ICT as Tool, Tutor and Tutee in Tertiary Institutions in Cross River State: A Panacea for Effective Instructional Process in Science Education

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Abstract
In the face of growing challenges in science education—ranging from insufficient laboratory facilities to limited instructional resources—tertiary institutions in Cross River State must embrace innovative pedagogies. This paper explored the integration of Information and Communication Technology (ICT) as a tool, tutor, and tutee, and its transformative potential for effective science instruction. ICT as a tool facilitates visualization of abstract concepts through simulations and multimedia; as a tutor, it enables personalized, self-paced learning via digital platforms; and as a tutee, it empowers students to engage in creative knowledge construction through programming and content generation. Drawing from recent research and practical applications in Nigerian institutions, the paper argues that ICT can bridge instructional gaps, enhance student engagement, and improve academic outcomes in science disciplines. It concludes that for ICT to serve as a panacea for science education, institutions must invest in infrastructure, build educator capacity, and implement sustainable digital policies aligned with national education frameworks
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1. Introduction

Tertiary institutions play a pivotal role in national development by advancing knowledge, fostering innovation, and producing a skilled workforce capable of addressing contemporary societal challenges. In Nigeria, universities, polytechnics, and colleges serve as engines for socio-economic progress, equipping graduates with the competencies needed to drive national transformation. Despite their strategic importance, these institutions face persistent challenges, including inadequate infrastructure, limited instructional resources, and increasing pressure to deliver quality education—particularly in science education, where hands-on learning and practical experimentation are indispensable.

The integration of Information and Communication Technology (ICT) offers a viable solution to many of these challenges. As educational demands grow and the need for innovation in teaching intensifies, ICT has emerged as a transformative force in instructional delivery. In tertiary institutions across Cross River State, ICT is increasingly recognized not only as a support mechanism but as a central component in enhancing the teaching and learning of science-related courses. Its application fosters active engagement, personalized learning, and greater accessibility to scientific content.

As educational demands intensify, ICT has become indispensable in reshaping instructional delivery. Its relevance in tertiary institutions across Cross River State is evident in its ability to transform science education into a more interactive, engaging, and student-centered process. ICT serves in three interrelated capacities—as a tool, a tutor, and a tutee—each playing a vital role in modern teaching practices. Each of these roles contributes significantly to improving the quality and effectiveness of science education in the 21st century.

2. ICT as a Tool in Science Education

Information and Communication Technology (ICT) as a tool plays a transformative role in modern science education by enriching instructional delivery, simplifying complex scientific phenomena, and enhancing both teachers and students engagement. In science-related disciplines—where abstract concepts often pose a barrier to student comprehension—ICT tools such as virtual laboratories, digital simulations, data analysis software, animations, and multimedia presentations serve to concretize theoretical knowledge and promote active learning (Eze & Igwe, 2020; Aina & Kayode, 2021).

These tools support educators in designing more interactive and visually stimulating lessons that foster deeper conceptual understanding. For instance, the use of PowerPoint slides, interactive whiteboards, graphing software, and digital data loggers has become standard in many tertiary institutions. These technologies help learners visualize molecular structures, analyze experimental data, and simulate complex biological or chemical reactions—skills that are otherwise difficult to acquire through traditional chalk-and-talk methods (Essien & Bassey, 2021).

ICT tools promote greater efficiency and communication within and beyond the classroom. Platforms like Google Classroom, WhatsApp groups, and email allow lecturers to share lecture materials, conduct virtual discussions, and provide real-time feedback to students. This enhances collaboration and extends learning beyond the physical classroom, particularly in environments constrained by limited laboratory infrastructure or large student populations (Nwosu & Okereke, 2021; Udo & Inyang, 2022).

In Mathematics, ICT is widely used as a tool to enhance visualization, computation, and modeling. Software such as Microsoft Excel, GeoGebra, and Desmos allow students to construct graphs, solve equations, and model real-world problems. These tools facilitate deeper understanding of concepts such as algebraic functions, statistics, and geometry. For example, Desmos is a graphing calculator app that allows students to input equations and observe their graphical representations, which enhances their understanding of the relationship between variables (Yusuf & Balogun, 2019). Similarly, Excel is used for statistical data analysis and visualization in probability and data management topics (Oludipe & Olayemi, 2020).

Physics education benefits from ICT tools through simulations, data collection interfaces, and visualization software. Tools like Logger Pro, Crocodile Physics, and Tracker Video Analysis support the collection, analysis, and visualization of physical phenomena such as motion, electricity, and waves. Tracker, for instance, is a video analysis tool used to study the motion of objects. Students record a video of a moving object and analyze its velocity, acceleration, and displacement using digital overlays. This supports hands-on learning and fosters inquiry-based skills (Idowu & Oyelami, 2021).

In Chemistry, ICT tools such as ChemSketch, Molecular Workbench, and Periodic Table Apps support molecular modeling, chemical structure drawing, and visualization of chemical reactions. These tools allow learners to manipulate and explore molecular models in three dimensions, helping them understand atomic structure, bonding, and reaction mechanisms. For example, ChemSketch enables students to draw complex chemical compounds and predict their structures, an important skill in organic chemistry (Nwafor & Akpan, 2020). Molecular Workbench provides interactive simulations that let students explore gas laws and chemical kinetics, improving conceptual clarity.

ICT tools in Biology include interactive atlases, digital microscopes, data loggers, and genetics simulators. These tools allow students to explore life systems and biological processes more effectively. For instance, the BioDigital Human platform allows users to explore the human body in interactive 3D, zooming in on organs, systems, and pathologies. Teachers and students can annotate structures and integrate the visuals into reports and presentations (Ogunlade & Afolabi, 2019). Additionally, data loggers are used in experiments to measure temperature, light, and pH changes in real-time during biological experiments like respiration and photosynthesis.

In Cross River State, the adoption of ICT tools in science education has seen gradual but impactful implementation in tertiary institutions such as the University of Calabar and the University of Cross River State (UNICROSS) among others in the State. These institutions have not integrated technologies such as virtual lab simulations, smart boards, and multimedia content delivery in departments like mathematics, physics, chemistry, and biology to improve instructional effectiveness. According to Bassey and Ogar (2022), students exposed to such ICT-enabled environments exhibit greater motivation, improved academic performance, and higher retention of scientific concepts. Ultimately, the use of ICT as a tool will enhance not only teaching strategies but also learner outcomes, positioning science education to meet the evolving demands of the 21st-century knowledge economy.

3. ICT as a Tutor in Science Education

In its role as a tutor, Information and Communication Technology (ICT) delivers structured and adaptive instruction to learners through platforms such as Computer-Assisted Learning (CAL), Intelligent Tutoring Systems (ITS), and Learning Management Systems (LMS) like Moodle, Google Classroom, and Edmodo. These systems offer interactive tutorials, assign assessments, track student progress, and provide real-time feedback—supporting self-regulated, individualized learning experiences (Afolabi & Ayeni, 2019; Adeyemo & Udo, 2020). In science education, where abstract concepts and complex processes often require repetitive and scaffolded instruction, ICT tutorial systems play a crucial role. In Mathematics, ICT tutoring systems such as Computer-Assisted Instruction (CAI), GeoGebra, and Mathletics serve as intelligent tutors by guiding learners through procedures, offering real-time hints, and correcting mistakes. These tools offer visualizations for algebra, geometry, and calculus, enhancing understanding through interactive graphics and step-by-step guidance. For instance, GeoGebra, an interactive geometry, algebra, and calculus application, acts as a tutor by enabling students to manipulate variables and observe mathematical relationships dynamically. It helps in topics like transformation, coordinate geometry, and functions, which are often abstract when taught conventionally (Yusuf & Balogun, 2019). Similarly, platforms like Khan Academy use artificial intelligence to tutor students individually by adapting to their pace, identifying weak areas, and suggesting personalized learning paths (Wang & Huang, 2021).

Physics requires the visualization of phenomena such as motion, force, and energy transformation. ICT-based tutoring tools like PhET Interactive Simulations, Virtual Physics Labs, and Smart Physics function as digital tutors by modeling real-world physical phenomena in simulated environments. For example, PhET simulations allow students to conduct experiments on topics like electric circuits, projectile motion, and Newtonian mechanics, guiding them through theoretical explanations and offering assessments to reinforce learning (Bayrak & Ozel, 2019). These tools make abstract Physics concepts more concrete, fostering deeper conceptual understanding and reducing misconceptions.

In Chemistry, ICT tools serve as tutors by providing simulations of molecular interactions, chemical reactions, and laboratory experiments. These tools often include guided problem-solving, virtual labs, and animated reaction mechanisms. ChemCollective, a virtual chemistry lab, enables students to practice laboratory skills such as titration and pH testing with automated feedback on their progress. According to Nwafor and Akpan (2020), the use of ChemCollective improved students' performance in stoichiometry and reaction kinetics, as it allowed them to repeat experiments under different conditions until mastery was achieved.

Biology instruction benefits from ICT tutoring through animations, virtual dissections, and tutorials that explain complex systems like the human circulatory system or genetic inheritance. Tools such as BioDigital Human, Virtual Biology Lab, and Visible Body provide tutoring support by allowing students to interact with 3D models and simulations. For instance, the BioDigital Human tool enables students to explore the anatomy and physiology of body systems with interactive feedback and narration, functioning much like a personal tutor. Similarly, virtual dissection software replaces physical dissection with step-by-step guides and quizzes to reinforce learning outcomes (Ogunlade & Afolabi, 2019).

In tertiary institutions across Cross River State, such technologies would have improved laboratory preparedness and theoretical grounding among undergraduates in disciplines like biology, chemistry, and physics. By supplementing face-to-face teaching, ICT tutorial tools reduce the cognitive workload of instructors while enhancing student engagement and performance (Ewa & Okon, 2021). For example, virtual labs and interactive software allow students to pre-learn procedures and concepts before engaging in physical experiments, thereby increasing efficiency during lab sessions.

Moreover, intelligent tutoring systems are capable of diagnosing students' learning gaps and adjusting instructional content accordingly. This formative feedback mechanism is vital in science education, where mastery often depends on students' ability to apply theoretical knowledge to problem-solving contexts. By allowing for differentiated instruction and adaptive remediation, ICT tutors help learners take ownership of their progress, fostering greater autonomy and motivation (Ukpong & Bassey, 2020). Ultimately, the use of ICT as a tutor in science education enables a more personalized, data-driven, and learner-centered approach, particularly in Nigerian tertiary institutions facing challenges of overcrowding, limited laboratory facilities, and teacher shortages.

4. ICT as a Tutee in Science Education

The concept of ICT as a tutee represents a constructivist approach to learning in which students use technology to create, program, or manipulate digital tools, thereby deepening their understanding through active engagement. Rather than passively receiving instruction, learners assume the role of tutors by teaching the machine—through activities such as coding, simulation building, digital modeling, and data analysis—which in turn strengthens their subject mastery (Anene & Okafor, 2020; Yusuf & Ayoola, 2019).

In Mathematics, students use programming languages such as Python, Scratch, or Logo to model problems and build algorithms for solving equations or visualizing functions. This approach allows learners to "teach" the computer how to perform calculations or draw geometric shapes by writing specific commands. For example, students can use Scratch to create animations that explain mathematical operations such as addition or plotting linear equations. Such activities encourage algorithmic thinking and logical reasoning (Olagunju & Ojo, 2019). Moreover, using Python to solve problems involving loops, variables, or matrices has been found to enhance students' mathematical modeling skills (Afolabi & Ogunlade, 2021).

Physics education benefits from ICT as a tutee through student-driven creation of simulations and models. Learners can design basic simulations of physical phenomena such as projectile motion, pendulum swings, or electrical circuits using platforms like PhET Simulation Toolkit for Developers, Scratch, or Python with VPython libraries. For instance, students can write a program to simulate Newton's laws of motion or model free-fall motion under gravity. In doing so, they refine their understanding of the underlying physics while simultaneously improving their computational skills (Adegboye & Jegede, 2020). Teaching the computer to simulate experiments reinforces both content mastery and ICT competence.

In Chemistry, students can engage with ICT as a tutee by developing simple animations or simulations to demonstrate chemical processes, such as balancing chemical equations or modeling molecular structures. Tools such as Alice, Scratch, or ChemReaX allow learners to animate chemical reactions or visualize stoichiometric relationships. For example, students might write a program in Scratch to visualize how reactants turn into products in a combustion reaction, or use a block-based coding environment to build interactive quizzes for chemical bonding (Nwafor & Akpan, 2020). These processes allow learners to embed their scientific understanding into digital formats.

In Biology, students can create animations, infographics, and simulations to explain biological processes such as photosynthesis, digestion, or genetics. Programming tools like Scratch, Tynker, and App Inventor are commonly used by students to build educational content that reflects their understanding of biological systems. For example, a student may design an interactive app using MIT App Inventor that teaches others about the structure of the human heart or the stages of mitosis. This form of "teaching the computer" enhances content mastery and helps students organize their thoughts in logical sequences (Ogunlade & Afolabi, 2019).

In science education, this approach facilitates computational thinking and inquiry-based learning. By programming simulations or building interactive models, students internalize complex scientific processes and acquire transferable problem-solving skills. For instance, tertiary students in Cross River State studying disciplines such as biology, chemistry, environmental science, and computer science have begun developing software applications and simulations that replicate natural phenomena—such as cell division, atmospheric change, or chemical reactions (Udo & Etim, 2021). This not only fosters creativity and innovation but also encourages deeper engagement with scientific concepts.

Using ICT in this way empowers students to take ownership of their learning process. As learners instruct the system to perform specific functions—whether building algorithms, creating animations of physics laws, or organizing scientific data—they actively reconstruct and reinforce their understanding. According to Essien and Bassey (2021), this interactive learning approach has been shown to enhance critical thinking, metacognitive awareness, and retention of scientific content among science and engineering undergraduates in Cross River State.

Moreover, ICT as a tutee helps bridge the gap between theory and application, allowing students to test hypotheses and explore real-world implications of their knowledge through digital experimentation. This aligns with global trends in STEM education that emphasize project-based learning and digital literacy as essential competencies for 21st-century learners (Ekanem & Inyang, 2020). By engaging with ICT as a tutee, students become active participants in knowledge construction, moving beyond passive consumption to the development of digital artifacts that reflect meaningful scientific inquiry and practical problem-solving.

5. A Panacea for Instructional Effectiveness in Science Education

The integration of Information and Communication Technology (ICT) as a tool, tutor, and tutee presents a transformative approach to addressing persistent challenges in science education—particularly in resource-constrained environments such as those found in Cross River State. These challenges include inadequate laboratory facilities, passive instructional methods, and limited access to up-to-date teaching materials. ICT not only mitigates these barriers but also promotes constructivist, learner-centered pedagogies that enhance student engagement, conceptual understanding, and scientific inquiry.

ICT applications in science education foster interactive learning environments, encourage problem-solving, and support real-time data analysis and visualization. As a tool, ICT simplifies the teaching of abstract scientific concepts; as a tutor, it provides adaptive and personalized instruction; and as a tutee, it empowers students to construct knowledge by designing digital content or simulations (Ekpenyong & Ibe, 2020; Essien & Bassey, 2021). This tripartite role of ICT has been associated with improved academic performance, motivation, and cognitive development among students in science disciplines.

Recent studies affirm that tertiary institutions investing in ICT infrastructure and professional development for academic staff experience measurable improvements in teaching effectiveness and learning outcomes. Udo and Inyang (2022) reported that science departments in Nigerian universities that adopted blended learning and virtual laboratories observed enhanced student satisfaction, greater instructional efficiency, and improved examination performance. In Cross River State, where many institutions struggle with underfunded science programs, ICT offers scalable, cost-effective alternatives to traditional laboratory instruction, bridging the digital divide and enhancing access to quality education (Okon & Asuquo, 2021).

Furthermore, national education bodies such as the National Universities Commission (NUC) and the National Board for Technical Education (NBTE) have recognized ICT as a critical driver of instructional quality. Both agencies have integrated ICT compliance into their quality assurance frameworks, requiring institutions to adopt digital technologies in curriculum delivery, laboratory instruction, and academic assessment (Olanrewaju & Ayoola, 2019). This institutional push highlights the strategic role of ICT in achieving the Sustainable Development Goals (SDGs), especially in ensuring inclusive, equitable, and quality science education.

The strategic deployment of ICT in its roles as tool, tutor, and tutee represents a holistic solution to the instructional challenges confronting science education in tertiary institutions. For states like Cross River, where physical infrastructure is often lacking, ICT provides an avenue to democratize learning, enhance pedagogical practice, and prepare students for innovation-driven careers in STEM fields.

6. Conclusion

When strategically implemented, Information and Communication Technology (ICT)—in its roles as a tool, tutor, and tutee—has the transformative potential to revolutionize instructional delivery in science education, particularly within tertiary institutions in Cross River State. ICT as a tool provides educators and learners with access to a wide range of digital resources, including virtual laboratories, simulations, and interactive models that make abstract scientific concepts more concrete. As a tutor, ICT offers adaptive learning platforms, digital tutorials, and automated feedback systems that guide students through personalized learning experiences, promoting mastery at an individual pace. Meanwhile, in its role as a tutee, ICT allows students to develop essential digital literacy and problem-solving skills, preparing them for participation in the knowledge-driven global economy.

The integration of ICT addresses persistent challenges in science education such as inadequate laboratory facilities, limited instructional resources, and traditional teacher-centered pedagogies. Through virtual experiments, interactive multimedia, and online collaborative tools, students can engage in inquiry-based learning even in the absence of physical laboratories. Furthermore, ICT fosters active learning, conceptual clarity, and learner-centered instruction, moving away from rote memorization to deeper understanding and application of scientific principles. The use of digital platforms also enables greater interactivity, real-time assessment, and student engagement, thereby enhancing overall learning outcomes.

However, the promise of ICT in science education cannot be realized without deliberate and sustained efforts. First, there is a need for intentional investment in digital infrastructure, such as reliable internet connectivity, modern computer laboratories, and adequate power supply. Second, capacity building for educators is crucial to ensure they possess the skills and confidence to effectively integrate ICT tools into their teaching practices. Third, the development and implementation of clear institutional policies are necessary to provide direction and sustainability for ICT integration efforts, ensuring they are not ad hoc or short-lived.

Without these foundational supports, ICT risks being underutilized or misapplied, thereby leaving the existing educational challenges unresolved. Therefore, stakeholders—including government agencies, institutional administrators, educators, and private sector partners—must adopt a holistic and future-oriented approach to ICT deployment. This approach should emphasize accessibility, quality, and sustainability, ensuring that science education in Cross River State aligns with 21st-century global educational standards and prepares graduates to thrive in an increasingly digital and scientific world.

7. Recommendations

1. Tertiary institutions in Cross River State should prioritize the development and maintenance of robust digital infrastructure—such as high-speed internet, virtual laboratories, and smart classrooms—to support ICT-enabled science instruction.
2. Regular training and workshops should be provided for science educators to enhance their competence in using ICT tools, tutoring platforms, and content creation applications that promote student engagement and independent learning.
3. Science curricula should be revised to integrate ICT-based instructional methodologies, allowing students to benefit from self-paced learning systems, digital modeling, simulations, and collaborative online learning environments.
4. Government and institutional administrators should allocate budgetary provisions for ICT procurement, software licensing, maintenance, and technical support in science faculties.
5. Establish mechanisms for tracking ICT usage and effectiveness in teaching science courses. Feedback from students and lecturers should guide periodic improvements in ICT implementation strategies.
6. Ensure all students, regardless of background, have equal access to ICT resources. This includes subsidized data access, provision of devices, and accessible learning platforms for students in underserved areas.

8. Policy Implications

1. National and state education bodies (e.g., NUC and NBTE) should mandate the integration of ICT in science education curricula and align teacher training programs accordingly.
2. Tertiary institutions should collaborate with ICT companies and NGOs to fund and support infrastructure upgrades, content development, and access to cutting-edge educational technology.
3. Science education policies should include digital literacy benchmarks for both students and educators as graduation and certification requirements, ensuring ICT fluency across the academic community.
4. Governments should create sustainable funding mechanisms—such as ICT education grants and intervention funds—for higher institutions, particularly in science and technology departments.
5. Institutions should adopt evidence-based decision-making models using data collected from ICT usage analytics, student performance, and feedback to shape instructional strategies and resource allocation.

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