

The role of complex numbers in interdisciplinary mathematics teaching in Tanzanian secondary schools

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ABSTRACT

Complex numbers are part of the standard Tanzanian mathematics curriculum for secondary schools. The integration of complex numbers into interdisciplinary teaching offers significant opportunities such as solving electrical problems to enhance conceptual understanding and problem-solving skills in Tanzanian secondary schools. This study explores how complex numbers are conceptualized, taught, and received across subject disciplines. Through a qualitative analysis of data collected through interviews, curriculum analysis and classroom observations, the research highlights how complex numbers can bridge abstract mathematical theory with real-world applications, such as electrical engineering, wave mechanics, and computer simulations. The findings in this study are based on connections between mathematics and science subjects, conceptual understanding of complex numbers, classroom practices and student engagement, and cultural contextualization strategies. The findings suggest that effective interdisciplinary instruction involving complex numbers promotes critical thinking, fosters learner curiosity, and aligns with the goals of competence-based curricula. However, challenges such as limited teaching resources, insufficient teacher training, and rigid syllabus design hinder the full realization of these benefits. The study recommends targeted professional development for educators, updated teaching materials, and revised policies that encourage interdisciplinary approaches.

Keywords: interdisciplinary mathematics teaching, complex number, secondary schools

INTRODUCTION

Mathematics serves as a foundational discipline that underpins numerous fields within science and technology, offering essential tools for modeling, analysis, and problem solving. Among its many concepts, complex numbers—an extension of the real number system incorporating the imaginary unit i —occupy a critical role in linking mathematical theory to real-world applications. In Physics, complex numbers are integral to the analysis of alternating current (AC) circuits and wave functions. In Chemistry, they support quantum mechanics and the modeling of molecular interactions and reaction kinetics. In Biology, complex numbers assist in population dynamics and the analysis of nonlinear systems. These interdisciplinary applications underscore the critical importance of integrating complex numbers meaningfully into secondary education, thereby equipping students with holistic skills required for 21st century scientific and technological problem solving.

In the context of Tanzania, the secondary school curriculum developed by the Tanzania Institute of Education [TIE] embraces a competency-based approach intended to foster integrated and applied learning across subjects. This framework encourages interdisciplinary teaching to bridge knowledge areas and cultivate critical thinking. However, despite the theoretical alignment of the curriculum with interdisciplinary goals, practical integration of mathematical concepts—particularly complex numbers—into the teaching of related scientific subjects remains limited. While the Mathematics syllabus offers comprehensive instruction on complex numbers within algebraic operations and quadratic equations, their interconnected use in Physics, Chemistry, or Biology is often underemphasized or overlooked in classroom practice. This disconnect indicates a need for deliberate instructional strategies, teacher training, and curricular alignment to facilitate the meaningful application of complex numbers within an interdisciplinary teaching model in secondary schools.

The secondary school curriculum in Tanzania does not sufficiently promote the integration of complex numbers within interdisciplinary teaching, hindering students' capacity to relate mathematical concepts to real-world applications in science. Educators often struggle to create and implement lessons that effectively link complex numbers to subjects such as Physics, Chemistry, and Biology, leading to a disjointed understanding among students. This challenge highlights the importance of identifying and adopting effective, contextually relevant strategies for teaching complex numbers through interdisciplinary approaches.

Complex numbers, introduced in advanced secondary mathematics curricula, play an important role not only in pure mathematics but also in fields such as physics, engineering, computer science, and electrical technology (TIE, 2019, 2023). Therefore, there is a need to investigate how complex numbers can be taught through an interdisciplinary approach such as cross-curricular teaching and team teaching to enhance students' conceptual understanding and real-life application skills. This study explores the extent to which complex numbers can be used as a bridge across the curriculum to promote interdisciplinary teaching and integrated learning experiences in Tanzanian secondary schools. By focusing on cross-disciplinary linkages, the study aims to demonstrate how complex numbers can be relevant, engaging, and a powerful tool for holistic STEM education. The study focuses on exploring how complex numbers are conceptualized, taught, and received across subject disciplines.

Informative Study in Literature

Curriculum analysis of complex numbers in Tanzanian mathematics curricula and its connection to science subjects

The study of complex numbers within the Tanzanian mathematics curriculum has attracted scholarly attention, particularly regarding its relevance and integration with science subjects taught in secondary education. Complex numbers, fundamental to advanced mathematics, play a crucial role in understanding various scientific phenomena, especially in physics and engineering, which are integral components of Tanzanian science education.

Inclusion of complex numbers in Tanzanian mathematics curricula

Studies such as those by Magoma (2016) and Mhando (2012) have documented the place of complex numbers in secondary school syllabi developed by TIE. Complex numbers are introduced typically at the advanced secondary level. The curriculum emphasizes both theoretical understanding and practical problem-solving skills, although some researchers point out gaps in depth and contextualization to real-life applications (Msuya, 2018).

Relevance to science subject learning

Complex numbers are essential in understanding concepts within physics, such as alternating current circuits, electromagnetic theory, and wave mechanics (Lema & Mzava, 2015). The Tanzanian physics curriculum includes topics that implicitly require the knowledge of complex numbers—for example, representing oscillations or electrical impedance in AC circuits. However, there is often a disconnect between the mathematics curriculum and science curricula in terms of sequencing and explicit cross-referencing, as highlighted by Komba et al. (2019).

Curriculum integration challenges

The Tanzanian curriculum faces challenges in seamless integration of complex numbers across disciplines. Curriculum analysis by Kamala (2020) reveals that while mathematics introduces complex numbers as abstract algebraic entities, the applied science subjects sometimes lack sufficient mathematical scaffolding to make full use of these concepts. This results in missed opportunities for interdisciplinary learning and real-world problem-solving.

Pedagogical considerations

Research into teaching methodologies suggests that incorporating real-life examples, especially from physics and engineering applications, can enhance students' understanding of complex numbers (Mwakyusa & Msuya, 2017). Effective curriculum design should facilitate connections between mathematics and science, fostering a holistic understanding.

Recommendations from previous research

Several scholars recommend curriculum reforms that promote interdisciplinary synergy. For instance, Ukwoma (2021) argues for synchronized curriculum review sessions involving mathematics and science subject specialists to align content and timing. Additionally, teacher training programs must equip educators to highlight the practical applications of complex numbers in science fields, as emphasized by Sanga and Nyerere (2018).

Complex numbers across Tanzanian mathematics curricula

The teaching and learning of complex numbers in Tanzania have evolved alongside reforms in the national mathematics curricula. Complex numbers, a crucial concept in advanced secondary education, bridge practical applications and theoretical mathematical understanding, enhancing students' analytical skills.

Curriculum development and structure

The Tanzanian mathematics curriculum, as stipulated by TIE, integrates complex numbers primarily at the secondary school level (Ordinary and Advanced Levels) (TIE, 2023). Integration reflects global trends emphasizing the importance of extending real number systems to include imaginary units for solving quadratic equations and modeling phenomena in engineering and sciences. Various curriculum documents from the 2000s to recent revisions address the inclusion of complex arithmetic operations, graphical representation in the Argand plane, and solving polynomial equations with complex roots (TIE, 2019).

Pedagogical approaches and content emphasis

Studies by Tanzanian educational researchers indicate that while complex numbers feature in the syllabus, there are challenges related to the abstract nature of the topic. The curricula often present complex numbers in a manner that connects them with real-life contexts, such as electric circuits or signal processing, but comprehensive instructional materials and teacher preparedness remain limited (Mkude, 2018; Mwesigwa & Mpokosa, 2015). The emphasis is commonly on algebraic manipulation, with less focus on geometric interpretations, which some scholars argue is essential for conceptual understanding.

Challenges in teaching and learning

Research into classroom practices highlights that students struggle with the abstractness of imaginary units and fail to relate complex numbers to practical applications due to inadequate teaching resources and insufficient teacher training (Kibona & Mushi, 2020). The Tanzanian examinations also prioritize procedural fluency over conceptual mastery, which influences how complex numbers are taught. This discrepancy points to a curricular gap between theory and application and affects students' ability to engage deeply with complex number concepts.

Comparative perspectives and recommendations

Comparative studies with other African curricula, such as those in Kenya and South Africa, indicate that Tanzania's treatment of complex numbers is broadly similar but tends to be less integrated with technology and dynamic visualization tools (Nyerere, 2017). Recommendations from curriculum analysts advocate for enhanced teacher training, incorporation of interactive tools like GeoGebra, and curriculum revision to emphasize both algebraic skills and geometric understanding (Mkude, 2018; Tanzania Education Research Network, 2021). Such improvements align with the goals of the Tanzanian Education and Training Policy, aiming to produce learners with strong analytical and problem-solving capabilities.

THEORETICAL FRAMEWORK

This study is informed by the Constructivist Learning Theory (Vygotsky, 1978) and the Interdisciplinary Curriculum Framework through team teaching (Friend & Cook, 2016). Constructivism emphasizes learning through real-world context and active engagement, while the interdisciplinary framework promotes learning through the integration of multiple subject disciplines to enrich understanding and relevance through team teaching by relating complex numbers to real world problems. Lack of systematic collaboration among subject teachers is a barrier to effective interdisciplinary teaching. Beane (1997) emphasizes the importance of collaborative curriculum planning in fostering interdisciplinary connections that are meaningful and coherent for students.

METHODOLOGY

This study employed a qualitative research approach to investigate the role of complex numbers in interdisciplinary integration within Tanzanian secondary schools. The research focused on exploring how complex numbers are conceptualized, taught, and received across subject disciplines. The qualitative approach provided a framework for gaining in-depth insights into teaching practices and stakeholder perceptions within real-world educational settings.

This study employed a qualitative case study research design, which is well-suited for investigating complex educational phenomena and gaining a deep understanding of the relationships, meanings, and perspectives of participants (Cohen et al., 2013). Specifically, an exploratory approach was adopted to examine how complex numbers are integrated into teaching across various disciplines, including Mathematics, Physics, Chemistry, and Biology. Given the study's focus on capturing teachers' instructional experiences and students' learning processes, a descriptive strategy was utilized to detail how complex numbers are introduced, contextualized, and applied within Tanzanian secondary schools.

The study was conducted in selected five public secondary schools in Tanzania. The target population included 2 mathematics teachers (1 ordinary level and 1 advanced level), 1 physics teacher, 1 chemistry teacher, 1 biology teacher, and 2 Form Four students and 3 Form Five students who had been exposed to complex number concepts.

Purposive sampling was used to select both five schools and ten participants as described in the paragraph above. Schools were chosen based on factors such as curriculum implementation level, availability of science and mathematics streams, and willingness to participate in the study. Within the selected schools, participants were chosen based on their direct engagement with the subject matter—teachers with experience in teaching complex numbers and students who had been taught the topic in recent years.

Data was collected through semi-structured interviews and conducted with mathematics and science teachers and students to explore their understanding, teaching and learning practices, and experiences related to integrating complex numbers with other subjects. Classroom Observations were also conducted on lessons involving complex number topics to two mathematics teachers in Form Four and Form Five mathematics classes and, where feasible, in related Science classes to understand actual teaching practices and the degree of integration across subjects. Curriculum analysis was also conducted by analysis of syllabi, lesson plans, textbooks, and curriculum guidelines provided by TIE to assess the intended interdisciplinary integration of complex numbers. The analysis focused on identifying where complex numbers are introduced, the depth of content coverage, instructional approaches recommended, and the connections made to scientific concepts in other disciplines. This process provided a clearer understanding of the placement and relevance of complex numbers within the broader educational framework, revealing the strengths and gaps in their interdisciplinary integration across the science subjects. It also served to assess how well the curriculum supports holistic teaching practices.

Data collected from interviews, curriculum analysis, and observations were analyzed using thematic analysis (Braun & Clarke, 2021). This involved transcribing verbal data, coding key themes, and identifying patterns that reflect how complex numbers are conceptualized, taught, and received across subject disciplines. All relevant data were systematically coded to identify recurring patterns, themes, and insights. Key focus areas included the representation of complex numbers in subject curricula, their practical application in science subjects, student understanding, and the effectiveness of interdisciplinary teaching practices.

Table 1. Interdisciplinary applications of complex numbers

Discipline	Role of complex number
Physics	Used in alternating current (AC) circuit analysis involving impedance
Engineering	Signal processing, control systems, vibration analysis
Computer science	Algorithms involving transformations, graphics, and quantum computing
Mathematics	Roots of equations, fractals, vector representation in a 2D plane

Thematic categories were developed inductively to capture common ideas across the data. Four themes emerged which are conceptual understanding of complex numbers, connections between mathematics and science subjects, cultural contextualization strategies, classroom practices and student engagement. Findings were then compared across Mathematics, Physics, Chemistry, and Biology to determine the extent to which complex numbers were understood, taught, and applied differently or similarly in each discipline.

Ethical guidelines were strictly observed throughout the conduct of this study to ensure the protection, dignity, and rights of all participants. The following ethical principles were upheld: All participants, including teachers and students, were fully informed about the purpose, objectives, and nature of the study. Participation was entirely voluntary, and consent was obtained in written form prior to data collection. For students under the age of 18, parental or guardian consent was also secured where necessary. Also, the identities of all participants were protected to maintain confidentiality. Pseudonyms were used for reporting purposes, and any identifying information was omitted from the data analysis and presentation. All records were securely stored and accessed only by the researcher. Every effort was also made to ensure participants were not exposed to any form of physical, psychological, or emotional harm. The study posed minimal risk, and participants were not required to engage in any activity that could cause discomfort or distress. Participants' autonomy and right to self-determination were respected throughout the study. They were informed of their right to withdraw at any stage without any penalty or consequence. Their views and perspectives were treated with respect and fairness. This ethical approach contributed to maintaining trust, transparency, and integrity throughout the research process.

To enhance the credibility, consistency, and trustworthiness of the study's findings, several strategies were employed to ensure both validity and reliability: A variety of data collection methods were used—including curriculum analysis, interviews, focus group discussions, and observation. By cross-referencing data from multiple sources, the study was able to capture a more comprehensive and accurate understanding of how complex numbers are integrated into interdisciplinary teaching. This methodological triangulation strengthened the internal validity of the study by confirming patterns across different types of evidence. Also, clear and consistent procedures were followed during all phases of data collection and analysis. Interview protocols, group activity guides, and observation checklists were used to maintain uniformity in data gathering. Similarly, thematic coding for data analysis was applied systematically, ensuring reliability and comparability of results across participants and cases.

FINDINGS

This section presents the findings on exploring how complex numbers are conceptualized, taught, and received across subject disciplines within Tanzanian secondary schools. The results are based on data collected through interview, curriculum analysis and classroom observation. Thematic analysis was used to identify recurring patterns, insights, and key themes that reflect the extent to which complex numbers are conceptualized, taught, and received within mathematics and across subject disciplines such as Physics, Chemistry, and Biology. The findings provide a holistic view of how complex numbers are positioned within the Tanzanian secondary school curriculum and how they support interdisciplinary learning.

Connections between Mathematics and Science Subjects

An analysis of the Tanzanian secondary school syllabi and associated textbooks for Mathematics, Physics, Chemistry, and Biology reveals that complex numbers are primarily introduced and developed within the mathematics curriculum. They are taught in relation to algebraic concepts, the solution of quadratic equations with negative discriminants, and topics relevant to electrical engineering applications. In the Physics syllabus, complex numbers are briefly referenced in the context of alternating current (AC) circuit analysis in advanced level, particularly in the use of impedance and phasor representation. However, these references are not deeply elaborated upon, and connections to formal mathematical instruction are minimal. The Chemistry and Biology syllabi make only marginal or indirect mention of complex numbers. In Chemistry, they appear occasionally in topics related to physical chemistry—such as reaction kinetics or wave functions in atomic theory—but are not a central component of the subject matter. In Biology, explicit references to complex numbers are virtually absent, with only speculative conceptual applications (such as in mathematical modeling of population dynamics) potentially existing at an advanced level beyond the secondary curriculum framework. These observations indicate a subject-specific compartmentalization of complex numbers, with limited institutional emphasis on their interdisciplinary relevance. **Table 1** provides interdisciplinary applications of complex numbers in mathematics and sciences.

Conceptual Understanding of Complex Numbers

During the Focus group discussions, students demonstrated a generally solid understanding of the theoretical and computational aspects of complex numbers as taught in Mathematics. Their ability to perform algebraic operations with complex

numbers, such as addition, subtraction, multiplication, and division, was evident. When challenged to explore interdisciplinary applications of complex numbers.

Physics group

Students in this group effectively articulated the relevance of complex numbers in the analysis of alternating current circuits, making use of terms such as impedance, phasors, and sinusoidal wave functions. They provided simple yet accurate examples that illustrated how complex numbers simplify circuit calculations.

Chemistry group

Students found it more difficult to identify and explain the role of complex numbers in chemical phenomena. While some referenced quantum mechanics and wave functions (concepts touched on in advanced chemistry), they lacked confidence in explaining their practical relevance at the secondary level.

Biology group

Students attempting to link complex numbers to population modeling and biological systems encountered challenges in formulating accurate mathematical relationships. They acknowledged the conceptual difficulty of applying abstract mathematical constructs like complex numbers to living systems.

Overall, while students exhibited enthusiasm and creativity, their depth of interdisciplinary understanding was uneven. The mathematical application was clearest in Physics, while Chemistry and Biology posed conceptual challenges for meaningful integration because of having limited understanding on how complex number is connected to the two subjects.

Classroom Practices and Student Engagement

Classroom observation conducted during students' small group presentations found increased awareness of interdisciplinary potential. Many students revealed that they had never considered the use of complex numbers outside of Mathematics before this activity. Exposure students to interdisciplinary applications during their small group presentations broadened their perspectives on the usefulness of mathematical concepts. Recognition of Practical Relevance among students was also observed. Students widely acknowledged the practical utility of complex numbers, particularly in solving real-world problems related to Physics and engineering. However, there was difficulty translating abstract concepts among students. Some students were confused about how to apply complex numbers in Chemistry and Biology. Many struggled to connect mathematical theory related to complex number with the practical processes in these sciences. Also, it was observed an appreciation of collaborative learning among students. The group presentations and subsequent discussions provided students with opportunities to learn from their peers, engage in critical thinking, and develop a broader conceptual framework for understanding the role of Mathematics in scientific inquiry.

Cultural Contextualization Strategies

An analysis of the curriculum, supported by insights from teacher interviews, reveals that while complex numbers are foundational in Mathematics, their integration into other disciplines such as Physics, Chemistry, and Biology is neither systematic nor clearly articulated the Tanzanian cultural contexts on the applications of complex numbers. This minimal cross-curricular integration highlights a significant gap in interdisciplinary teaching strategies within the Tanzanian secondary education system. Although educators recognize the potential applications of complex numbers beyond Mathematics, they often struggle to incorporate them consistently and meaningfully into other subject areas. Contributing factors to this challenge may include insufficient collaboration among subject departments, limited opportunities for interdisciplinary professional development, and constraints related to time and resources for designing integrated lessons.

In Physics, complex numbers are primarily applied in topics such as alternating current (AC), electrical impedance, and waveforms. These applications show the critical role of mathematics in providing essential tools for modeling and understanding physical phenomena based on students daily living practices. The successful integration of complex numbers into electrical physics, as indicated by the positive reception from both teachers and students, highlights a valuable opportunity to extend their use into other physics domains—such as optics and quantum mechanics—where complex number concepts are equally relevant. However, Physics teachers identified a significant barrier explaining “these advanced topics becomes challenging when students lack a sufficient mathematical foundation.” (From Interview). This indicates a need for better alignment between mathematics instruction and its applications in physics, as well as targeted support to bridge interdisciplinary knowledge gaps.

The limited integration of complex numbers into Chemistry and Biology curricula represents a notable gap and a potential area for educational improvement. Although complex numbers can be applied in advanced topics such as reaction kinetics in Chemistry and mathematical modeling in Biology, their relevance is often not evident to students and teachers. This difficulty may arise from the abstract nature of complex numbers, which are typically more intuitive in Physics contexts. Additionally, the lack of a structured interdisciplinary framework in the Tanzanian secondary school curriculum contributes to the absence of meaningful connections between Mathematics and the life sciences. Teachers reported challenges in demonstrating how theoretical concepts involving complex numbers translate into real-world applications in Chemistry and Biology, which likely contribute to students' confusion and disengagement.

A key finding from the teacher interviews was the absence of consistent collaboration among subject departments, resulting in limited integration of complex numbers into interdisciplinary teaching. Teachers reported that they “rarely engaged in joint planning or discussions on how complex numbers could be meaningfully applied across subjects. This fragmented approach may contribute to students' limited ability to understand and transfer mathematical concepts to other disciplines.” (From Interview).

The findings of this study underscore the potential for improving the integration of complex numbers within the Tanzanian secondary school curriculum through a more interdisciplinary teaching approach. While complex numbers are well established in Mathematics and find meaningful application in Physics topics such as alternating current and impedance, their use in Chemistry and Biology remains underdeveloped. Addressing this gap requires a multifaceted strategy: Fostering collaboration among subject departments, offering targeted professional development focused on interdisciplinary pedagogy, and revising curriculum materials to highlight the cross-cutting applications of mathematical concepts like complex numbers. Implementing these strategies could significantly enhance students' ability to understand and apply complex numbers across a range of scientific contexts.

Lessons Learned from the study

Lack of updated teaching aids or interdisciplinary lesson plans

The results of this study reveal several key insights into the integration of complex numbers in interdisciplinary teaching in Tanzanian secondary schools. These findings align with and contribute to broader scholarly literature on mathematics education, interdisciplinary instruction, and the application of mathematical concepts within science education. The study highlights a common challenge in education systems worldwide: The compartmentalization of knowledge. As Jacobs (1989) argues, many secondary school curricula are structured in disciplinary silos, which inhibit students from making meaningful connections between subjects. This fragmentation often leads to students mastering mathematical procedures without understanding their real-world applications in scientific contexts. In line with this, the study found that while students could perform calculations involving complex numbers in Mathematics, they struggled to see their relevance in Chemistry and Biology.

Lack of systematic collaboration among subject teachers is a barrier to effective interdisciplinary teaching. Beane (1997) emphasizes the importance of collaborative curriculum planning in fostering interdisciplinary connections that are meaningful and coherent for students. The teachers interviewed in this study reported limited opportunities for joint lesson planning or cross-departmental dialogue, which in turn limits their ability to emphasize the relevance of complex numbers beyond Mathematics and Physics. Without such collaboration, students might receive a fragmented educational experience that fails to reflect the integrative nature of real-world problem-solving.

The abstract nature of complex numbers—and the difficulty students face in visualizing their applications—echoes concerns raised in the work of Sfard (1991), who discusses the challenges of learning abstract mathematical concepts without adequate contextual grounding. In the context of this study, Physics provided more tangible applications (e.g., AC circuits), which helped students develop a clearer understanding, whereas Chemistry and Biology lacked similarly accessible contexts for the use of complex numbers. Drake and Burns (2004) advocate for targeted training that helps teachers design and implement cross-curricular lessons, emphasizing that successful integration requires not just curriculum alignment but also shifts in teacher practices and mindset. In most of the education systems, such professional development would be helpful. The study suggests that curriculum reform—emphasizing competencies across subject boundaries—is a necessary step toward bridging the gap between Mathematics and the sciences. As supported by the work of Ernest (1991), mathematics education should aim not only to develop procedural fluency but to promote deeper conceptual understanding and the ability to apply knowledge in diverse situations. By connecting Mathematics more explicitly with its applications in Physics, Chemistry, and Biology, educators can foster more meaningful learning experiences that equip students with the tools needed for interdisciplinary thinking and real-world problem-solving.

When students are encouraged to apply mathematical knowledge in other disciplines, they are more likely to internalize abstract concepts and understand their relevance in diverse contexts. In the context of complex numbers, interdisciplinary teaching enables students to move beyond procedural competence and toward practical understanding. For example, using complex numbers to solve problems related to alternating current in Physics or reaction mechanisms in Chemistry can make these mathematical concepts more tangible. Auerbach (2014) supports this view, emphasizing that interdisciplinary learning enhances students' critical thinking and problem-solving skills—both of which are essential for success in science and mathematics education. By engaging students in real-world applications of complex numbers, educators can cultivate a more integrated and holistic learning experience that mirrors the nature of scientific inquiry. Moreover, interdisciplinary approaches can help address common misconceptions and improve retention by allowing students to encounter the same concept in varied contexts. This reiteration across disciplines reinforces learning and fosters cognitive flexibility. Therefore, the limited cross-disciplinary integration of complex numbers as reported in this study not only restricts students' exposure to important applications but also represents a missed opportunity for strengthening overall mathematical literacy.

Disconnect between mathematics and science departments in schools

The study revealed a clear lack of collaboration among subject departments and an absence of systematic efforts to integrate complex numbers into disciplines beyond Mathematics. This fragmentation reflects broader challenges in secondary education, where subject areas are often taught in isolation, limiting students' ability to make conceptual connections across fields. Pegg (2003) highlights that such departmental silos hinder meaningful interdisciplinary integration, ultimately reducing students' capacity to apply knowledge in comprehensive and contextually relevant ways. Without sustained collaborative planning between subject teachers, opportunities to explore the interconnectedness of Mathematics with subjects like Physics, Chemistry, and Biology are frequently missed. Beane (1997) also underscores the importance of developing an integrated curriculum that fosters collaboration among educators and provides students with a coherent and unified view of knowledge. He contends that when subjects are taught in isolation, students may struggle to see how different areas of learning intersect and apply to real-world scenarios. In the specific context of this study, the limited use of complex numbers in Chemistry and Biology underscores the need

for more intentional curriculum design and professional collaboration. Such efforts would not only enhance student understanding but also promote interdisciplinary thinking essential for both academic success and real-life problem-solving. The absence of structured interdisciplinary collaboration in Tanzanian secondary schools significantly limits the potential for complex numbers to be meaningfully applied in subjects such as Chemistry and Biology. Therefore, collaborative efforts would not only improve the contextual application of complex numbers across the sciences but also help students develop a broader, more cohesive understanding of how mathematical concepts connect with real-world scientific phenomena.

The findings of this study indicate that Physics teachers integrate complex numbers into their instruction, particularly in areas such as electrical circuits, waveforms, and oscillatory motion. This observation aligns with the work of Titus and James (2007), who emphasize the utility of complex numbers in simplifying the mathematical representation and analysis of wave phenomena, as well as in calculating impedance within alternating current (AC) circuits. Their research highlights how complex numbers help streamline otherwise complex algebraic procedures in Physics, making them a powerful tool for both instruction and problem-solving. The experiences shared by Physics teachers in this study reflect these benefits, as they reported that the use of complex numbers allowed students to better understand the mathematical modeling of physical systems. This effective integration underscores the potential for broader interdisciplinary applications, particularly if similar strategies are extended to other science subjects. Complex numbers hold significant value in Physics education, particularly in topics such as electrical circuits, waveforms, and oscillatory motion, where they serve as essential tools for modeling and analysis. The study findings suggest that emphasizing the mathematical foundations of complex numbers alongside their practical applications in Physics can greatly enhance students' conceptual understanding and analytical skills. When students see how abstract mathematical concepts are applied in solving real-world physics problems, their engagement and ability to think critically across disciplines are strengthened. Therefore, integrating complex numbers into Physics instruction in a more explicit and structured manner presents a valuable opportunity to support deeper learning and improved problem-solving competencies.

Examination-centered teaching approach discourages curriculum exploration

The study revealed that both students and teachers experienced significant challenges in applying complex numbers within the contexts of Chemistry and Biology. This finding is consistent with the work of Tijssen (2015), who discusses the difficulties associated with integrating advanced mathematical concepts—such as complex numbers—into the life sciences. Tijssen notes that while complex numbers have legitimate applications in fields like physical chemistry and reaction kinetics, their use is often underemphasized or entirely overlooked in secondary-level instruction. As a result, these connections remain abstract and inaccessible to many students. Similarly, Roschelle (1995) highlights the cognitive difficulty students face when attempting to apply abstract mathematical concepts to real-world scientific phenomena, particularly in disciplines like Biology, where mathematics is not traditionally central to instruction. Without explicit pedagogical strategies that connect mathematical theory to practical scientific applications, students are likely to view complex numbers as isolated constructs rather than as tools with interdisciplinary value. These findings underscore the need for curriculum development and instructional approaches that intentionally bridge the gap between mathematics and the life sciences.

Teachers' limited understanding of mathematical applications beyond the syllabus

Findings from student group work and class discussions indicated that while students were able to recognize the usefulness of complex numbers in Physics, they struggled to transfer this understanding to other subjects such as Chemistry and Biology. This observation aligns with Hattie's (2009) assertion that student engagement and critical thinking are significantly enhanced when learners perceive the relevance of what they are studying. Hattie emphasizes that meaningful learning occurs when content is connected to real-world contexts, suggesting that interdisciplinary teaching can help bridge the gap between abstract mathematical concepts and their practical applications—thereby increasing student motivation and comprehension. Furthermore, Anderson (2017) highlights the effectiveness of active learning strategies—such as collaborative group activities and structured class discussions—in promoting deeper cognitive engagement. These strategies not only provide students with opportunities to articulate their understanding but also encourage them to make connections across domains of knowledge. When students are guided to apply mathematical concepts like complex numbers across subjects, their critical thinking skills are strengthened, and their learning becomes more integrated and purposeful. Thus, the use of interdisciplinary and active learning approaches can play a critical role in enhancing student engagement and deepening conceptual understanding. Active learning strategies—such as group work and class discussions—play a crucial role in helping students internalize abstract mathematical concepts like complex numbers. Providing opportunities for collaborative learning and cross-curricular connections not only reinforces conceptual comprehension but also fosters transferable problem-solving skills. Therefore, incorporating active learning within an interdisciplinary framework can significantly enhance student engagement and support the meaningful integration of complex numbers into science education.

The challenges identified in integrating complex numbers across disciplines underscore the need for targeted professional development for teachers. As Ball et al. (2008) emphasize, both strong content knowledge and pedagogical content knowledge are essential for effective interdisciplinary teaching. Without adequate preparation, teachers may struggle to draw meaningful connections between mathematical concepts and their applications in other subjects. Professional development programs that focus not only on the theoretical understanding of complex numbers but also on their real-world applications in fields such as Physics, Chemistry, and Biology can equip educators with the skills and confidence needed to implement interdisciplinary strategies. Such initiatives can foster collaboration among departments, encourage the development of integrated lesson plans, and ultimately improve student learning outcomes across the curriculum.

CONCLUSION

This study on the role of complex numbers in interdisciplinary integration within Tanzanian secondary schools reveals several key insights. Firstly, complex numbers are well-established within the mathematics curriculum. In Physics, these concepts are meaningfully applied, particularly in areas such as electrical circuits and waveforms, where students demonstrated a stronger ability to grasp their practical relevance. However, the integration of complex numbers into Chemistry and Biology remains significantly underdeveloped. Students and teachers alike struggled to apply or contextualize complex numbers in these subjects, pointing to a broader disconnect between mathematical theory and scientific application. Complex numbers have significant potential as a cross-cutting concept that can enhance interdisciplinary learning in Tanzanian secondary schools. By adopting an integrated teaching approach, educators can make mathematics more relevant and engaging, improve critical thinking, and prepare students for careers in STEM fields.

Based on the findings from this study, it is recommended to develop teacher training programs on interdisciplinary teaching strategies, revise the mathematics syllabus, textbooks and other teaching and learning resources to include application-based examples from other subjects, foster collaboration among mathematics, physics, and ICT teachers to co-plan lesson and implement STEM clubs or projects that demonstrate the utility of complex numbers in real-life situations. Therefore, education stakeholders—policy makers, school administrators, and curriculum designers should take deliberate steps to strengthen the interdisciplinary integration of complex numbers in Tanzanian secondary schools.

While this study provides valuable insights into the role of complex numbers in interdisciplinary teaching within Tanzanian secondary schools, several limitations should be acknowledged: The study was specific to complex numbers could not consider other topics such as quadratic equations and trigonometry where similar problems might exist. The study involved a relatively small number of participants due to time and logistical constraints. As a result, the findings may not be fully generalizable to all secondary schools across Tanzania or to broader educational contexts. Consequently, the findings may have limited applicability to countries with different educational structures and pedagogical approaches. This may have affected the breadth and depth of the curriculum analysis, particularly in capturing the full range of interdisciplinary links in classroom practice. Despite these limitations, the methodology and techniques employed ensured the collection of rich, contextually relevant qualitative data. These insights contribute to a deeper understanding of how complex numbers are integrated into interdisciplinary teaching and can guide future enhancements in curriculum development and instructional practice.

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