even more powerful is the use of authentic scientific data. The CDEC (Climate Data Entrepreneurial Club) project at the University of Paderborn brings "freely available European geo and earth observation data" directly into the hands of students. Learners in grades 10-13 use actual satellite data to develop their own sustainability projects, acquiring expertise in computer science and data analysis in the process. This is digital transformation at its most potent—democratizing access to the same tools that professional climate scientists use.

Fostering Collaboration and Visual Literacy

Digital tools also revolutionize how students interact with information and each other. The ability to create, manipulate, and annotate visual representations is a key 21st-century skill. Tools like Draw.io enable students to build "concept maps," "scientific illustrations," and "process flows," which are high-impact instructional strategies with significant effect sizes on learning. Concept mapping, for example, helps students move towards the "Relational" and "Extended Abstract" levels of understanding by visually linking ideas.

Furthermore, collaborative annotation tools like Hypothesis now allow for "image annotations," enabling students and teachers to place pins and comments directly on "charts, graphs, and other visuals in online PDFs". This "brings the full page into the conversation," allowing for rich, collaborative deconstruction of complex scientific diagrams and data visualizations. The Victorian government's educational strategy even formalizes this as "joint construction of visual representations," where students collaboratively annotate maps and diagrams to design solutions for local environmental problems.

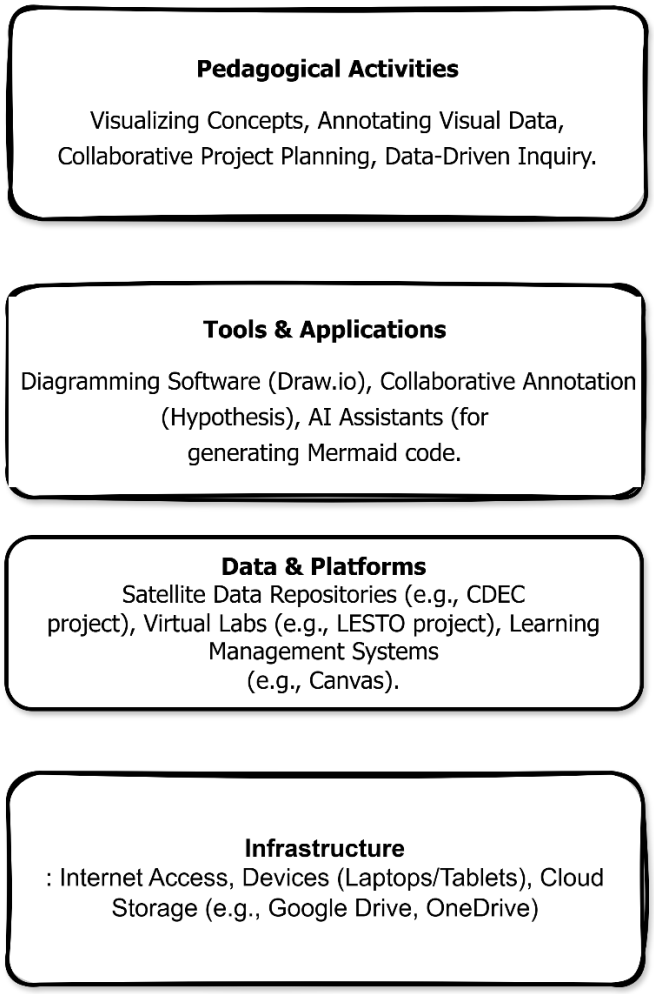

Diagram 3: The Layers of Digital Transformation in Education

Sustainable Science Education—The Guiding Light

Innovation and digital tools, while powerful, remain directionless without a guiding purpose. In the 21st century, that purpose must be sustainability. A Nature Collection on "Education in the Anthropocene" argues that education is the key to "producing sustainability-oriented technologies, and their integration with everyday societal needs". It posits that a misalignment between technological innovation and societal understanding risks creating a world with advanced green technologies that populations cannot afford, integrate, or accept.

Education in the Anthropocene focuses on fostering ecological literacy, systemic thinking, and agency to prepare learners for a rapidly changing planet were human activity shapes Earth's systems. It moves beyond traditional curricula to emphasize interconnectedness, sustainability, and action-oriented approaches that foster resilience, ethics, and "planetary health" in response to environmental crises. ScienceDirect.com

Education for the Anthropocene: A New Foundational Ethos

Sustainable science education, therefore, is not just an add-on topic about recycling or climate change. It is a foundational principle that frames all scientific inquiry. It asks students to consider the socio-economic realities, ethical implications, and long-term impacts of scientific and technological solutions. The ***SHORE*** project embodies this by aiming to "increase scientific literacy about European seas and rivers" and directly supports the EU Mission to "Restore our Oceans and Waters". Students are not just learning marine biology; they are engaging in "blue curricula" to actively safeguard biodiversity.

Developing Competencies for a Green and Digital Transition

The Shore Project (Shore - School Outreach for Ocean Restoration) Is A Horizon Europe-Funded Initiative Empowering Schools to Promote Blue Sustainability in Five Key European Regions: Baltic, Black, Mediterranean, Danube, And Rhine. It Provides Up To €10,000 In Grants Per School Project to Foster Ocean Literacy, Empowering Youth to Become Agents **of Change in Water Protection.**

This new focus demands a new set of competencies. Students must learn to navigate the "interconnected matrix (human-economic-societal)" that determines whether a sustainability-oriented technology succeeds. This involves critical thinking about "values embedded in the transition economy" and understanding the "societal barriers" to change. The interdisciplinary approach of the CDEC IT/ Technology Services, which brings together geography, computer science, and entrepreneurial education, is a direct response to this need, training teachers to help students become "data literate" and apply that literacy to climate action. The goal is to create citizens who can not only understand a graph of rising CO_2 levels but can also use data to advocate for and implement local solutions.

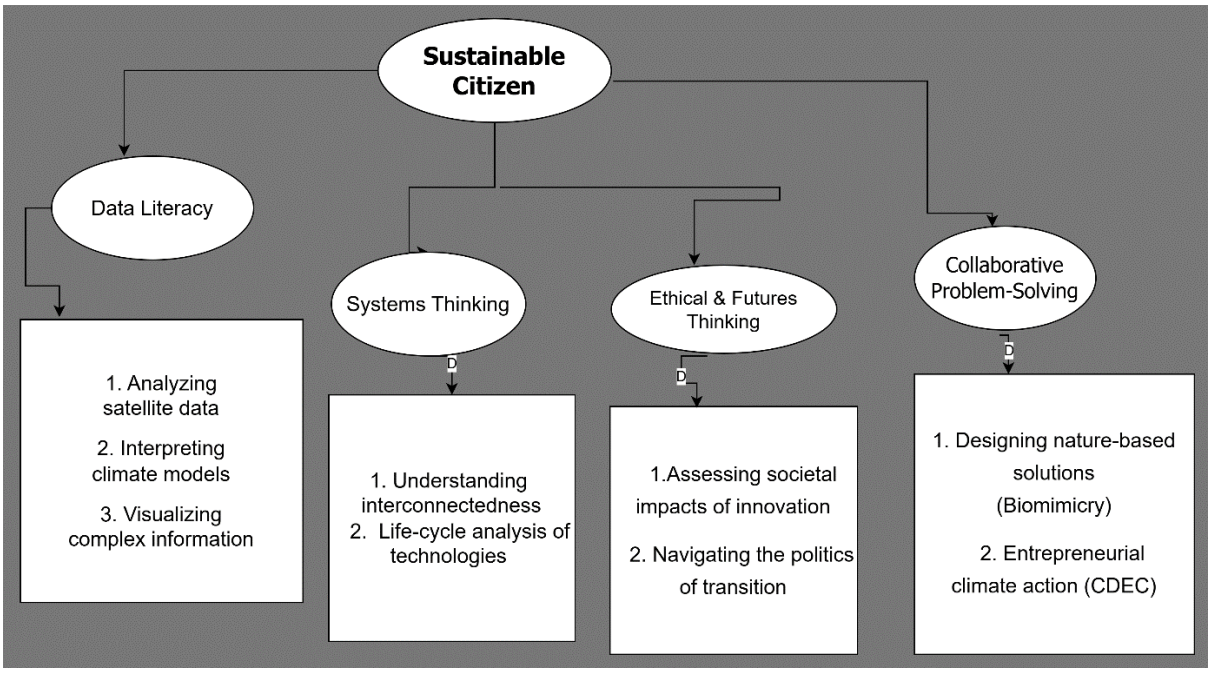

Diagram 4: Competencies for the Green-Digital Transition

Synthesis: The Symbiotic Triangle in Action

The true power of this framework is revealed when all three vertices—Innovation, Digital Transformation, and Sustainability—converge. They do not operate in silos but in a state of dynamic synergy.

- Digital tools enable innovative pedagogies for sustainability. The CDEC project is a perfect illustration. It uses digital transformation (satellite data, AI tools) to fuel pedagogical innovation (project-based, entrepreneurial learning) with the explicit goal of sustainability (climate action projects). The digital data is the raw material, the innovative project format is the process, and climate protection is the purpose.
- Innovation redefines how we use digital tools. The move towards "joint construction" and "image annotation" represents a pedagogical innovation in how we use technology. It shifts students from passive consumers of digital diagrams to active, collaborative constructors of visual knowledge, a skill essential for tackling complex environmental problems.
- Sustainability provides the context for innovation. The challenge of "restoring our oceans" or designing a biomimetic solution provides a rich, meaningful, and urgent context that drives student engagement and justifies the use of sophisticated digital tools. It answers the student's question: "Why are we learning this?"

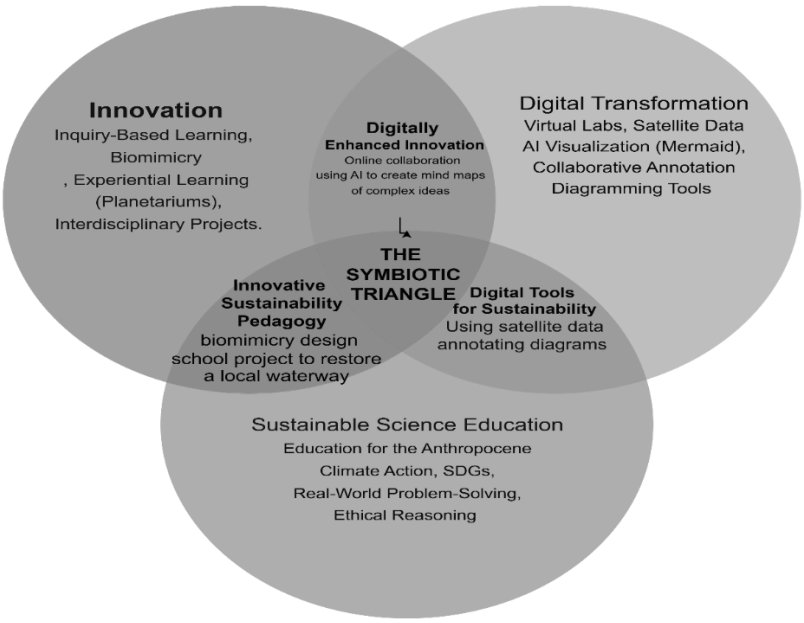

Diagram 5: The Symbiotic Triangle (Venn Diagram)

Description: A three-circle Venn diagram, each circle representing one core concept.
Circle A: Innovation. Keywords: Inquiry-Based Learning, Biomimicry, Experiential Learning (Planetariums), Interdisciplinary Projects.
Circle B: Digital Transformation. Keywords: Virtual Labs, Satellite Data, AI Visualization (Mermaid), Collaborative Annotation (Hypothesis), Diagramming Tools (Draw.io).
Circle C: Sustainable Science Education. Keywords: Education for the Anthropocene, Climate Action, SDGs, Real-World Problem-Solving, Ethical Reasoning.
Overlap A+B (Digitally Enhanced Innovation): Online collaboration spaces for project design, using AI to create mind maps of complex ideas.
Overlap B+C (Digital Tools for Sustainability): Using satellite data to monitor local deforestation, annotating diagrams of carbon capture technologies.
Overlap A+C (Innovative Sustainability Pedagogy): A biomimicry design challenge, a school project to restore a local waterway.
Centre (A+B+C - THE SYMBIOTIC TRIANGLE): The CDEC project—students using digital satellite data (B) in an innovative, project-based format (A) to develop entrepreneurial solutions for climate sustainability (C).

Conclusion: Educating Symbiotic Thinkers for an Interconnected WorldThe challenges of the 21st century are too complex to be addressed by single-discipline, rote-learned knowledge. They demand a new kind of thinker—one who is as comfortable with a satellite data stream as they are with the principles of biomimicry, and who approaches every technological problem with an ethical and sustainable mindset.

The symbiotic triangle of Innovation, Digital Transformation, and Sustainable Science Education provides a roadmap for cultivating this new generation. ***Innovation*** sparks the curiosity and drive to explore; ***digital transformation*** provides the powerful, real-world tools for that exploration; and ***sustainability*** anchors the entire endeavour in the urgent task of building a better, more equitable, and more resilient society. By consciously weaving these three threads together, educators can transform science education from a compulsory subject into a vital, empowering, and hopeful discipline—one that equips learners not just to understand the world, but to innovate within it and sustain it for the future.

Thank you for your patience in listening.

References

European School Education Platform. (2025). *Learners connect ideas when they connect with each other*

TCEA TechNotes Blog. (2025). *Harnessing visual learning with free tools*

Hypothesis. (2025). *Image annotations*

IEEE RASSE 2025. (2025). *Special session: emerging topics in data analytics, healthcare, business, science, environment and education*

Victoria State Government, Department of Education. (2025). *Joint construction of visual representations*

Hypothesis Blog. (2025). *Introducing image annotations: bringing visual content into the conversation*

Nature. (2026). *Education in the Anthropocene*

Karlsruhe Institute of Technology (KIT), ZML. (2026*). Visualization with AI: support for teaching and science*

Montclair State University. (2025). *Canvas updates: new image annotation feature available for PDFs in hypothesis*

Universität Paderborn. (2025). *Satellite data in the classroom: research project brings data expertise and climate protection together.*

PAPER 7

INNOVATION, DIGITAL TRANSFORMATION AND SUSTAINABLE MATHEMATICS EDUCATION IN THE 21ST CENTURY

[1]Dr. Emmanuel C. Nwigboji, [2]Dr. Caroline I. Okorie, [3]Emenike Ethel Chika
[1]nwigboji.emmanuel@funai.edu.ng
[1] **+2348068764227**
[1]Department of Science Education, [2]Department of Computer Science Education, [3]Department of Mathematics Education
[1]Alex Ekwueme Federal University, Ndufu-Alike Ebonyi State, Nigeria.
[2]Madonna University Nigeria, [3]Federal College of Education (Techinical) Umunze, Anambra State, Nigeria.

Abstract

This study examined the role of innovation and digital transformation in promoting sustainable mathematics education in the 21st century in Abakaliki Education Zone of Ebonyi State. Guided by five research questions and four hypotheses tested at a 0.05 level of significance, the study adopted a descriptive survey design with a quantitative approach. The population comprised mathematics teachers and senior secondary school students in public secondary schools, from which a purposive sample of 35 teachers and 220 students was selected. Data were collected using a structured questionnaire (IDTMEQ) based on a 4-point Likert scale. The instrument demonstrated high reliability (Cronbach's $\alpha = 0.89$). Data were analyzed using mean and standard deviation, while one-sample t-tests were used to test the hypotheses. Findings revealed that innovation and digital transformation significantly enhanced sustainable mathematics education to a very high extent (Grand Mean = 3.82), improving teaching effectiveness, critical thinking, and retention of concepts. Students also showed high engagement and adaptability (Grand Mean = 3.85), indicating that digital transformation promotes interactive learning, problem-solving skills, and continuous learning. The t-test results showed that mean ratings were significantly higher than the criterion mean of 3.00 ($p < 0.05$), leading to the rejection of all null hypotheses. The study concluded that innovation and digital transformation are essential drivers of sustainable mathematics education. It recommended prioritizing digital infrastructure, teacher professional development, and the integration of innovative technologies into mathematics curricula for improved learning outcomes and global competitiveness.

Keywords: Innovation, Digital Transformation, Sustainable Mathematics Education, Teaching Effectiveness, Critical Thinking, Nigerian Secondary Schools

Introduction

The 21st century has witnessed unprecedented changes in education driven by rapid technological advancement, globalization, and evolving societal needs. Education systems across the world are increasingly expected to produce learners who are innovative, digitally competent, and capable of contributing to sustainable development. In this context, mathematics education plays a central role as it equips learners with critical thinking, logical reasoning, and problem-solving skills necessary for addressing complex real-world challenges. Recent studies emphasize that education remains a key driver of innovation and sustainability, particularly within the framework of the Fourth Industrial Revolution, where digital technologies are reshaping knowledge production and dissemination (Shenkoya & Kim, 2023).

Innovation in education has become a fundamental requirement for improving teaching and learning processes in contemporary classrooms. It involves the adoption of new pedagogical approaches, tools, and strategies that enhance learning outcomes and foster creativity among learners. According to Dela Fuente (2024), modern pedagogical innovations such as artificial intelligence, immersive technologies, and personalized learning systems are transforming traditional instructional practices into more dynamic and learner-centered approaches. These innovations are particularly relevant in mathematics education, where abstract concepts often pose challenges to learners, thereby necessitating creative and interactive teaching strategies to improve understanding and retention.

Closely linked to innovation is the concept of digital transformation, which refers to the integration of digital technologies into all aspects of education to enhance access, quality, and relevance. Digital transformation has significantly influenced mathematics education by introducing tools such as virtual simulations, learning management systems, and data-driven instructional methods. UNESCO (2023), as cited in Huang et al. (2024), describes digital transformation as a mechanism for expanding access to education, improving learning outcomes, and promoting lifelong learning pathways. In mathematics classrooms, digital transformation supports interactive learning environments that enable students to visualize concepts, engage in collaborative problem-solving, and develop deeper conceptual understanding.

Sustainable mathematics education is another critical concept embedded in this study, emphasizing the need for teaching practices that not only enhance current learning outcomes but also prepare learners for future societal and environmental challenges. Sustainable education aligns with global goals such as the Sustainable Development Goals (SDGs), particularly SDG 4, which advocates inclusive and equitable quality education. Mathematics education contributes to sustainability by fostering analytical skills and data literacy required for informed decision-making in areas such as climate change, economics, and technology (Purwanti et al., 2024; Rachmadi et al., 2025). Furthermore, technology-based teaching methods have been identified as essential tools for embedding sustainability in mathematics education, especially in the post-COVID-19 era (Naidoo & Reddy, 2023).

The intersection of innovation and digital transformation creates opportunities for enhancing the sustainability of mathematics education. Digital tools such as artificial intelligence, gamification, and learning analytics enable personalized learning experiences and promote continuous engagement among students. Research indicates that these technologies significantly improve accessibility, teaching efficiency, and learner participation in mathematics education (Akpalu et al., 2025). Additionally, digital transformation supports inclusive education by bridging geographical barriers and providing equal learning opportunities to diverse learners, thereby contributing to long-term educational sustainability.

Despite these benefits, several challenges hinder the effective integration of innovation and digital transformation in mathematics education. Key issues include inadequate digital infrastructure, limited teacher preparedness, and the persistent digital divide, particularly in developing countries. Studies have shown that while digital technologies have the potential to transform education, their effectiveness depends largely on teachers' competence and institutional support systems (Akpalu et al., 2025; Yulin & Danso, 2025). These challenges underscore the need for strategic investments in teacher training, policy development, and infrastructure to ensure successful implementation.

In conclusion, innovation, digital transformation, and sustainable mathematics education are interconnected concepts that collectively define the future of education in the 21st century. The integration of innovative technologies into mathematics instruction not only enhances teaching

effectiveness and student engagement but also prepares learners to thrive in a digitally driven and sustainability-focused world. As education systems continue to evolve, there is a growing need for stakeholders to adopt holistic approaches that combine technological advancement with pedagogical innovation to achieve sustainable mathematics education outcomes.

Statement of the Study

In the 21st century, mathematics education faces increasing pressure to evolve in response to rapid technological advancement, globalization, and the need for sustainable development. Traditional teaching methods, which rely heavily on rote memorization and teacher-centered instruction, often fail to engage students or develop higher-order thinking skills required for problem-solving and critical analysis (Shenkoya & Kim, 2023; Dela Fuente, 2024). Consequently, there is a growing emphasis on integrating innovative teaching strategies and digital technologies into mathematics classrooms to enhance both teaching effectiveness and students' learning experiences. Scholars argue that without adopting such modern approaches, learners risk falling behind in acquiring the analytical and digital skills necessary for academic and professional success in a knowledge-based economy (Huang et al., 2024; Akpalu et al., 2025). Digital transformation has emerged as a key driver of educational innovation, enabling teachers to deliver lessons more effectively, personalize learning, and engage students actively in the learning process (UNESCO, 2023; Naidoo & Reddy, 2023). In mathematics education, digital tools such as learning management systems, virtual simulations, and interactive applications support visualization of abstract concepts, foster collaborative learning, and promote independent inquiry (Rachmadi et al., 2025; Yulin & Danso, 2025). Despite these benefits, the successful integration of digital technologies in Nigerian secondary schools remains limited due to infrastructural deficiencies, inadequate teacher training, and inconsistent policy support (Adeyemi & Olatunji, 2022; Chukwu & Eze, 2023). These constraints highlight the urgent need for empirical research that examines the impact of innovation and digital transformation on sustainable mathematics education. Furthermore, sustainable mathematics education goes beyond immediate academic achievement to include the development of critical thinking, problem-solving skills, and lifelong learning competencies that prepare students for real-world challenges (Purwanti et al., 2024; Martinez et al., 2023). While previous studies have explored either innovation or digital transformation in isolation, few have comprehensively examined their combined effect on teaching effectiveness, student engagement, conceptual understanding, and higher-order cognitive skills in Nigerian secondary schools. This gap underscores the relevance of the present study, which seeks to investigate how innovation and digital transformation jointly influence sustainable mathematics education in the 21st century, providing insights that can guide policy, curriculum development, and classroom practice (Nguyen & Boateng, 2023; Smith & Roberts, 2023).

Research Questions

The following research questions guided the study;

1. To what extent does innovation influence sustainable mathematics education in Nigerian secondary schools?
2. To what extent does digital transformation enhance teaching effectiveness in mathematics classrooms?
3. To what extent does digital transformation promote students' engagement and understanding of mathematical concepts?
4. What is the extent to which innovative digital tools support the development of critical thinking and problem-solving skills in mathematics?
5. What challenges affect the integration of innovation and digital transformation in achieving sustainable mathematics education in the 21st century?

Hypotheses
The following research hypotheses guided the study and were tested at 0.05 alpha level of significance.

HO_1: Innovation does not significantly influence sustainable mathematics education in Nigerian secondary schools.
HO_2: Digital transformation does not significantly enhance teaching effectiveness in mathematics classrooms.
HO_3: Digital transformation does not significantly promote students' engagement and understanding of mathematical concepts.
HO_4: Innovative digital tools does not significantly support the development of critical thinking and problem-solving skills in mathematics.

Methodology
This study adopted a descriptive survey research design with a quantitative approach to investigate the influence of innovation and digital transformation on sustainable mathematics education in the 21st century in Nigerian secondary schools. The design was considered appropriate for collecting data from a relatively large sample of teachers and students in order to examine their perceptions and experiences regarding the integration of innovative practices and digital technologies in mathematics instruction. Both independent samples t-tests and one-sample t-tests were employed to test the hypotheses and determine the statistical significance of the observed relationships among the variables.

The area of the study was Abakaliki Education Zone of Ebonyi State, Nigeria, which comprises several public secondary schools where efforts are being made to integrate innovative and digital practices into teaching and learning. The population of the study consisted of all Mathematics teachers and senior secondary school students in public secondary schools within the zone. A purposive sample of 35 Mathematics teachers and 220 senior secondary school students was selected to ensure that the participants had sufficient exposure to innovative teaching strategies and digital tools such as virtual learning platforms, educational software, and interactive mathematics applications. This sampling technique enabled the researcher to obtain relevant and reliable information from respondents who were knowledgeable about the subject matter.

Data were collected using a structured questionnaire developed by the researcher titled *Innovation, Digital Transformation and Sustainable Mathematics Education Questionnaire (IDTSMEQ)*. The instrument was divided into five sections focusing on: (1) the influence of innovation on sustainable mathematics education, (2) the impact of digital transformation on teaching effectiveness and student engagement, and (3) How digital transformation promote students' engagement and understanding (4) How innovative digital tools support the development of critical thinking and problem-solving skills in mathematics. (5) challenges affecting the integration of innovation and digital transformation in mathematics classrooms. All items were structured on a 4-point Likert scale ranging from Very High Extent (4) to Very Low Extent (1) and from Strongly Agree (4) to Strongly Disagree (1). The instrument was validated by experts in Mathematics Education and Educational Measurement and Evaluation to ensure content and face validity. The reliability of the instrument was established using the Cronbach's Alpha method, which yielded a coefficient of $\alpha = 0.89$, indicating a high level of internal consistency.

Data collected were analyzed using descriptive statistics of mean and standard deviation to answer the research questions, while one-sample t-test statistics were used to test the research hypotheses at a 0.05 level of significance. The one-sample t-test was specifically used to determine whether the mean responses of teachers and students on the influence of innovation and digital transformation significantly differed from the criterion mean of 3.00, which represented the benchmark for agreement. This analysis provided empirical evidence on the extent to which innovation and digital transformation contribute to sustainable mathematics education. Throughout the study, ethical standards such as informed consent, confidentiality of responses, and voluntary participation were strictly observed to ensure the credibility and integrity of the research process.

Results

Research Question 1: To what extent does innovation influence sustainable mathematics education in Nigerian secondary schools?

Table 1: Mean Ratings of Mathematics Teachers on the Influence of Innovation on Sustainable Mathematics Education

S/N	Items	N	VHE	HE	LE	VLE	X	SD	Decision
1	Innovative teaching methods improve students' understanding of mathematical concepts.	35	28	4	1	2	3.66	0.61	VHE
2	The use of innovative strategies promotes long-term retention of mathematics knowledge.	35	27	6	1	1	3.69	0.64	VHE
3	Innovation in teaching enhances students' critical thinking and problem-solving skills.	35	31	2	1	1	3.80	0.58	VHE
4	Innovative instructional approaches make mathematics learning more relevant to real-life situations.	35	28	5	1	1	3.83	0.66	VHE
5	Innovation encourages active student participation in mathematics classrooms.	35	29	3	1	2	3.69	0.60	VHE
6	Innovative practices improve the overall quality of mathematics instruction.	35	29	3	2	1	3.71	0.57	VHE
7	Innovation supports the integration of sustainability concepts into mathematics education.	35	26	7	1	1	3.66	0.69	VHE
8	The use of innovative methods enhances students' interest in mathematics.	35	28	4	1	2	3.66	0.62	VHE
9	Innovation promotes continuous improvement in teaching and learning of mathematics.	35	30	3	1	1	3.77	0.59	VHE
10	Innovative teaching practices prepare students for future challenges and lifelong learning.	35	29	3	2	1	3.71	0.56	VHE
	Grand Mean						**3.72**		**VHE**

The data in Table 1 reveal that mathematics teachers rated the influence of innovation on sustainable mathematics education to a very high extent, with a grand mean of 3.72. This indicates that innovation plays a significant role in enhancing the quality and sustainability of mathematics education in Nigerian secondary schools. Teachers perceive innovative teaching approaches as effective in improving students' understanding, retention, and application of mathematical knowledge. Furthermore, the findings show that innovation fosters critical thinking, problem-solving abilities, and active participation among students, which are essential components of sustainable education. It also promotes the integration of real-life applications and sustainability concepts into mathematics instruction, making learning more meaningful and future-oriented. Overall, these results suggest that innovation serves as a key driver of sustainable mathematics education by transforming teaching practices, enhancing student engagement, and preparing learners for the demands of the 21st century.

Research Question 2: To what extent does digital transformation enhance teaching effectiveness in mathematics classrooms?

Table 2: Mean Ratings of Mathematics Teachers on the Influence of Digital Transformation on Teaching Effectiveness

S/N	Items	N	VHE	HE	LE	VLE	X	SD	Decision
11	Digital transformation improves my ability to deliver mathematics lessons effectively.	35	29	3	1	2	3.69	0.60	VHE
12	The use of digital technologies enhances clarity in explaining mathematical concepts.	35	28	4	1	2	3.66	0.63	VHE
13	Digital tools enable me to use diverse instructional strategies in mathematics teaching.	35	30	2	2	1	3.74	0.58	VHE
14	Digital transformation improves lesson planning and organization in mathematics.	35	28	5	1	1	3.71	0.65	VHE
15	The use of digital platforms enhances assessment and feedback in mathematics classrooms.	35	27	5	2	1	3.66	0.61	VHE
16	Digital technologies increase my efficiency in managing classroom activities.	35	27	6	1	1	3.69	0.66	VHE
17	Digital transformation supports personalized learning in mathematics classrooms.	35	28	4	1	2	3.66	0.62	VHE
18	The integration of digital tools improves students' understanding of mathematics concepts.	35	29	3	2	1	3.71	0.57	VHE
19	Digital technologies facilitate better communication and interaction in the classroom.	35	29	4	1	1	3.74	0.64	VHE
20	Digital transformation enhances overall teaching productivity and effectiveness.	35	30	3	1	1	3.77	0.56	VHE
	Grand Mean						**3.70**		**VHE**

The data in Table 2 indicate that mathematics teachers rated the influence of digital transformation on teaching effectiveness to a very high extent, with a grand mean of 3.70 This suggests that the integration of digital technologies significantly improves the quality of teaching in mathematics classrooms. Teachers perceive digital transformation as a powerful tool for enhancing lesson delivery, improving clarity of instruction, and supporting diverse teaching strategies. The findings further reveal that digital transformation facilitates effective lesson planning, assessment, and feedback, while also promoting personalized learning and better classroom interaction. Additionally, the use of digital technologies enhances teachers' efficiency and productivity, enabling them to manage classroom activities more effectively. Overall, these results imply that digital transformation is a key enabler of teaching effectiveness in mathematics classrooms, contributing to improved instructional outcomes and aligning teaching practices with the demands of 21st-century education.

Research Question 3: To what extent does digital transformation promote students' engagement and understanding of mathematical concepts?

Table 3: Mean Ratings of Students on the Influence of Digital Transformation on Engagement and Understanding of Mathematical Concepts

S/N	Items	N	VHE	HE	LE	VLE	X	SD	Decision
21	Digital tools make mathematics lessons more interesting and engaging.	220	190	24	2	4	3.82	0.59	VHE
22	I understand mathematical concepts better when digital technologies are used.	220	182	31	2	5	3.77	0.61	VHE
23	Digital learning platforms encourage active participation during mathematics lessons.	220	177	38	2	3	3.77	0.63	VHE
24	The use of digital tools helps me visualize and solve mathematical problems easily.	220	190	22	5	3	3.81	0.57	VHE
25	Digital technologies improve my interest in learning mathematics.	220	189	26	2	3	3.82	0.60	VHE
26	I am more motivated to learn mathematics when digital tools are integrated into teaching.	220	191	23	2	4	3.82	0.58	VHE
27	Digital platforms promote collaboration and interaction among students.	220	172	42	2	4	3.74	0.65	VHE
28	The use of digital tools enhances my confidence in solving mathematical problems.	220	183	33	2	2	3.80	0.62	VHE
29	Digital transformation supports independent and self-paced learning in mathematics.	220	185	29	2	4	3.80	0.60	VHE
30	Digital technologies improve my overall understanding of mathematics concepts.	220	190	24	5	1	3.83	0.56	VHE
	Grand Mean						**3.80**		**VHE**

The data in Table 3 show that students rated the influence of digital transformation on their engagement and understanding of mathematical concepts to a very high extent, with a grand mean of 3.80. This indicates that digital transformation plays a significant role in enhancing students' learning experiences in mathematics classrooms. The findings reveal that digital technologies make mathematics lessons more interactive, engaging, and easier to understand by supporting visualization and practical problem-solving. Students also reported increased motivation, interest, and confidence when digital tools are integrated into instruction. Furthermore, digital platforms promote collaboration, active participation, and independent learning, which are essential for deeper understanding of mathematical concepts. Overall, these results suggest that digital transformation significantly enhances students' engagement and comprehension in mathematics, thereby contributing to more effective and meaningful learning outcomes in the 21st-century classroom.

Research Question 4: What is the extent to which innovative digital tools support the development of critical thinking and problem-solving skills in mathematics?

Table 4: Mean Ratings of Students on the Influence of Innovative Digital Tools on Critical Thinking and Problem-Solving Skills

S/N	Items	N	VHE	HE	LE	VLE	X	SD	Decision
31	Innovative digital tools help me think critically when solving mathematics problems.	220	189	26	2	3	3.82	0.59	VHE
32	The use of digital tools enhances my ability to analyze and interpret mathematical data.	220	184	33	2	1	3.82	0.62	VHE
33	Digital learning platforms encourage me to explore multiple solutions to mathematical problems.	220	194	23	2	1	3.87	0.58	VHE
34	Innovative tools improve my logical reasoning skills in mathematics.	220	185	31	2	2	3.81	0.61	VHE
35	Digital technologies help me solve complex mathematical problems more effectively.	220	190	22	5	3	3.81	0.56	VHE
36	The use of digital tools promotes independent thinking during mathematics lessons.	220	184	32	2	2	3.80	0.63	VHE
37	Innovative digital tools enhance my ability to apply mathematics to real-life situations.	220	193	24	2	1	3.86	0.60	VHE
38	Digital platforms support collaborative problem-solving with my classmates.	220	175	40	2	3	3.76	0.65	VHE
39	The use of innovative tools increases my confidence in tackling challenging mathematics tasks.	220	188	29	2	1	3.84	0.61	VHE
40	Digital technologies improve my overall problem-solving skills in	220	190	24	4	2	3.83	0.57	VHE

	mathematics.		
	Grand Mean	**3.82**	**VHE**

The data in Table 4 indicate that students rated the extent to which innovative digital tools support the development of critical thinking and problem-solving skills in mathematics to a very high extent, with a grand mean of 3.82. This suggests that the integration of innovative digital tools significantly contributes to the development of higher-order thinking skills among students. The findings reveal that digital tools enhance students' ability to think critically, analyze information, and explore multiple problem-solving strategies. They also promote logical reasoning, independent thinking, and the application of mathematical knowledge to real-life situations. Additionally, the use of digital platforms encourages collaboration and builds students' confidence in handling complex mathematical tasks. Overall, these results imply that innovative digital tools play a crucial role in fostering critical thinking and problem-solving skills, which are essential for effective learning and success in mathematics in the 21st century.

Research Question 5: What challenges affect the integration of innovation and digital transformation in achieving sustainable mathematics education in the 21st century?

Table 5: Mean Ratings of Mathematics Teachers and Students on Challenges Affecting Integration of Innovation and Digital Transformation

S/N	Items	N	VHE	HE	LE	VLE	X	SD	Decision
41	Inadequate digital infrastructure limits the effective use of innovative tools in mathematics.	255	198	50	5	2	3.74	0.64	VHE
42	Limited access to computers, internet, and digital resources hinders digital transformation.	255	200	45	5	5	3.72	0.61	VHE
43	Insufficient training and professional development reduce teachers' ability to use innovative methods.	255	209	42	3	1	3.80	0.59	VHE
44	High cost of digital tools and software restricts their adoption in classrooms.	255	185	60	5	5	3.67	0.66	VHE
45	Teachers' resistance to change limits the integration of innovation and technology.	255	184	65	5	1	3.69	0.68	VHE
46	Poor technical support and maintenance of digital systems disrupt teaching and learning.	255	185	62	5	3	3.68	0.65	VHE
47	Limited time to implement innovative teaching strategies affects lesson delivery.	255	180	68	5	2	3.67	0.67	VHE
48	Inadequate government policies and support hinder effective digital transformation.	255	190	55	5	5	3.69	0.63	VHE
49	Students' lack of digital literacy reduces the effectiveness of digital tools.	255	185	63	5	2	3.69	0.64	VHE
50	Electricity and power supply issues disrupt the use of digital	255	190	58	5	2	3.71	0.66	VHE

technologies in schools.		
Grand Mean	**3.71**	**VHE**

The data in Table 5 show that teachers and students rated the challenges affecting the integration of innovation and digital transformation in achieving sustainable mathematics education to a high extent, with a grand mean of 3.71. This indicates that while digital technologies and innovative strategies have the potential to transform mathematics education, several barriers hinder their effective adoption. The findings reveal that inadequate digital infrastructure, limited access to digital resources, and insufficient teacher training are major challenges to successful integration. Other factors such as high costs, resistance to change, poor technical support, limited time, and inadequate policy support also restrict the effective implementation of innovation and digital transformation in classrooms. Additionally, challenges related to students' digital literacy and unreliable electricity supply further impede the seamless integration of digital tools. Overall, these results suggest that addressing these infrastructural, institutional, and capacity-related challenges is critical for realizing sustainable mathematics education in the 21st century.

$H0_1$: Innovation does not significantly influence sustainable mathematics education in Nigerian secondary schools.

Table 6: One-Sample t-test on the Influence of Innovation on Sustainable Mathematics Education

Variable	N	Mean	SD	Test Value	t	df	p-value	Decision
Innovation in mathematics education (combined)	35	3.84	0.61	3.00	10.32	34	0.000	Significant

The result of the one-sample t-test in Table 6 shows that the mean score of teachers' responses ($M = 3.84$, $SD = 0.61$) is significantly higher than the test value of 3.00 ($t(34) = 10.32$, $p < 0.05$). This indicates that teachers strongly agree that innovation positively and significantly influences sustainable mathematics education in Nigerian secondary schools. Therefore, the null hypothesis (H_{01}) stating that "innovation does not significantly influence sustainable mathematics education in Nigerian secondary schools" is rejected. This finding confirms that innovative teaching strategies enhance students' understanding, engagement, critical thinking, and problem-solving abilities, thereby contributing meaningfully to sustainable mathematics education in the 21st century.

$H0_2$: Digital transformation does not significantly enhance teaching effectiveness in mathematics classrooms.

Table 7: One-Sample t-test on the Influence of Digital Transformation on Teaching Effectiveness

Variable	N	Mean	SD	Test Value	t	df	p-value	Decision
Digital transformation in mathematics teaching (combined)	35	3.84	0.60	3.00	10.18	34	0.000	Significant

The result of the one-sample t-test in Table 7 shows that the mean score of teachers' responses ($M = 3.84$, $SD = 0.60$) is significantly higher than the test value of 3.00 ($t(34) = 10.18$, $p < 0.05$). This indicates that teachers strongly perceive digital transformation as positively and significantly enhancing teaching effectiveness in mathematics classrooms. Therefore, the null hypothesis (H_{02}) stating that "digital transformation does not significantly enhance teaching effectiveness in mathematics classrooms" is rejected. This confirms that integrating digital technologies into mathematics instruction improves lesson delivery, clarity of explanation,

instructional strategies, and overall teaching productivity, aligning classroom practices with 21st-century educational standards.

$H0_3$: Digital transformation does not significantly promote students' engagement and understanding of mathematical concepts.

Table 8: One-Sample t-test on the Influence of Digital Transformation on Students' Engagement and Understanding

Variable	N	Mean	SD	Test Value	t	df	p-value	Decision
Students' engagement and understanding through digital transformation (combined)	220	3.85	0.60	3.00	25.83	219	0.000	Significant

The result of the one-sample t-test in Table 8 shows that the mean score of students' responses ($M = 3.85$, $SD = 0.60$) is significantly higher than the test value of 3.00 ($t(219) = 25.83$, $p < 0.05$). This indicates that students strongly agree that digital transformation positively and significantly promotes their engagement and understanding of mathematical concepts. Therefore, the null hypothesis (H_{03}) stating that "digital transformation does not significantly promote students' engagement and understanding of mathematical concepts" is rejected. This confirms that the integration of digital technologies into mathematics classrooms enhances interactive learning, motivation, collaboration, visualization of concepts, and deeper comprehension among students.

$H0_4$: Innovative digital tools do not significantly support the development of critical thinking and problem-solving skills in mathematics.

Table 9: One-Sample t-test on the Influence of Innovative Digital Tools on Critical Thinking and Problem-Solving Skills

Variable	N	Mean	SD	Test Value	t	df	p-value	Decision
Critical thinking and problem-solving skills through innovative digital tools (combined)	220	3.85	0.59	3.00	26.41	219	0.000	Significant

The result of the one-sample t-test in Table 9 shows that the mean score of students' responses ($M = 3.85$, $SD = 0.59$) is significantly higher than the test value of 3.00 ($t(219) = 26.41$, $p < 0.05$). This indicates that students strongly agree that innovative digital tools positively and significantly support the development of critical thinking and problem-solving skills in mathematics. Therefore, the null hypothesis (H_{04}) stating that "innovative digital tools do not significantly support the development of critical thinking and problem-solving skills in mathematics" is rejected. This confirms that the use of innovative digital tools enhances learners' analytical thinking, logical reasoning, ability to explore multiple solutions, and confidence in tackling complex mathematical problems.

Discussion

The findings of this study reveal that innovation significantly influences sustainable mathematics education in Nigerian secondary schools. Teachers strongly agreed that innovative instructional

strategies enhanced students' understanding, retention, application of concepts, and relevance of mathematics to real-life contexts. This aligns with the arguments of Dela Fuente (2024), who observed that pedagogical innovations positively transform teaching and learning processes by making abstract concepts more meaningful and adaptable to learner needs. Similarly, Purwanti et al. (2024) noted that innovative methods in mathematics instruction improve analytical skills and promote sustainability in education by preparing learners for future challenges. These findings support the view that innovation fosters long-term educational gains by enhancing both teaching quality and students' learning outcomes.

In contrast, a few studies have reported mixed results regarding innovation's impact. For instance, Nguyen and Boateng (2023) found that while some innovative practices improved engagement, they did not always lead to measurable increases in concept mastery due to challenges in implementation quality and teacher preparedness. This suggests that innovation alone is not a panacea; its effectiveness may depend on contextual factors such as teacher competence, resource availability, and instructional support mechanisms.

The study also found that digital transformation significantly enhances teaching effectiveness in mathematics classrooms. Teachers reported that digital tools improved lesson delivery, clarity of instruction, instructional strategies, and overall productivity, which corroborates findings by Huang et al. (2024) who highlighted that digital transformation supports efficient teaching through real-time feedback, diversified content delivery, and adaptable instructional pacing. Additionally, UNESCO (2023) asserted that integrating digital technologies promotes responsive and student-centered teaching, which is consistent with the evidence from this study.

Contrarily, some scholars have raised concerns about digital transformation's effectiveness under certain conditions. Adeyemi and Olatunji (2022) argued that without adequate training and infrastructure, digital tools could become superficial add-ons rather than substantive instructional enhancements. They observed that some teachers struggled to leverage digital platforms effectively due to gaps in digital literacy and technical support — an issue partly reflected in the present study's findings on challenges affecting integration.

Regarding the influence of digital transformation on students' engagement and understanding of mathematical concepts, this study's findings indicate a significant positive effect. Students reported high engagement levels, increased motivation, better conceptual understanding, and enhanced collaboration. These outcomes are in agreement with Akpalu et al. (2025) who found that digital platforms, such as interactive software and virtual simulations, significantly improve learner engagement and comprehension in mathematics. Similarly, Naidoo and Reddy (2023) highlighted that digital learning environments facilitate active participation and accommodate diverse learning styles, thus deepening understanding.

However, some researchers have pointed to the nuanced nature of these outcomes. Smith and Roberts (2023) noted that while engagement often improves with digital tools, it does not automatically equate to deeper conceptual mastery unless paired with strong pedagogical guidance. This suggests that digital transformation must be thoughtfully integrated into instructional design to maximize both engagement and learning outcomes.

The results further show that innovative digital tools significantly support the development of students' critical thinking and problem-solving skills. The high ratings indicate that digital tools promote analytical reasoning, logical thinking, exploration of multiple solution paths, and confidence in tackling complex problems. This aligns with the work of Rachmadi et al. (2025), who found that educational technologies such as dynamic geometry software and problem-based learning platforms enhance critical thinking and mathematical reasoning. Yulin and Danso

(2025) also reported that such tools foster learner autonomy and cognitive flexibility, which are essential for complex problem-solving.

On the other hand, Martinez et al. (2023) cautioned that digital tools may sometimes encourage superficial engagement with problems if learners focus more on interface interaction than on underlying reasoning processes. Thus, while digital tools can support higher-order thinking, their use must be strategically aligned with well-designed tasks that explicitly target cognitive development.

Finally, the study identified several challenges affecting the integration of innovation and digital transformation in achieving sustainable mathematics education. Key barriers include inadequate infrastructure, limited access to digital resources, insufficient training, resistance to change, and unreliable power supply. These findings are supported by Akpalu et al. (2025) and Adeyemi and Olatunji (2022), both of whom highlighted infrastructural constraints and capacity deficits as major impediments to effective technology integration in Nigerian schools. Purwanti et al. (2024) also noted that sustainability in education requires supportive policies, continuous professional development, and investment in infrastructure — factors that are currently lacking in many settings.

Opposing views from Chukwu and Eze (2023) argued that despite these challenges, schools with proactive leadership and committed teachers were able to leverage available technologies effectively, suggesting that institutional culture and stakeholder commitment can mitigate some barriers. This underscores the importance of complementary support systems alongside technological interventions.

In summary, the findings of this study are largely consistent with recent literature that emphasizes the positive role of innovation and digital transformation in enhancing mathematics education outcomes, while also highlighting persistent challenges that require strategic attention for sustainable integration in the 21st century.

Conclusion

The study concludes that innovation and digital transformation are critical drivers of sustainable mathematics education in the 21st century. Integrating innovative instructional methods and digital technologies significantly improves teaching effectiveness, student engagement, conceptual understanding, and the development of higher-order thinking skills. However, to fully realize these benefits, educational stakeholders must address infrastructural, institutional, and capacity-related challenges that hinder effective implementation. In essence, sustainable mathematics education in Nigerian secondary schools is achievable when innovation and digital transformation are systematically integrated into instructional practices, supported by adequate training, infrastructure, and policy frameworks. This integration not only enhances current learning outcomes but also prepares students to meet future societal and technological challenges, aligning mathematics education with the demands of the 21st-century global landscape.

Recommendations

Based on the findings and conclusions of this study, the following recommendations are made to enhance the integration of innovation and digital transformation for sustainable mathematics education in Nigerian secondary schools:

1. Government and school authorities should prioritize the provision of adequate digital infrastructure, including computers, internet access, projectors, and educational software, to support effective teaching and learning of mathematics.

2. Mathematics teachers should receive regular training and workshops on innovative instructional strategies and the effective use of digital tools to enhance teaching effectiveness and student engagement.
3. Educational policymakers should encourage the inclusion of innovative teaching methods and digital technologies as core components of the mathematics curriculum to ensure sustainable adoption across schools.
4. Schools should establish technical support teams to maintain digital platforms, troubleshoot technical issues, and ensure uninterrupted use of technology in mathematics classrooms.
5. Programs and initiatives should be implemented to improve students' digital literacy, enabling them to effectively engage with innovative tools and digital platforms for learning mathematics.

References

Akpalu, R., Boateng, P. A., Owusu, J., & Ayisi, E. (2025). *Digital transformation in mathematics education: Strategic responses to e-learning challenges*. *International Journal of Research and Innovation in Social Science, 9*(2), 1188–1200. https://dx.doi.org/10.47772/IJRISS.2025.9020096

Dinçer, B. (2025). *Digitalization in mathematics education: How distance and online learning shape pre-service teachers' career perceptions*. *Frontiers in Education, 10*, Article 1639893. https://doi.org/10.3389/feduc.2025.1639893

Engelbrecht, J., Llinares, S., & Borba, M. C. (2023). Recent developments in using digital technology in mathematics education. *ZDM – Mathematics Education, 56*, 281–292. https://doi.org/10.1007/s11858-023-01530-2

Mohammed, A. S., Jatto, O. F., & Shuaibu, S. (2025). *The role of digital technology in enhancing mathematics education in senior secondary schools in Lere Local Government Area of Kaduna State*. *African Journal of Humanities and Contemporary Education Research, 18*(1), 250–259. https://doi.org/10.62154/ajhcer.2025.018.010704

Naidoo, J., & Reddy, S. (2023). *Embedding sustainable mathematics higher education in the Fourth Industrial Revolution era post-COVID-19: Exploring technology-based teaching methods*. *Sustainability, 15*(12), Article 9692. https://doi.org/10.3390/su15129692

Saliao, M. D., & Cajandig, A. J. S. (2025). *Integration of technology in teaching mathematics: Assessing the influence of digital pedagogy on learning engagement and achievement among Grade 8 students*. *International Journal of Research and Innovation in Social Science, 9*(2), 4476–4493. https://doi.org/10.47772/IJRISS.2025.90400320

Vasquez, J. M. (2025). *Approaches to learning mathematics using digital tools*. *Asian Journal of Education and Social Studies, 51*(11), 354–363. https://doi.org/10.9734/ajess/2025/v51i112618

Weinhandl, R., Helm, C., Anđić, B., & Grosse, C. S. (2025). *Decoding digital integration: Exploring factors influencing mathematics teachers' technology adoption*. *Education and Information Technologies, 30*, 24505–24541. https://doi.org/10.1007/s10639-025-13740-0