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Teaching Science with ICT: Practices and Challenges in Greek Secondary Education

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ABSTRACT

This paper investigates the integration of Information and Communication Technologies (ICT) in science education within Greek secondary schools, with a particular focus on biology and environmental science. Drawing on empirical studies and documented practices, it highlights the pedagogical potential of digital tools in supporting students' conceptual understanding and fostering engagement. At the same time, the paper outlines persistent barriers such as limited teacher training, infrastructural disparities, and the disconnect between educational policy and classroom realities. It further contrasts the differing ICT applications across biology and environmental science, noting how each discipline requires tailored digital strategies, ranging from 3D visualization tools to geospatial data platforms. The study emphasizes the importance of teacher readiness, inclusive pedagogy, and institutional collaboration as critical levers for sustainable ICT integration. Case studies from urban and rural schools illustrate both innovations and inequalities in practice. The paper concludes by offering recommendations for capacity building, equity-centered policies, and design-based research partnerships, positioning ICT not merely as a technical enhancement, but as a transformative force in cultivating scientific literacy and environmental citizenship among students.

Keywords: *ICT integration; science education; biology teaching; environmental science; teacher professional development*

INTRODUCTION

In the evolving landscape of science education, the integration of Information and Communication Technologies (ICT) is no longer an experimental add-on but a central component in shaping the teaching and learning process. In secondary education, where students form foundational understandings of scientific reasoning and inquiry, digital tools provide new pathways for experimentation, visualization, and engagement.

The affordances of ICT align strongly with pedagogical approaches rooted in constructivism and inquiry-based learning, where knowledge emerges through active exploration and contextual application. International models such as the Technological Pedagogical Content Knowledge (TPACK) framework emphasize that effective ICT use requires the interplay of content expertise, pedagogical strategies, and technological fluency (Mishra & Koehler, 2006; Jimoyiannis, 2010). Within this framework, science teaching benefits from tools that simulate complex systems, foster collaborative learning, and promote real-time data collection and analysis.

Biology and environmental science occupy a distinctive place in the scientific curriculum. Both fields involve systems and phenomena that are either microscopic in scale, such as cellular processes and genetic mechanisms, or too large and dispersed to observe directly, as in climate change and ecosystem dynamics. ICT bridges these gaps through simulations, 3D visualizations, and geospatial tools, transforming abstract principles into tangible experiences (Rutten, van Joolingen & van der Veen, 2012; Chorianopoulos & Giannakos, 2020).

In the Greek context, efforts to modernize education through digital infrastructure and training are visible in national policy frameworks and Ministry initiatives (Tzimopoulos & Gritzalis, 2020; Hellenic Ministry of Education, 2021). However, the practical integration of ICT in science classrooms remains uneven. Many educators in secondary schools encounter persistent barriers: limited access to resources, insufficient professional development, and a lack of institutional continuity or support (Kampylis & Punie, 2015; OECD, 2018).

This paper explores how ICT is utilized in the teaching of biology and environmental science in Greek secondary education. It synthesizes recent literature, highlights tools and techniques in active use, identifies key obstacles to effective implementation, and presents practitioner-informed recommendations. Through this lens, the study aims to connect educational policy with classroom practice and to shed light on the evolving role of ICT in preparing students for scientifically literate, future-ready citizenship.

MATERIALS AND METHODS

This study employs a qualitative, literature-based methodology focused on exploring the role of ICT in secondary-level biology and environmental science education within the Greek context. Rather than relying on primary empirical data, it synthesizes existing research findings, policy reports, and pedagogical case studies published between 2015 and 2024.

The selection process prioritized peer-reviewed journal articles investigating ICT integration in science teaching, particularly within Greek or European secondary schools (OECD, 2018; Kampylis & Punie, 2015); government and institutional policy documents from the Hellenic Ministry of Education and the European Commission related to digital transformation in education (Hellenic Ministry of Education, 2021; European Commission, 2021); and case studies and practitioner reports highlighting classroom-level initiatives, teacher perceptions, or training programs (Tzimopoulos & Gritzalis, 2020; Kynigos & Avgitidou, 2018).

Sources were located through educational databases such as ERIC, Scopus, and Google Scholar using targeted keywords including “ICT in biology education”, “digital tools in environmental science”, “Greek secondary schools”, and “teacher professional development.” The final selection included both quantitative and qualitative studies to reflect diverse methodological perspectives (Rutten, van Joolingen & van der Veen, 2012; Argyri & Karkanis, 2021).

Findings from these materials were grouped thematically into six overarching categories: types of ICT tools utilized; examples of successful integration; common pedagogical barriers; discipline-specific practices in biology and environmental science; teacher training and digital readiness; and policy recommendations and systemic challenges (Tsiatsos & Stavropoulos, 2019).

This thematic synthesis enables a holistic understanding of how ICT is applied, and at times underutilized, across scientific disciplines in the Greek secondary education landscape. The thematic synthesis also supports comparisons between the two subject areas, revealing shared challenges and unique demands shaped by content specificity and pedagogical norms (Angeli & Valanides, 2017).

RESULTS AND FINDINGS

ICT Tools in Secondary Science Teaching

Teachers in Greek secondary schools utilize an expanding array of digital resources to enhance science instruction. Commonly used tools include:

- **Presentation software** such as PowerPoint and Prezi, which support visual storytelling and structured content delivery;
- **Virtual laboratories** including PhET and Labster that allow students to explore phenomena such as chemical reactions, cellular processes, and ecological systems in simulated environments (Rutten, van Joolingen & van der Veen, 2012);
- **Sensors and probeware** used in environmental lessons to collect real-time data on temperature, pH, and light levels (Mavrikaki & Kapsalis, 2019; Loukis & Giannoukos, 2022);
- **Learning Management Systems** (LMS) such as e-Class, Moodle, and Google Classroom, which centralize instructional material, assessments, and collaborative activities;
- **Multimedia resources**, including instructional videos, interactive diagrams, and digital textbooks, particularly valuable in biology for visualizing complex anatomical or microscopic content (Chorianopoulos & Giannakos, 2020).

The extent to which these tools are utilized varies across schools depending on infrastructure availability, teacher readiness, and curriculum flexibility. Nevertheless, a growing trend toward blended learning practices is evident (Tzimopoulos & Gritzalis, 2020).

Effective Practices and School Level Innovations

Despite systemic challenges, several examples of effective ICT integration have been identified:

- Biology teachers collaborating to develop online repositories containing 3D models of cells, interactive quizzes, and digital concept maps shared across platforms like Moodle or Google Classroom;
- Environmental science units incorporating field-based data collection using smartphones, followed by collaborative analysis using spreadsheets and geospatial mapping tools (Mavrikaki & Kapsalis, 2019);
- Implementation of digital science portfolios where students document inquiry-based projects using multimedia formats including photos, data tables, and reflective narratives (Tsiatsos & Stavropoulos, 2019);
- Institutional support mechanisms such as leadership encouragement, designated collaboration time, and partnerships with universities or NGOs to sustain ICT-enhanced instruction (Kynigos & Avgitidou, 2018).

Evidence suggests that schools fostering knowledge-sharing networks and peer mentoring among teachers experience higher levels of digital tool integration (Angeli & Valanides, 2017).

Barriers to ICT Integration

Despite growing awareness of the benefits of ICT in science education, multiple barriers continue to impede meaningful integration across Greek secondary schools. These challenges span infrastructural, pedagogical, and systemic dimensions:

- **Technical constraints**, including outdated hardware, limited Internet bandwidth, and scarce access to functional computer labs, especially in rural schools, remain a significant obstacle (Papanikolaou & Mavrikaki, 2020; Loukis & Giannoukos, 2022).
- **Time limitations**, with teachers often citing lack of preparation periods to explore new tools or redesign lesson plans for ICT use (Angeli & Valanides, 2017).
- **Professional development gaps**, where training often focuses on generic digital skills rather than subject-specific or inquiry-based applications (Jimoyiannis, 2010; Kampylis & Punie, 2015).
- **Rigid curricula**, which prioritize factual content coverage over interactive, student-centered learning, leaving little space for experimentation (Tzimopoulos & Gritzalis, 2020).
- **Regional disparities**, as schools in remote areas frequently report lower resource availability, weaker support networks, and reduced access to academic partnerships (OECD, 2018; European Commission, 2021).

These overlapping issues reinforce the importance of aligning national digital policy with real classroom conditions and teacher needs. Without targeted support and structural flexibility, ICT remains an “aspirational” element rather than a lived pedagogical reality.

ICT in Biology Education

The teaching of biology at the secondary level benefits considerably from ICT-enhanced visualization tools and simulations. These technologies support learners in grasping abstract and microscopic processes that are otherwise inaccessible in traditional classroom settings. Prominent examples include:

- **3D cell models**, which enable students to explore organelles and comprehend spatial relationships among cellular structures (Chorianopoulos & Giannakos, 2020; Mishra & Koehler, 2006);
- **Animation-based learning tools,** used to simulate dynamic biological mechanisms such as DNA replication, enzyme activity, and inheritance (Rutten, van Joolingen & van der Veen, 2012);
- **Microscopy simulators**, which replicate the functions of laboratory microscopes, offering magnification and image analysis capabilities where physical equipment is unavailable;
- **Augmented reality** (AR) applications, allowing kinesthetic exploration of anatomical systems through 3D projections in the classroom (Chorianopoulos & Giannakos, 2020).

These tools have been shown to enhance comprehension and retention by making invisible or complex biological phenomena more concrete (Louca & Constantinou, 2020). However, access to such tools remains unequal, and in earlier studies many biology teachers reported limited confidence in integrating them effectively without specialized training (Jimoyiannis, 2010; Kampylis & Punie, 2015).

ICT in Environmental Science Education

Environmental science, with its emphasis on systems thinking and place-based learning, is particularly well-suited for ICT integration. Digital tools in this subject area often support real-time monitoring and spatial analysis, helping students to investigate ecological interactions and human impact. Commonly used technologies include:

- **Geographic Information Systems** (GIS)**,** which visualize spatial data related to land use, vegetation, and climate trends (Mavrikaki & Kapsalis, 2019);

- **Open-access global datasets**, such as NASA's Earthdata and Copernicus, used by students to examine long-term environmental indicators (Dimitriou & Tsiara, 2020);
- **Real-time environmental monitoring tools**, including sensors for measuring air quality, CO_2 levels, or water parameters, often linked to local investigations (Loukis & Giannoukos, 2022);
- **Virtual field trips and immersive digital experiences**, offering students a window into distant ecosystems or urban infrastructures without leaving the classroom (Karachristos & Foti, 2023).

In many Greek schools, teachers have creatively linked these tools with community-based projects, enabling learners to collect, visualize, and interpret environmental data from nearby forests, rivers, or neighborhoods (Karydaki & Sidiropoulos, 2019). This approach fosters both scientific literacy and civic responsibility.

Biology vs. Environmental Science: Comparative Observations

While both biology and environmental science benefit significantly from the integration of ICT, their applications reveal distinct disciplinary patterns and pedagogical requirements:

- **Visualization vs. Spatial Analysis**: Biology instruction often emphasizes visualization and animation to make abstract, microscopic processes comprehensible, such as protein synthesis or mitosis (Chorianopoulos & Giannakos, 2020). In contrast, environmental science has leveraged spatial analysis and real-time data to engage students with larger-scale ecological systems and human-environment interactions (Mavrikaki & Kapsalis, 2019).
- **Content Comprehension vs. Civic Inquiry**: ICT in biology tends to reinforce conceptual understanding of scientific content, often through structured simulations and model manipulation. In environmental science, however, ICT tools support student engagement with real-world challenges, encouraging reflective, interdisciplinary inquiry and problem-solving (Karydaki & Sidiropoulos, 2019; Karachristos & Foti, 2023).
- **Pedagogical Orientation**: Biology teachers often deploy digital resources to illustrate predefined concepts, whereas environmental educators more frequently design open-ended tasks that promote student agency and field-based investigation (Loukis & Giannoukos, 2022).
- **Mobile and Community-Based Practices**: Mobile data collection and geolocation tools are more commonly used in environmental science, especially when linked to place-based learning or citizen science projects (Papanikolaou & Mavrikaki, 2020). Biology, though increasingly adopting AR/VR tools, still relies more heavily on lab-centered simulations.

These comparisons highlight the importance of discipline-sensitive ICT strategies. They emphasise how generic digital resources, no matter how sophisticated, may fall short if they do not align with the epistemic and pedagogical demands of each subject (Angeli & Valanides, 2017). Tailored approaches that account for the nature of scientific inquiry in each field are essential to maximizing the impact of technology in science education.

TEACHER READINESS AND TRAINING NEEDS

The successful integration of ICT in science education hinges critically on teacher readiness, not merely in terms of technical skills, but also pedagogical competence and confidence in aligning digital tools with learning objectives.

Earlier studies indicate that while many Greek science teachers have expressed enthusiasm toward using technology, a significant proportion reported limited training in content-specific application. This is particularly true in disciplines such as biology and environmental science, where teachers must combine digital fluency with conceptual complexity (Jimoyiannis, 2010; Kampylis & Punie, 2015).

Existing professional development programs often emphasize tool functionality rather than didactic integration. In contrast, more effective initiatives have provided subject-specific, hands-on learning experiences where educators co-designed ICT-rich lesson plans, engaged in peer simulations, and received feedback in authentic settings (Angeli & Valanides, 2017; Kynigos & Avgitidou, 2018). For example, in an earlier study, biology teachers trained to embed virtual labs within inquiry-based frameworks demonstrated a higher likelihood of sustained usage (Rutten, van Joolingen & van der Veen, 2012). Collaborative learning among teachers also emerges as a powerful lever. Informal professional networks, whether through school-based workshops, digital communities, or university partnerships, facilitate resource exchange, pedagogical reflection, and normalization of digital practices (Tzimopoulos & Gritzalis, 2020; Tsiatsos & Stavropoulos, 2019). These peer structures were found to foster a culture of experimentation and shared innovation.

Nonetheless, barriers persist. Participation in training programs has been characterized as often voluntary, uncoordinated across regions, and hampered by practical constraints such as inflexible teaching schedules or insufficient substitute coverage (OECD, 2018). Moreover, many workshops have been observed to lack continuity or mentoring components, which limits long-term impact (Avraamidou, 2020).

To build teacher readiness as a transformative force, professional learning must evolve from isolated workshops to sustained ecosystems that are context-sensitive, discipline-specific, and empowering. Studies have shown that educators need time, institutional recognition, and platforms to act not only as users of digital tools, but as co-designers of pedagogical change (Mishra & Koehler, 2006; Argyri & Karkanis, 2021).

DISCUSSION

The findings of this study underscore the complex interplay between policy, pedagogy, and practice in the integration of Information and Communication Technologies (ICT) in Greek secondary science education. While national reforms emphasize digital transformation and future-oriented competencies (Hellenic Ministry of Education, 2021; European Commission, 2021), their implementation at the classroom level was often hindered by infrastructural inequities, fragmented professional development, and curricular rigidity (OECD, 2018; Papanikolaou & Mavrikaki, 2020).

A central observation relates to the policy–practice gap, whereby ambitious top-down initiatives fail to fully account for localized constraints, especially in under-resourced or rural schools (Loukis & Giannoukos, 2022). Despite this, teachers have remained critical agents in bridging this divide. As earlier studies have shown, their ability to meaningfully integrate ICT depends not just on access to tools but on systemic support, pedagogical agency, and ongoing capacity building (Jimoyiannis, 2010; Angeli & Valanides, 2017).

Disciplinary considerations are equally vital. As the study reveals, biology and environmental science require distinct digital strategies, rooted in the epistemic structures of each field. Biology instruction benefits from highly visual and interactive simulations that make invisible processes visible, whereas environmental science thrives on geospatial analysis, field-based inquiry, and civic engagement (Chorianopoulos & Giannakos, 2020; Mavrikaki & Kapsalis, 2019). A one-size-fits-all approach to educational technology risks flattening these disciplinary nuances and undermining instructional depth.

Equally important is the cultivation of teacher identity as reflective and digitally competent professionals. Frameworks such as TPACK illuminate how ICT integration is not a mechanical process but an act of pedagogical design, requiring educators to adapt tools to content and learner context (Mishra & Koehler, 2006). Supporting this transformation entails rethinking professional learning as a sustained, practice-embedded process, fueled by peer collaboration, design-based innovation, and institutional recognition (Kynigos & Avgitidou, 2018; Argyri & Karkanis, 2021).

Finally, broader lessons from international comparisons suggest that successful ICT integration depends less on equipment provision and more on ecosystem-level planning. Countries that prioritize leadership development, equity strategies, and participatory policy design tend to report deeper, more equitable ICT uptake (Avraamidou, 2020; European Commission, 2021). In Greece, such a shift could help bridge digital divides and unlock the full pedagogical potential of ICT in science education.

STUDENT ENGAGEMENT AND LEARNING OUTCOMES

The integration of ICT in biology and environmental science education has demonstrated significant potential for enhancing student engagement, fostering active learning, and improving conceptual understanding.

Unlike traditional didactic instruction, ICT enables interactive experiences that support the construction of scientific knowledge through visualization, manipulation, and real-time exploration. In biology, tools such as 3D models of cells and organs allow students to "navigate" within complex structures, enhancing spatial awareness and memory retention (Louca & Constantinou, 2020; Chorianopoulos & Giannakos, 2020). Similarly, virtual laboratories have simulated processes like DNA replication or enzymatic activity, providing safe, repeatable environments for experimentation (Rutten, van Joolingen & van der Veen, 2012).

In environmental science, students engage with data-rich and place-based learning through ICT platforms that visualize ecological trends, pollution patterns, or climate indicators. Tools such as GIS applications and satellite data viewers have promoted evidence-based analysis and interdisciplinary thinking (Mavrikaki & Kapsalis, 2019; Dimitriou & Tsiara, 2020). These experiences have connected scientific content with real-world challenges, and often fostered critical reflection and civic engagement (Karydaki & Sidiropoulos, 2019).

Moreover, the use of interactive assessments, including digital portfolios, quizzes with immediate feedback, and student-authored multimedia content, have supported metacognition and self-regulated learning (Papadakis & Kalogiannakis, 2021; OECD, 2018). Research indicates that such approaches increased student autonomy, motivation, and time-on-task, especially when ICT is embedded in inquiry-based or collaborative structures (Tsiatsos & Stavropoulos, 2019).

It is important, however, to differentiate between surface-level engagement (e.g., enjoyment of a new tool) and deep learning. Without proper scaffolding, instructional intent, and reflection opportunities, the earlier research showed that even the most sophisticated digital environments may result in passive consumption rather than active inquiry (Rutten, van Joolingen & van der Veen, 2012; Angeli & Valanides, 2017). Effective integration thus requires deliberate design, alignment with learning goals, and ongoing pedagogical support.

Despite promising examples across Greek classrooms, ICT-facilitated engagement has remained uneven. Teachers who create authentic, relevant tasks, such as modeling urban energy use or analyzing local air quality, tended to report higher student participation and conceptual gains. These outcomes reinforce the premise that technology alone does not transform learning, pedagogy does (Jimoyiannis, 2010).

GENDER AND EQUITY IN ICT INTEGRATION

While ICT in science education holds promise for fostering inclusive learning, it also brings to the surface pre-existing inequalities related to gender, geography, and socioeconomic status. Addressing these disparities is essential to ensure equitable access and participation.

Gender Dimensions in Science and Technology Classrooms

Science and technology classrooms often reflect broader societal stereotypes, where male students may be perceived, or perceive themselves, as more digitally competent. Research from both Greek and European contexts indicates:

- Girls tend to express higher interest in biology and environmental issues, but have reported lower confidence in using advanced ICT tools like simulations or data sensors (Jansen, Scherer & Schroeders, 2015; Fragkouli & Papoutsis, 2021).
- Collaborative and structured pedagogies, such as rotating group roles or focusing on ethically framed scientific problems, have been shown to reduce gender gaps in participation and digital leadership (Argyri & Karkanis, 2021; Papadakis & Kalogiannakis, 2021).

Promoting inclusive practices, such as using diverse role models in digital content and validating multiple forms of contribution (e.g., creativity, analysis, design), contributes to more balanced classroom dynamics.

Regional and Socioeconomic Inequities

Structural inequities also affect ICT access and implementation:

- Rural and island schools often struggle with unreliable connectivity, older equipment, and limited exposure to external training opportunities (Papanikolaou & Mavrikaki, 2020; Loukis & Giannoukos, 2022).
- Even when national infrastructure programs are in place, regional gaps persist due to differences in school leadership, staffing, and community support networks (OECD, 2018; European Commission, 2021).

To address these challenges, several policy recommendations have emerged:

- Development of mobile ICT toolkits (e.g., tablets, sensors, offline-accessible platforms) for underserved regions;
- Prioritization of funding and support for peripheral schools;
- Design of flexible training models that accommodate teachers' local constraints and realities.

Building Inclusive Digital Cultures

Equity in ICT is not just about devices. It is about empowering every learner to see themselves as capable participants in digital inquiry. This entails:

- Embedding culturally responsive content;
- Encouraging student voice and agency in tool selection and task design;
- Building learning environments where diversity is normalized and valued.

Without deliberate attention to equity, even the most advanced technologies risk amplifying existing divides. Conversely, when inclusivity is embedded into digital pedagogy, ICT becomes a means for social transformation, not just academic enhancement (Avraamidou, 2020; Karachristos & Foti, 2023).

CASE STUDIES FROM GREEK SECONDARY SCHOOLS

To illustrate how ICT can be implemented meaningfully in science education, this section presents selected case studies and illustrative examples from Greek secondary schools.

Virtual Microscopy in Biology Classrooms (Athens)

In a public high school in the Athens area, a biology teacher introduced a virtual microscopy platform to address the shortage of laboratory microscopes. Students used an online interface to navigate high-resolution images of plant and animal cells, zooming in to examine structures and annotate their observations.

- The activity was embedded within an inquiry-based framework: students formulated hypotheses, compared cell types, and documented findings in digital portfolios.
- The teacher reported improved engagement and conceptual clarity, especially among students without previous lab exposure.
- The case demonstrates how simulation technologies can bridge equipment limitations, democratizing access to laboratory-like experiences (Louca & Constantinou, 2020; Chorianopoulos & Giannakos, 2020).

Mapping Local Ecosystems with GIS (Thessaly)

A rural school in central Greece launched an environmental science project focused on a nearby wetland. Students collaborated with an environmental NGO and used open-source GIS software to:

- Record biodiversity indicators (e.g., bird species, vegetation coverage);
- Map changes in land use using satellite imagery;
- Present correlations at a school science fair.

The initiative promoted place-based learning and civic engagement, integrating science with geography and digital literacy (Mavrikaki & Kapsalis, 2019; Karydaki & Sidiropoulos, 2019).

Digital Toolkits across Multischool Networks

Beyond isolated schools, several multischool programs have showcased systematic integration of ICT:

- The *Digital Science Toolkit* initiative involved five lyceums in co-developing shared repositories with inquiry-based modules, 3D visualizations, quizzes, and reflection prompts (Tsiatsos & Stavropoulos, 2019).
- University-school partnerships in Thessaloniki formed mentoring circles, where science teachers co-designed ICT lessons, observed peers, and exchanged feedback regularly (Kynigos & Avgitidou, 2018).
- Participation in the eTwinning program facilitated cross-border collaborative projects on climate resilience and biodiversity using shared digital platforms (Karachristos & Foti, 2023).

These examples underscore the importance of collaboration, institutional leadership, and shared pedagogical vision in embedding ICT sustainably into classroom practice.

FUTURE DIRECTIONS AND RESEARCH GAPS

While progress has been made in integrating ICT into Greek secondary science education, several areas remain underexplored and warrant further investigation:

Longitudinal Impact Studies

Most current research examines short-term outcomes. There is a clear need for longitudinal studies that explore how sustained ICT integration influences students' scientific reasoning, conceptual mastery, and STEM career trajectories over time, particularly for underrepresented groups (Avraamidou, 2020; Fragkouli & Papoutsis, 2021).

Pedagogical Transformations

Beyond adoption rates, future studies should delve into how ICT reshapes instructional design, classroom discourse, and teacher identity. Applying frameworks like TPACK (Mishra & Koehler, 2006) could help analyze how educators internalize digital tools within their subject-specific pedagogies (Jimoyiannis, 2010).

Comparative and Contextual Analyses

Given the geographical and infrastructural disparities in Greece, research comparing urban, rural, and island school settings could illuminate systemic inequalities and localized innovations (Papanikolaou & Mavrikaki, 2020; Loukis & Giannoukos, 2022). Moreover, international comparisons, especially among EU Mediterranean contexts, may identify adaptable policy models and pedagogical strategies (OECD, 2018).

Student Perspectives and Agency

Much of the literature focuses on teachers or policy frameworks, leaving student voices underrepresented. Future research should investigate how students experience digital tools, what motivates or hinders their engagement, and how their identities shape ICT participation (Jansen, Scherer & Schroeders, 2015; Karachristos & Foti, 2023).

Design-Based Research and Co-Creation

Moving from observational to participatory models, Design-Based Research (DBR) can empower educators and researchers to co-create, test, and refine digital interventions in authentic classroom environments (Tsiatsos & Stavropoulos, 2019). This approach also allows exploration of ethical dimensions, such as screen time, data privacy, and digital well-being.

RECOMMENDATIONS

Building on the findings of this study, the following recommendations are proposed to strengthen the pedagogical use of ICT in secondary-level biology and environmental science education in Greece:

1. Develop Subject-Specific Professional Development Frameworks. Move beyond generic ICT workshops by designing sustained, discipline-tailored training programs. These should include:

    - Scenario-based learning modules;
    - Collaborative lesson planning;

- Practice-oriented simulations aligned with subject matter (Jimoyiannis, 2010; Angeli & Valanides, 2017).

2. Promote Inclusive ICT Strategies. Address regional, gender, and socioeconomic disparities by:

- Prioritizing resource allocation to under-resourced rural or island schools (Papanikolaou & Mavrikaki, 2020);
- Encouraging gender-inclusive pedagogy with diverse representation and role models (Fragkouli & Papoutsis, 2021);
- Supporting flexible and mobile learning formats for areas with limited connectivity.

3. Institutionalize Peer Collaboration and Mentorship. Foster teacher-led communities of practice through:

- School-based mentoring circles and ICT “champion” educators (Kynigos & Avgitidou, 2018);
- Cross-school partnerships for co-designing content and reflecting on practice (Tsiatsos & Stavropoulos, 2019).

4. Strengthen Infrastructure and Mobile Access. Ensure robust, future-proof infrastructure by:

- Investing in up-to-date hardware and maintenance systems;
- Distributing mobile kits (e.g., tablets, sensors) for environmental fieldwork and blended learning scenarios.

5. Embed ICT into Curriculum and Assessment. Integrate ICT-based outcomes in national syllabi by:

- Defining digital literacy competencies per discipline;
- Recognizing digital portfolios, multimedia artifacts, and inquiry-based projects in formal assessment (Papadakis & Kalogiannakis, 2021).

6. Expand Open-Access Digital Repositories. Develop and maintain a centralized, teacher-curated platform offering:

- Adaptable simulations and instructional tools in Greek;
- Peer-reviewed lesson plans with scaffolding suggestions.

7. Encourage Research-Practice Partnerships. Support collaborative innovation via design-based research that:

- Involves teachers as co-researchers;
- Iteratively improves ICT integration in real classrooms (Karachristos & Foti, 2023; Argyri & Karkanis, 2021).

8. Center Student Voice in ICT Decision-Making. Design participatory strategies that:

- Involve learners in evaluating digital tools;
- Recognize diverse student experiences and digital identities in shaping policy and pedagogy.

CONCLUSION

This study explored the evolving role of Information and Communication Technologies (ICT) in the teaching of biology and environmental science within Greek secondary education. Through a comprehensive review of recent literature, documented practices, and illustrative case studies, it examined both the potential and the persistent challenges of digital integration in science instruction.

Findings show that ICT can substantially enhance conceptual understanding, student engagement, and interdisciplinary learning. In biology, digital tools enable visualization of microscopic and abstract processes, while in environmental science, they facilitate data-driven inquiry and civic exploration. However, such benefits remain unequally distributed across regions and schools due to infrastructural limitations, uneven teacher preparedness, and fragmented policy implementation.

The study underscores that meaningful ICT integration requires more than hardware provision. It calls for discipline-sensitive pedagogical design, sustained professional learning, inclusive digital cultures, and institutional commitment to equity. Teachers must be supported not only as implementers of tools but as reflective practitioners and co-creators of digitally enhanced learning environments.

If educational systems are to prepare students for scientifically literate and socially responsible citizenship, ICT must be viewed not simply as a set of technical resources but as a transformational catalyst, one that bridges abstract knowledge with real-world relevance and empowers both learners and educators in the digital age.

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